Appendix 5.A.2

Climate Change Approach and Implications for Aquatic Species

Appendix 5.A.2
Climate Change Approach and Implications for Aquatic Species

5.A.2.0 Executive Summary

Northern California is expected to experience changes to the physical environment because of climate change. It is expected that climate change will result in a shift from snow to rain in winter, leading to reduced snowpack, earlier snowmelt, and reduced river flows and reservoir storage in summer (Knowles and Cayan 2002; Miller et al. 2003; Mote et al. 2005), causing changes to the seasonal timing of flows in rivers. Air temperatures will continue to rise, increasing water temperatures and altering the movements of aquatic species in search of cool-water refuges. Accelerated rates of relative sea level rise will increase the intrusion of seawater into the upper estuary (Cayan et al. 2009). Sea level rise combined with an increase in coastal storms, storm surge, and river runoff will increase shoreline flooding and erosion.

The purpose of this appendix is to characterize the potential effects of climate change on aquatic covered species and identify the approach and methods used to incorporate climate change into the Bay Delta Conservation Plan (BDCP) modeling. Section 5.A.2.2, *BDCP Approach and Methods for Aquatic Species,* summarizes the approach used to select climate change scenarios that were incorporated into the various models for habitat conditions of aquatic species (e.g., CALSIM II for flows, water temperature models, tidal flow and salinity models). It discusses the methods applied to evaluate the effects of climate change on physical parameters (e.g., air and water temperature) considered in the aquatic species analysis and presents the expected upstream and Sacramento–San Joaquin River Delta (Delta) changes to these physical parameters. The modeling results presented in Section 5.A.2.3, *Aquatic Methods and Models*, were used in Appendices 5.B, *Entrainment;* 5.C, *Flow, Passage, Salinity, and Turbidity*; 5.D *Contaminants;* 5.E, *Habitat Restoration;* 5.F, *Biological Stressors on Covered Fish*; 5.G, *Fish Life Cycle Models*; 5.H, *Aquatic Construction and Maintenance Effects*; and 5.I, *Critical Habitat and Essential Fish Habitat Analyses* to determine the effects on individual covered fish species under future conditions with climate change.

Results of upstream inflow and water temperature modeling are presented in Section 5.A.2.4, *Upstream Inflow Modeling and Results*, and Section 5.A.2.5, *Upstream Water Temperatures Modeling Results,* respectively. Section 5.A.2.6, *Delta Water Temperatures and Salinity Modeling Results,* presents Delta temperature and salinity modeling results. Potential effects on covered fish species are discussed in Section 5.A.2.7, *Upstream Effects,* and Section 5.A.2.8, *Delta Effects.* Key modeling results and associated species effects include the following:

- Flows on the Sacramento River and its tributaries are projected to show no change or only small changes, whereas San Joaquin River flows are projected to decline, primarily due to reduced inflows on tributaries above Friant Dam.
- Warmer reservoir inflows and increased warming of Central Valley rivers would interact with reservoir operations (flood control releases and water supply storage) to increase the temperature of releases from the major CVP and SWP reservoirs.

- Water temperatures in rivers below the CVP and SWP reservoirs are expected to increase and exceed water temperature criteria, except in the Trinity River.
- High temperature events are expected to become more common under climate change upstream of the Delta and could result in stress for species with specific temperature limits at one or more life stages. Of the four runs of Chinook salmon that spawn in the Sacramento and San Joaquin Rivers and tributaries, spring-run adults in Butte Creek and winter-run (all life stages) are highly vulnerable because of life history stages that are present during the heat of the summer.
- The potential increase in temperature because of climate change may reduce the length of river with suitable water temperature for rearing of juvenile winter-run Chinook salmon. Modeling results project a continuing increase in the frequency of higher temperatures over time because of climate change and with distance downstream of the Keswick Dam.
- Habitat conditions for spawning winter-run Chinook salmon are projected to decline in response to climate change. In years when escapement is high and exceeds the carrying capacity of the reduced habitat, competition among spawners for space (e.g., increased redd superimposition) may increase, resulting in reduced reproductive success.
- Combined effects of rising sea level, greater salinity intrusion, and warming waters in the Delta are expected to adversely affect covered endemic fishes and the quality (suitability) of their habitat in the Delta. Delta smelt is the most vulnerable of the endemic fishes to these changes because it spends the majority of its life in the Delta.
- Longfin smelt and striped bass have higher salinity tolerances than delta smelt, and can move into the cooler Central Bay or the Pacific as the climate changes. Splittail have a comparatively higher temperature tolerance so are unlikely to be affected by projected water temperature increases. Salmonids moving through the Delta during the migration period would experience increases in temperatures, but no lethal temperatures are projected, and they are less susceptible to water temperature changes because of spending a shorter time in the Delta.

The physical changes associated with climate change are expected to be widespread and long lasting, even if meaningful reductions in greenhouse gas emissions (i.e., climate change mitigation) are made now (Solomon et al. 2009). The BDCP cannot reverse these physical trends. However, BDCP conservation measures will provide benefits to the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) ecosystem, natural communities, and covered species that are expected to reduce their vulnerability to the adverse physical and biological effects of climate change. Table 5.A.2.0-1 identifies the hypothesized benefits of BDCP for climate change adaptation on covered aquatic species.

Table 5.A.2.0-1. Summary of Hypothesized Climate Change Adaptation Benefits of the BDCP

Benefit	Description
Enhanced ecosystem services	Restoration of wetlands, floodplains, and riparian habitats will restore ecosystem services, including flow regulation, nutrient cycling, and sediment processes that enhance the functioning of aquatic habitats (Mitsch and Gosselink 2000).
Protection from sea level rise	Increased wetland plant biomass, including belowground production, helps to promote accretion and the ability of the marsh to keep pace with sea level rise (Callaway et al. 2011; Parker et al. 2011). A wider and more extensive marsh plain in tidal wetlands and a wider floodplain in river systems increase protection of upland habitat from flooding and storm surges, which are projected to get worse with climate change (Cayan et al. 2008).
Natural water management	Improved floodplain connections to rivers will restore the ability of floodplains to absorb floodflows and provide a reservoir of water to help aquatic species withstand droughts.
Increased resilience against to invasive species	Seasonally inundated floodplains provide more resilience from invasive species by increasing numbers and health of native species and excluding invasive species (Moyle et al. 2007).
Increased habitat variability	Restoration supports species diversity by providing a mosaic of habitats that can be used by different species that have evolved to use specific habitats.
Increased habitat complexity	Wetland restoration will include networks of channels within marshes that are used by fish for foraging, refuge, and movement into and out of the marsh. Currently, such channels are rare (Parker et al. 2011).
Increased habitat patch size and connectivity	Protection and restoration of a variety of natural communities will increase the patch size and connectivity of these habitats. Increasing patch size will tend to increase population sizes of native species, which provides more resilience against a changing climate. Increasing connectivity allows more genetic exchange among populations and movement to more suitable habitats as environmental conditions change.

Monitoring and adaptive management are essential tools for addressing the uncertainty associated with climate change projections and ecological responses to climate change. Adaptive management is a widely recognized approach for addressing uncertainty in natural resource management. It is an iterative process involving adjustments in management actions as monitoring and management experience provide new information. Landscape-level monitoring is designed to detect large-scale changes in ecosystem processes, shifts in natural community distribution, and alterations in the integrity of landscape linkages. Community-level monitoring, in turn, is designed to detect changes in the composition and function of natural communities, including changes in the relative abundances of key predator or prey populations, invasive species, and other important habitat factors for covered species. Finally, species-level monitoring indicates how species are responding to climate change on an ongoing basis. Collectively, these monitoring activities will allow early detection and response to the ecological effects of climate change, such as changes in the range, distribution, and abundance of natural communities and covered species (Chapter 3, Section 3.6, *Adaptive Management and Monitoring Program*).

References

Callaway, J. C., V. T. Parker, M. C. Vasey, L. M. Schile, and E. R. Herbert. 2011. Tidal wetland restoration in San Francisco Bay: history and current issues. *San Francisco Estuary and Watershed Science* 9(3):1–12. Available: <http://www.escholarship.org/uc/item/5dd3n9x3>

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. *Climatic Change* 87:S21–S42.

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick. 2009. *Climate Change Scenarios and Sea Level Rise Estimates for the California 2008 Climate Change Scenarios Assessment*.

Knowles, N., and D. Cayan. 2002. Potential Effects of Global Warming on the Sacramento/San Joaquin Watershed and the San Francisco Estuary. *Geophysical Research Letters* 29:38-1–38-4.

Miller, N. L., K. E. Bashford and E. Strem. 2003. Potential Impacts of Climate Change on California Hydrology. *J. Amer. Water Resour. Assoc.* 39, 771–784.

Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands 3. Canada: John Wiley and Sons.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining Mountain Snowpack in Western North America. *Bulletin of the American Meteorological Society* 86(1): 39–49.

Moyle, P. B., P. K. Crain, and K. Whitener. 2007. Patterns in the Use of a Restored California Floodplain by Native and Alien Fishes. *San Francisco Estuary and Watershed Science* 5 (3): 1–27.

Parker, V. T., J. C. Calloway, L. M. Schile, M. C. Vasey, and E. R. Herbert. 2011. Climate Change and San Francisco Bay–Delta Tidal Wetlands. San Francisco Estuary and Watershed. *Science* 9(3), 16 pp.

Solomon, S., G.-K. Plattner, R. Knutti, and P. Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences of the United States of America* 106: 1704–1709.

Appendix 5.A.2

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Acronyms and Abbreviations

°F	degrees Fahrenheit
ANNs	Artificial Neural Networks
Bay-Delta	San Francisco Bay/Sacramento–San Joaquin River Delta
BDCP	Bay Delta Conservation Plan
BCSD	bias-corrected and statistically downscaled
BiOp	biological opinion
BTU	British Thermal Units
CALFED	CALFED Bay-Delta Program
CAT	California Climate Action Team
CCAR	California Climate Action Registry
CCS	California Current System
CDF	cumulative distribution function
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CH_4	methane
CMIP3	Coupled Model Intercomparison Project Phase 3
CO_2	carbon dioxide
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
D-1641	State Water Resources Control Board water right Decision 1641
DCP	downscaled climate projections
Delta	Sacramento–San Joaquin River Delta
DWR	California Department of Water Resources
EBC	existing biological conditions
EC	Salinity, or electrical conductivity
ELT	Early Long-Term
ENSO	El Niño Southern Oscillation
ESO	evaluated starting operation
GCMs	Global Circulation Models
GHGs	greenhouse gases
H_2O	water vapor
HSI	Habitat Suitability Index
IPCC	Intergovernmental Panel on Climate Change
ISB	CALFED Bay-Delta Program Independent Science Board
km	kilometers
k-NN	nearest neighbor
LLNL	Lawrence Livermore National Laboratory
LLT	Late Long-Term
MAF	million acre-feet
MHHW	mean higher high water
MLLW	mean lower low water

N_2O	nitrous oxide
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
O_3	ozone
PDO	Pacific Decadal Oscillation
Reclamation	Bureau of Reclamation
ROA	Restoration Opportunity Area
SIO	Scripps Institute of Oceanography
SRCD	Suisun Resource Conservation District
SRES	IPCC Special Report on Emissions Scenarios
SRWQM	Sacramento River Water Quality Model
State Water Board	State Water Resources Control Board
SWP	State Water Project
TAF	thousand acre-feet
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
VIC	Variable Infiltration Capacity
WCRP	World Climate Research Program
WMO	World Meteorological Organization
WY	Water Year

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5.A.2.1 Introduction

Climate is the average weather observed over many years, measured most often in terms of temperature and precipitation. *Climate change* refers to a statistically significant variation in the mean state of the climate or its variability, persisting for an extended period (typically decades or longer). *Projected climate change* refers to the potential change in future climate as simulated by global circulation models (GCMs). The overall approach used to project future climate for the Bay Delta Conservation Plan (BDCP) was developed by reviewing multiple state and federal climate change approaches. Currently, no standardized climate change methodology has been adopted by either the state of California or federal agencies for use in analysis and assessments. Climate change could be addressed in a qualitative and/or quantitative manner, could focus on GCM projections or recent observed trends, and could explore broader descriptions of observed variability by incorporating paleoclimate information. Several potential approaches were considered for incorporating climate change into the BDCP effects analysis and modeling. In general, consistency with previous state and federal approaches is desirable. However, as summarized in Table 5.A.2.2-1, several different methods have been applied by different agencies in the recent water planning efforts.

5.A.2.2 BDCP Approach and Methods for Aquatic Species

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 represent both the range of projections and the central tendency of the projections. Third, it applies a method that incorporates both to the mean climate as well as to the variability in climate. While there is 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). For the BDCP, quantitative analyses have been conducted for two points in time to adequately disclose the impacts/effects of the BDCP over the 50-year permit term. The two points are as described below.

1. **Early Long-Term (ELT).** Approximately 10 years from issuance of permit (approximately 2025) and will include substantial habitat restoration and operation of the dual conveyance system.
2. **Late Long-Term (LLT).** Approximately 45 years from issuance of permit (approximately 2060) and will include the full implementation and operation of the conservation strategy.

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 Intergovernmental Panel on Climate Change (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.

It is not practical to simulate the watershed-scale effects and system response for all the potential future scenarios. Therefore, selecting representative climate change scenarios from the vast array of GCM projections is an important decision. Table 5.A.2.2-2 summarizes the four potential approaches considered for use in the BDCP.

5.A.2.2.1 Climate Projections

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

5.A.2.2.2 Climate Periods

Projected changes in temperature and precipitation for any particular emissions scenario are compared to a historical period. The period of 1971–2000 is selected as the reference climate because it is the currently established climate norm used by the National Oceanic and Atmospheric Administration (NOAA) and represents the most recent climate time period used for analyses. For the BDCP analysis, future climate periods are identified as approximately 2025 (2011–2040 [ELT]) and 2060 (2046–2075 [LLT]). The difference in mean annual temperature and precipitation among the two future periods and the historical period were identified as the climate change metric.

1 **Table 5.A.2.2-1. 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	Cal-EPA	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	California 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 historical 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 Draft EIR, 2007	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 percentile change in temp and precipitation	1-foot sea level rise at 2030 based on availability of DSM2 simulations
California Climate Action Team Report, 2008–2009	DWR	Scenario analysis using 12 GCM emission scenarios	Twelve GCM emission scenarios–derived climatology; selected based on output availability and historical skill.	1- and 2-foot sea level rise
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-foot rise at end-of-century
San Joaquin River Restoration Program, 2012	Reclamation	Sensitivity analysis with bracketing and median scenarios approach	Selected scenarios that represented 10th, 50th, and 90th percentile change in temp and precipitation	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- and 2-foot sea level rise scenarios documented, but unknown analytical approach
Suisun Marsh Plan	Reclamation, USFWS, NMFS, DWR, CDFW, SRCD	Used future scenarios developed by IPCC and information by CCAR (2009)	Emissions scenarios from IPCC and CCAR	Sea level rise for the Suisun Bay area would equate to up to 17.7 inches at high tide in 2050 and up to 80.4 inches at high tide in 2099

Project	Lead Agency	Methodology	Climate Change Assumptions	Sea Level Rise Assumptions
Southern Delta Wetlands	Semitropic Water Storage District	Used future scenarios developed by IPCC and information by CCAR (2009)	Projections from IPCC and CCAR	Sea level rise projected by Climate Change Center 4 to 35 inches every century.
Secure Water Act Report	Reclamation	World Climate Research Program's Coupled Model Intercomparison Project Phase 3 (WCRP CMIP3) were bias-corrected and spatially downscaled	Projections from IPCC	The CALFED Independent Science Board range of sea level rise at Golden Gate of 1.6 to 4.6 feet by the end of the century and DWR levels: sea level rise by midcentury ranges from 0.8 to 1.0 feet with an uncertainty range spanning 0.5 to 1.3 feet; sea level rise projections ranged from 1.8 to 3.1 feet, with an uncertainty range spanning from 1.0 to 3.9 feet by end of century.

Cal-EPA = California Environmental Protection Agency
CAT = California Climate Action Team
CCAR = California Climate Action Registry
CMIP3 = Coupled Model Intercomparison Project Phase 3
CDFW = California Department of Fish and Wildlife
DWR = California Department of Water Resources
EIR = Environmental Impact Report
GCM = Global Circulation Model
IPCC = Intergovernmental Panel on Climate Change
NMFS = National Marine Fisheries Service
PEIR = Programmatic Environmental Impact Report
Reclamation = Bureau of Reclamation
SRCD = Suisun Resource Conservation District
USFWS = U.S. Fish and Wildlife Section
WCRP = World Climate Research Program

Table 5.A.2.2-2. Potential Approaches

No.	Approach	Description	Pro	Con
1 and 2	Bracket Approach and "Median" Approach	• Similar to what has been used for the 2008 Operations Criteria and Plan (OCAP) • Treats all future projections as equally plausible and selects scenarios that best reflect the range of projected temperature and precipitation changes • Bracketing leads to the selection of four scenarios • Selection of a median scenario can be similarly made for the 50th percentile change	• Uses the full range of projection uncertainty and does not prejudge particular scenarios or Global Circulation Models (GCMs) • Inclusion of a median scenario adds a central tendency estimate	• Bracketing uses a single projection to represent each bracketing range • Brackets may be sampling outliers from the projection range • The portion of the uncertainty range that is sampled based on the position of the selected scenario may shift depending on location and climatologic period
3	Historical Performance Approach	• Is similar to what was used by the California Climate Action Team (CAT) (2009) • Makes use of the historical skill of the GCMs in creating a smaller subset of projections for consideration • Smaller subset of projections then can be analyzed in more detail • CAT 2009 assessment created a subset of six GCMs and two emission scenarios (total of 12 scenarios) for this purpose • Selection of the six GCMs was made on the basis of particular output availability (daily or sub-daily) and upon consideration of certain aspects of their historical performance	• Provides some greater scrutiny of the GCMs in relation to regional performance in simulating historical climate	• Range of uncertainty as represented from the selected subset will not represent the range of uncertainty from the full set of projections • Apparent in the CAT 2009 assessments in which the 12 scenarios are considerably drier than the full projection range • Not strongly founded that historical skill is reflective of future climate change performance (Pierce et al. 2009; Brekke et al. 2008)
4	Multi-Model Ensemble-Informed Approach	• Makes use of the full range of temperature and precipitation change uncertainty derived from all available projections • A similar approach—sub-ensembles can be developed to preference certain climate change trends within the full ensemble (e.g., more warming, drier) • Resulting scenarios more closely reflect the median of the sampled projections than the selection of any individual projection • 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)	• 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	• Collapses the uncertainty of the multiple realizations into one or several representative scenarios • To make statements of uncertainty, one would need to refer back to the full projection range

5.A.2.2.3 Multi-Model Ensemble and Sub-Ensembles

The BDCP 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 a historical reference period. At any selected 30-year future climatologic period, each projection represents one point of change among the others. This is depicted graphically in Figure 5.A.2.2-1 for a region in the Feather River watershed.

Because 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 Figure 5.A.2.2-1). 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 5.A.2.2-1. 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., the 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 U.S. Fish and Wildlife Service (USFWS) 2008 and National Marine Fisheries Service (NMFS) 2009 biological opinions (BiOps), 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 that commonly are made up of 25 to 35 projections and are based on the direction of change from the 50th percentile statistic.

The very small ensemble sample sizes exhibited month by month changes that were sometimes dramatically different from 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 because of 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 their representation of seasonal trends. The 10-NN approach (Figure 5.A.2.2-1) 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 five projections—multiple simulations—could come from one GCM–emission scenario combination). The state and federal agency representatives agreed to use the following climate scenario selection process for BDCP.

1. The use of the original quadrant approach for Q5 (projections within the 25th to 75th percentile bounding box) because it provides the best estimate of the consensus of climate projections.
2. The use of the 10-NN method to develop 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.

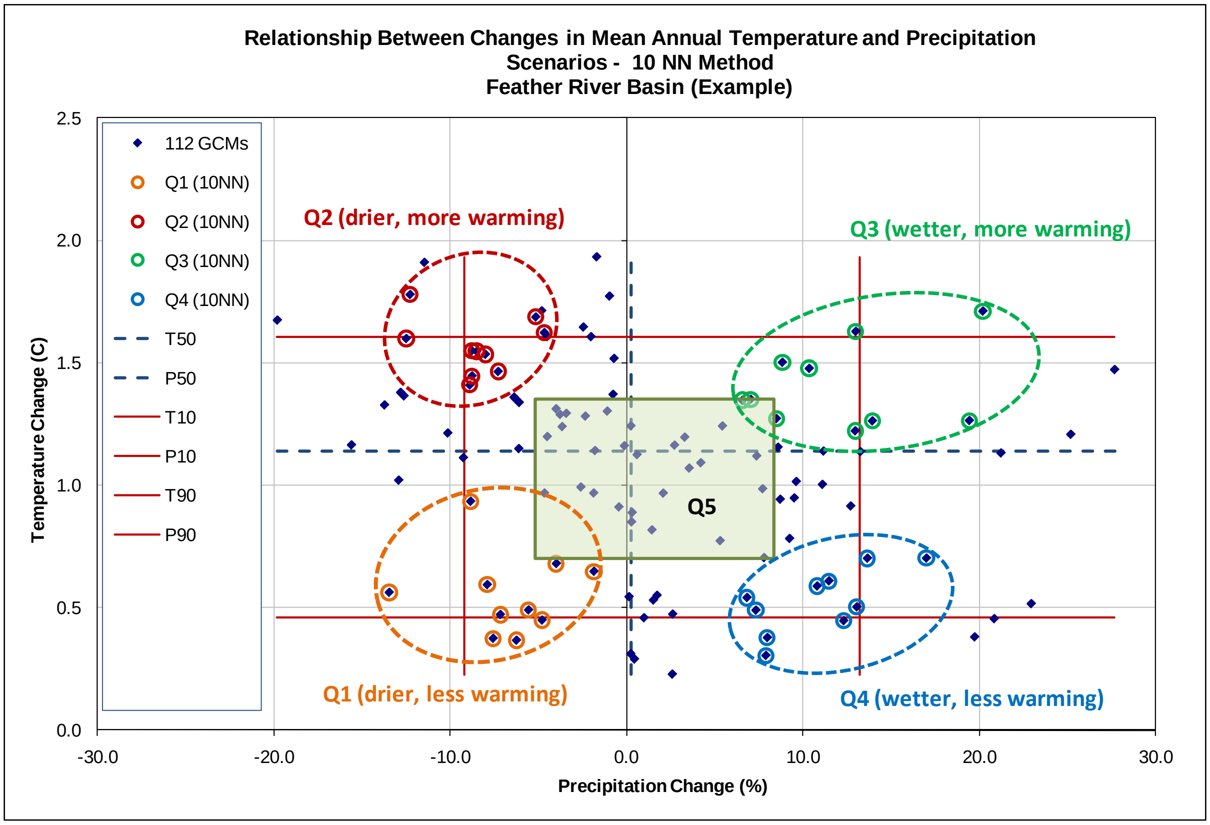

Figure 5.A.2.2-1. Example of Downscaled Climate Projections and Sub-Ensembles Used for Deriving Climate Scenarios (Q1–Q5), Feather River Basin at 2025[1]

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[1] 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. The temperature and precipitation changes are normalized before determining the nearest neighbors.

5.A.2.2.4 Incorporating Climate Change Effects

One difficulty 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 order to incorporate both the climate change signal and the natural variability in the longer-term observed record, the approach was to create an expanded time series that 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 Bureau of Reclamation (Reclamation) planning (Bureau of 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 historical 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 (e.g., 2025 or 2060).
2. For each calendar month (e.g., 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 this case), determine the statistical properties (CDFs) of temperature and precipitation at each grid cell.
4. Develop quantile maps between the historical 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 monthly or daily time series of temperature and precipitation that has the range of variability observed in the historical record, but also contains the shift in climate properties (both mean and expanded variability) found in the downscaled climate projection. Figure 5.A.2.2-2 provides an example of this process for a grid cell in the Feather River watershed. As shown in Figure 5.A.2.2-2, 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 (EBC). However, for large precipitation events (i.e., the 90th percentile) January precipitation is projected to increase by almost 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 statistical climate shift is important to characterize the projected effects of climate change.

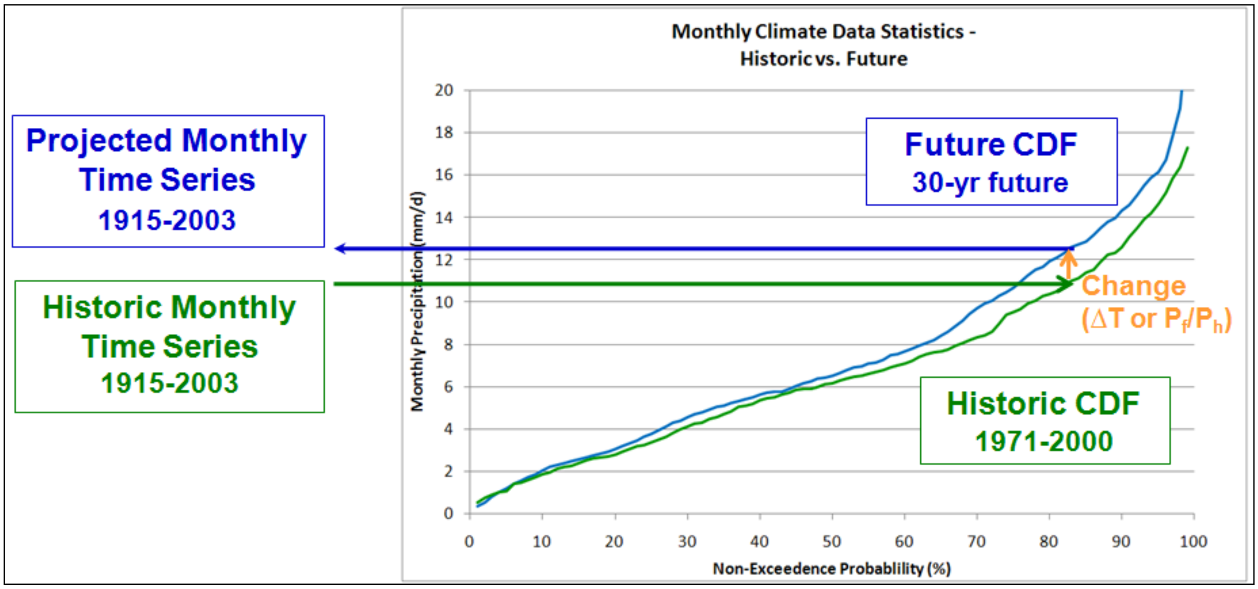


Figure 5.A.2.2-2. Example of an Historical Monthly Precipitation Statistics for a Grid Cell

5.A.2.2.5 Sea Level Rise Scenarios

In 2007, the IPCC estimated a rise in sea level of 0.6 to 1.9 feet by 2100 (Intergovernmental Panel on Climate Change 2007). However, more recent estimates suggest an even greater rise, particularly if melting of the Greenland and Antarctic ice sheets accelerates, as suggested by recent satellite observations. Rahmstorf (2007) used a semi-empirical approach to project future sea level rise, yielding a proportionality coefficient of 3.4 millimeters per year per degree Celsius of warming, and a projected sea level rise of 1.6 to 4.6 feet above 1990 levels in 2100 when applying IPCC Third Assessment Report warming scenarios. Other recent estimates of global increases by 2100 include 1.6 to 3.3 feet (National Research Council 2010), 2.6 to 6.6 feet (Pfeffer et al. 2008), and 3.2 to 5.1 feet (Vermeer and Rahmstorf 2009).

Using the Rahmstorf (2007) method, the CALFED Bay-Delta Program (CALFED) Independent Science Board (ISB) estimated ranges of sea level rise of 2.3 to 3.3 feet at mid-century and of 1.6 to 4.6 feet by the end of the century (CALFED Independent Science Board 2007). Scenarios modeled by the California Climate Action Team (CAT) projected sea level rise increases along the California Coast of 1.0 to 1.5 feet above 2000 levels by 2050 and 1.8 to 4.6 feet by 2100 (Cayan et al. 2009). However, if California's sea level continues to mirror global trends, increases in sea level during this century could be considerably greater.

For water planning purposes, the California Department of Water Resources (DWR) estimated sea level rise over the twenty-first century using the method of Rahmstorf (2007) and 12 climate projections selected by the CAT (Chung et al. 2009). The historical 95% confidence interval was extrapolated to estimate the uncertainties in the future projections. Mid-century sea level rise projections ranged from 0.8 to 1.0 feet, with an uncertainty range spanning 0.5 to 1.2 feet. End-of-century projections ranged from 1.8 to 3.1 feet, with an uncertainty range of 1.0 to 3.9 feet. These estimates are slightly lower than those of Rahmstorf (2007) because DWR used a more limited ensemble of climate projections that did not include the highest projections of temperature increases (Chung et al. 2009).

Using the method of Rahmstorf (2007), the projected sea level rise at the ELT timeline for the BDCP analysis (2025) is approximately 12 to 18 centimeters (cm) (5 to 7 inches). At the LLT timeline (2060), the projected sea level rise is approximately 30 to 60 cm (12 to 24 inches). These sea level rise estimates are also consistent with those outlined in the U.S. Army Corps of Engineers (USACE) guidance circular for incorporating sea level changes into civil works programs (U.S. Army Corps of Engineers 2009). Because of the considerable uncertainty in these projections and the state of sea level rise science, the mid-range of the estimates was used for each BDCP timeline: 15 cm (6 inches) by 2025 and 45 cm (18 inches) by 2060. In addition, sensitivity scenarios were prepared to consider sea level rise of up to 55 cm by 2060 as required by Water Code Section 85320(b)(2)(C) (Figure 5.A.2.2-3).

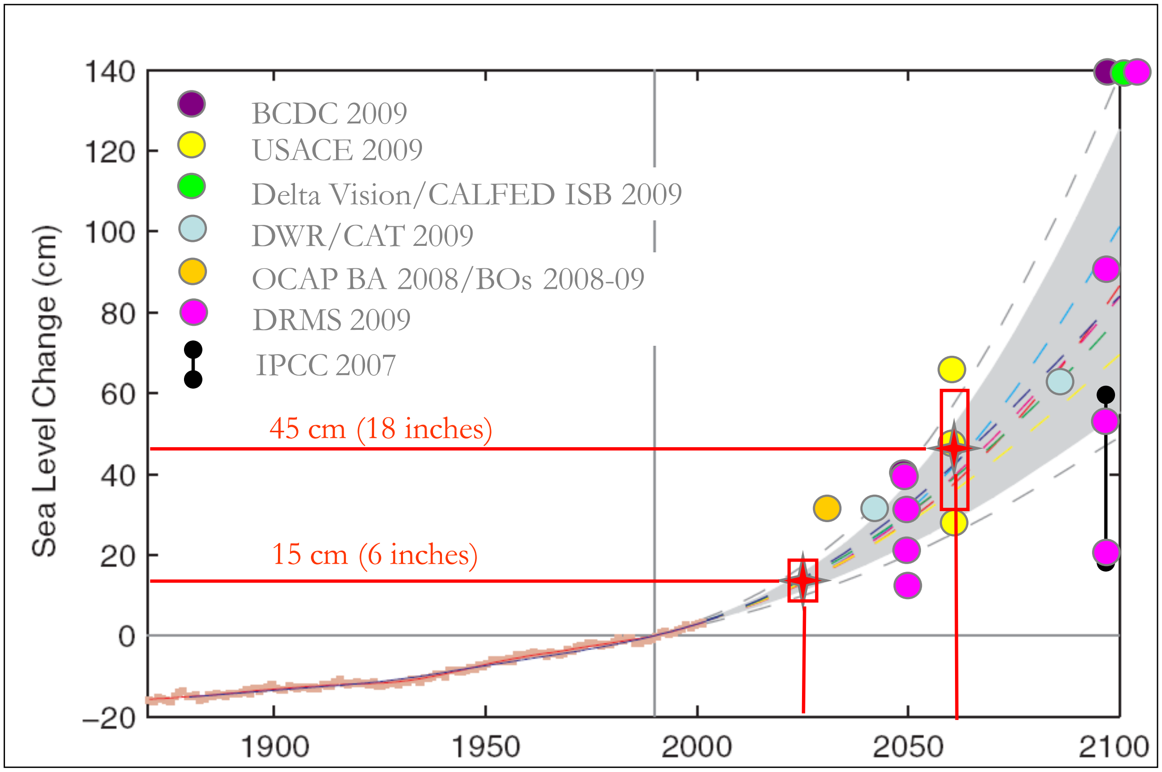


Figure 5.A.2.2-3. Expected Sea Level Change and BDCP Sea Levels for ELT and LLT

5.A.2.2.6 Tidal Amplitude Changes

Tidal amplitude also may be increasing. Flick and coauthors (2003) found a statistically significant increase in tidal amplitude (mean higher high water [MHHW]–mean lower low water [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 to 5% increase per century. Jay (2009) recently completed research into changes in tidal pattern components 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 amphidromic 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.

Due to the considerable uncertainty associated with the tidal amplitude increases, a sensitivity analysis of increased tidal amplitude was made. A simulation with a 5% increase in tidal amplitude was made using the UnTRIM model to evaluate the increased tidal flows in the Sacramento–San Joaquin River Delta (Delta) in comparison to the effects of mean sea level increase. The UnTRIM model sensitivity to increased tidal amplitude indicated that this increased tidal energy would propagate upstream to increase the tidal fluctuations at Martinez and Chipps Island by about the same magnitude as at the Golden Gate; however, the dominant effects of climate change on tidal amplitudes in the Delta will be compensated for by the reduced tidal amplitude caused by the increased tidal acreage from sea level rise and tidal restoration under the BDCP.

5.A.2.3 Aquatic Methods and Models

Multiple methods and models were used to project climate change outputs associated with precipitation and runoff, reservoir inflow and stratification, upstream and Delta water temperature, salinity (electrical conductivity [EC]), and tidal flow. The outputs then were used as inputs for other analysis to project effects on aquatic habitat and covered fish species (e.g., SALMOD or habitat suitability index). For example, the downscaled GCMs were used to project climate conditions (temperature and precipitation) at localized areas. These data then were used as inputs to the Variable Infiltration Capacity (VIC), which is a hydrologic model that simulates streamflow from rainfall in each watershed. The streamflow outputs from VIC were used as input to an operations model, CALSIM II, and the Reclamation temperature models. CALSIM II simulates how much water would be released from the Central Valley Project (CVP) and State Water Project (SWP) reservoirs (i.e., river flows), reservoir storage levels, and water deliveries for the CVP and SWP. The Reclamation temperature models calculate reservoir temperature profiles, release temperatures, and downstream river temperatures, which then were used in SALMOD and other habitat assessment models to determine the upstream effects on salmonids under the various model scenarios, including those in the ELT and LLT without the BDCP (i.e., EBC_ELT and EBC_LLT [EBC = existing biological conditions]). The models and overall methods for how models were incorporated to generate climate change output for upstream and the Delta aquatic habitats are described below. The methods and results associated with the analysis were used to determine effects on fish species (e.g., SALMOD) attributable to the combination of climate change and the BDCP are described in Appendices 5.B to 5.G.

5.A.2.3.1 Overview of Methods

The analytical process for incorporation of climate change effects in BDCP planning included the use of several sequenced analytical tools (Figure 5.A.2.3-1). The GCM downscaled climate projections (DCP), developed through the process described above, were used to create modified temperature and precipitation inputs for the VIC hydrology model. The VIC model simulates hydrologic processes on the 1/8 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 were translated into modified monthly 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. The Reclamation temperature models used the DCP air temperature changes for ELT and LLT at six meteorological stations to calculate the changes in inflow temperatures, equilibrium temperatures, and heat exchange rates and to calculate the reservoir temperature profiles and the release temperatures, as well as the downstream river temperatures.

DSM2 model simulations were developed for each habitat condition (existing, partial restoration at ELT, and full restoration at LLT) and sea level rise scenario (15 cm at ELT, 45 cm at LLT) that is coincident with the BDCP timeline. New Artificial Neural Networks (ANNs) were developed based on the flow-salinity response simulated by the DSM2 model. These sea level rise –habitat ANNs (salinity-outflow relationships) subsequently were included in CALSIM II models. The CALSIM II model was used to simulate reservoir and Delta operations for each of the two climate change hydrologic conditions (ELT and LLT) in addition to the historical hydrologic conditions.

These CALSIM II simulations provide estimates of the change in operations, upstream storage and river flow conditions, and Delta facility and export operations associated with future climate change. The existing facilities and operations were simulated for the EBC_ELT and EBC_LLT conditions; the BDCP restorations, facilities, and evaluated starting operation (ESO) were simulated for the ELT and LLT runoff and temperature conditions. DSM2 hydrodynamic and water quality simulations were developed for existing conditions (EBC1 and EBC2), with distinct simulations for each climate change–sea level rise scenario (ELT and LLT). These DSM2 simulations provide information related to Delta system performance under changes to inflows (pattern and magnitudes), exports, and sea levels.

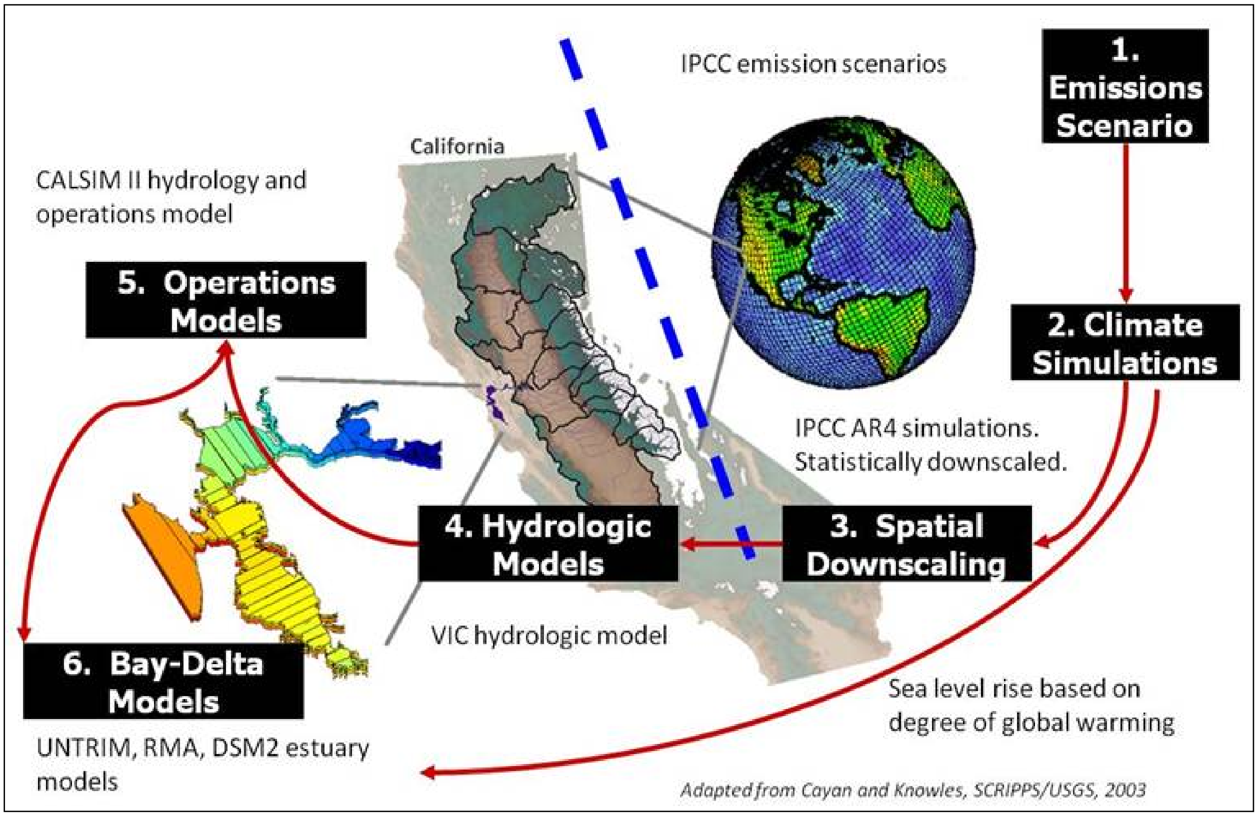


Figure 5.A.2.3-1. Graphical Depiction of the Analytical Process for Incorporating Climate Change into Water Planning

5.A.2.3.2 Precipitation and Runoff

Regional hydrologic modeling is necessary to understand the watershed-scale impacts of projected climate patterns on the processes of rainfall, snowpack development and snowmelt, soil moisture depletion, evapotranspiration, and ultimately changes in streamflow patterns. Hydrologic models enable these watershed processes to be characterized and provide estimates of changes in magnitude and timing of basin runoff with changes in climate conditions.

Regional hydrologic modeling using the VIC model (Liang et al. 1994, 1996; Nijssen et al. 1997) was applied to support an assessment of changes in runoff associated with future projected changes in climate. These results are intended for use in comparative assessments and serve the primary purpose of adjusting inflow records in the CALSIM II long-term operations model to reflect anticipated changes in climate. The GCM DCP were used to adjust historical California climate for the effects of climate change for the ELT and LLT timeframes. The resulting adjusted climate patterns—primarily temperature and precipitation fields—are used as inputs to the VIC hydrology model. The VIC model simulations produce outputs of hydrologic parameters for each grid cell and daily and monthly streamflows at key locations in the Sacramento River and San Joaquin River watersheds. The changes in “natural” flow at these locations between the observed and climate scenarios then are applied to adjust historical inflows to the CALSIM II model.

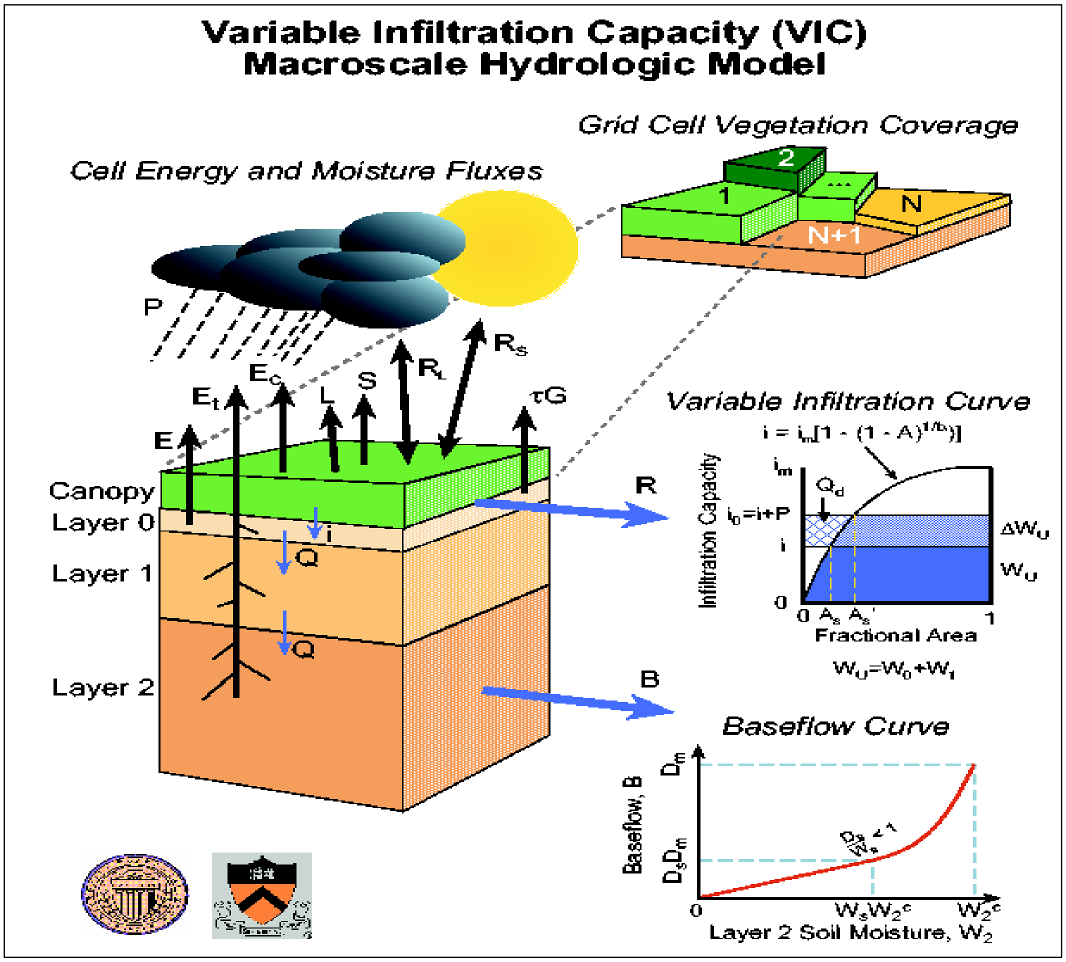
The VIC model is a spatially distributed hydrologic model with parameters describing topography, soils, land use, and vegetation classes. It applies to larger basins with fairly coarse grids. Rainfall, snow, infiltration, evapotranspiration, runoff, soil moisture, baseflow, and water balance are computed over each grid cell on a daily basis for the entire period of simulation. An offline routing tool processes the individual cell runoff and baseflow terms and routes the flow to develop streamflow at various locations in the watershed based on flow direction and flow accumulation inputs derived from digital elevation models. For the simulations performed for the BDCP, streamflow was routed to 21 locations that generally align with long-term gaging stations throughout the watershed. The monthly flow at these locations also allows for assessment of changes in various hydrologic indices used in water management in the Delta. VIC routed flows are considered unimpaired, in that they do not include effects of diversions, imports, storage, or other human management of the water resource. Figure 5.A.2.3-2 shows the hydrologic processes included in the VIC model.

VIC is driven by daily inputs of precipitation, maximum and minimum temperature, and wind speed. The model internally calculates additional meteorological forcings such as short-wave and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficits. VIC accepts input meteorological data directly from global or national gridded databases or from GCM projections. Historical calibration is achieved through adjustments to parameters describing the rates of infiltration and baseflow as a function of soil properties, as well as the soil layers depths.

The VIC model has been applied to many major basins in the United States, including large-scale applications to California's Central Valley (Maurer et al. 2002; Cayan et al. 2009) and the Colorado River Basin (Christensen and Lettenmaier 2006), and several other western United States basins. The VIC model application for California was obtained from Dan Cayan and Tapash Das at Scripps Institute of Oceanography (SIO) and is identical to that used in the recent CAT (2009) studies. The VIC model was simulated by CH2M Hill, and comparisons were performed with SIO to ensure appropriate transfer of data sets. No refinements to the existing calibration were performed for the BDCP application.

The VIC application for California was developed by the University of Washington and has been subsequently refined (Maurer et al. 2002). The model grid consists of approximately 3,000 grid cells at a 1/8 degree latitude by longitude spatial resolution. The VIC model domain is shown in Figure 5.A.2.3-3 and covers all major drainages in California. Daily observed meteorology for the modeling grid was obtained from the University of Washington for the period 1915–2003. This historical data set was used to confirm the historical estimates of natural monthly runoff using the VIC model.

Scenarios of future climate were developed as described above in Section 5.A.2.2.1, *Climate Projections*. These scenarios consist of daily time series and monthly distribution statistics of temperature and precipitation for each grid cell for the entire state of California.



Source: University of Washington 2010.

Figure 5.A.2.3-2. Hydrologic Processes Included in the VIC Model

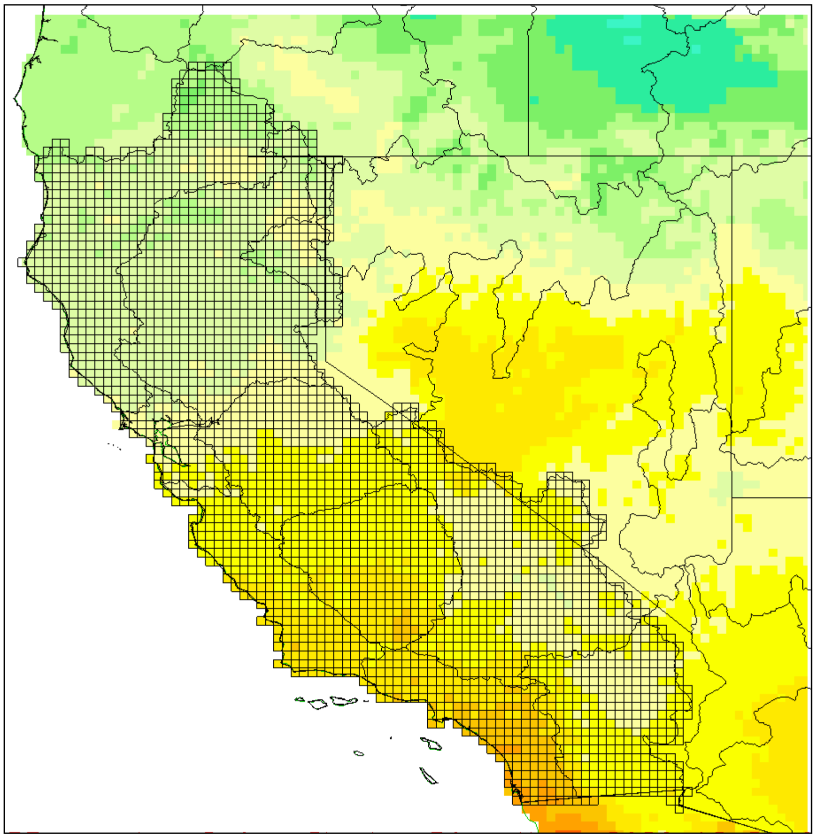


Figure 5.A.2.3-3. VIC Model Domain and Grid as Applied for the BDCP Application

5.A.2.3.3 Water Temperature

Water temperatures upstream and in the Delta would be influenced by climate change. The methods and assumptions used to estimate equilibrium temperature from meteorological conditions and water temperature from reservoir operations and river flows are described below.

In California, the seasonal changes in meteorology are the strongest factors controlling water temperatures. The seasonal effects of meteorology can be summarized with the monthly equilibrium water temperatures. Equilibrium temperature is the theoretical (steady-state) water temperature that would be established (observed) if a water surface were exposed to constant (average) meteorological conditions. The equilibrium temperature corresponds to a balance, with "no net heat exchange" between the air and water. The monthly equilibrium water temperature is usually slightly less (2–5 degrees Fahrenheit [°F]) than the monthly average air temperature, but is higher (2–5°F) than the air temperature in the spring months. Because a substantial part of the total heat exchange into the water is caused by direct solar radiation, shading from topography or vegetation will lower the equilibrium temperatures by 5°F or more. Table 5.A.2.3-1 shows the monthly air temperatures, monthly inflow water temperatures, monthly equilibrium temperatures, and monthly heat exchange rates estimated from available data for the monthly Reclamation temperature model, using the measured 1971–1977 meteorology at various reservoirs.

The monthly average inflow (river) water temperatures are about 5–10°F less than equilibrium temperature in the spring and summer months because of the cooling effects of snowmelt, shallow groundwater discharge (springs), and shading from topography and vegetation.

The expected increase in water temperatures with climate change will be some portion of the expected increase in air temperatures. The expected change in water temperatures at higher elevations may be less than the projected increase in water temperatures at lower elevations. The expected effects on inflow water temperatures or downstream river temperatures may be somewhat less than the change in air temperatures. Nevertheless, climate change is expected to increase monthly water temperatures throughout the Central Valley by about the same amount as the average monthly air temperature increases.

Table 5.A.2.3-1. Monthly Average Air Temperatures (°F), Inflow Temperatures, Equilibrium Temperatures, and Heat Exchange Rates Calculated for the Reclamation Monthly Water Temperature Model for 1971–1977 Conditions

Month	Local Air Temp	Estimated Inflow Temp	Equilibrium Temp	Heat Exchange Rate (Btu/[ft^2-day-°F])	Local Air Temp	Estimated Inflow Temp	Equilibrium Temp	Heat Exchange Rate (BTU/[ft^2-day-°F])
	Trinity-Lewiston				**Shasta-Keswick**			
January	39.6	36.7	37.4	90	45.2	42.5	43.9	101
February	43.9	40.3	43.5	101	49.7	44.8	49.9	108
March	46.1	40.3	48.2	109	52.1	46.9	54.1	125
April	51.8	41.3	55.3	123	58.2	49.6	61.0	137
May	61.0	43.8	63.5	138	67.9	54.4	69.3	163
June	69.6	54.2	68.9	151	77.1	61.1	74.7	173
July	74.8	60.7	72.4	151	82.5	67.2	78.3	151
August	72.3	62.2	70.0	134	79.9	65.9	75.9	144
September	67.7	61.1	63.4	125	75.0	61.5	69.6	136
October	57.4	52.1	53.8	109	64.1	54.6	60.3	119
November	45.7	41.3	43.3	96	51.6	48.8	49.8	105
December	40.0	37.7	37.3	86	45.7	43.1	43.9	93
	Oroville-Thermalito				**Folsom-Nimbus**			
January	45.1	41	44	95	44.5	43.1	44	87
February	51	44.6	50.5	104	50.3	44.8	51.5	101
March	53.7	46.4	55	121	52.5	48.2	55.4	118
April	58.7	50	61.2	134	57.2	51.2	61.5	132
May	67.4	55.4	68.5	155	64.6	55.3	67.9	148
June	75.7	62.6	74	177	72.3	60.8	73.3	183
July	80.1	69.8	77.5	160	76.5	64.2	76.5	169
August	78.3	69.8	75.7	154	75.8	62.9	75.5	162
September	73.7	66.2	70.5	137	72.4	61.4	71.4	138
October	64.9	57.2	62	112	64.4	58.4	63.3	107
November	53.6	50	51	94	53.1	51.4	52.7	84
December	46.5	42.8	44	85	46.4	45.3	44.9	79

BTU/ft^2 = British thermal units per square foot.

The major change assumed for the water temperature modeling of ELT and LLT was increased monthly air temperatures for each simulated reservoir and for the Delta. The increased air temperatures will cause the reservoir inflow temperatures and the equilibrium temperatures to increase. The generation of the ELT and LLT monthly air temperatures for the historical period used for CALSIM and the temperature models (1922–2003) used “climate mapping” of the cumulative distribution of historical monthly air temperatures into the future cumulative distribution of air temperatures, obtained from a selected “middle quadrant (Q5)” of the full ensemble of 112 GCM projections of future climate conditions.

For example, the GCMs predict that the future air temperature distribution will be shifted (increased) more for the highest seasonal temperatures. Perhaps the shift would be 1°F at the low end of the monthly historical temperature range (winter) and 5°F at the high end of the historical temperature range (summer). To provide a general summary of the magnitude of ELT and LLT climate change effects, the monthly average air temperatures, equilibrium temperatures, and inflow temperatures for each reservoir were adjusted based on this “climate mapping” of the GCM results. Table 5.A.2.3-2 gives the average monthly increases in air temperatures used for the ELT and LLT climate conditions for the six stations used in the Reclamation temperature models. Similar changes were calculated from the GCM results for other stations. The average annual increase in air temperatures was about 1°F for the ELT and about 2°F for the LLT, but the summer temperatures (August and September) were increased the most and the spring temperatures (March and April) were increased the least.

Figure 5.A.2.3-4 shows the estimated shifts (increases) in monthly air temperatures at Trinity, Shasta, Folsom, and New Melones Reservoirs that were used for the ELT and LLT meteorology inputs for the Reclamation temperature models to simulate effects of climate change on water temperatures in the Sacramento River. Similar air temperature shifts were determined for the other CVP and SWP reservoirs and downstream rivers.

Table 5.A.2.3-2. Monthly Average Historical and Increase in Air Temperatures for ELT and LLT Climate Change Conditions at CVP and SWP Reservoirs

	Trinity Air Temperature			Whiskeytown Air Temperature			Shasta Air Temperature		
	Historical	ELT Increase	LLT Increase	Historical	ELT Increase	LLT Increase	Historical	ELT Increase	LLT Increase
January	38.92	0.68	1.61	44.40	0.63	1.50	44.49	0.63	1.53
February	43.02	0.75	1.48	48.68	0.78	1.43	48.85	0.76	1.43
March	46.77	0.49	1.20	52.59	0.29	1.04	52.83	0.33	0.95
April	52.06	0.54	1.39	58.11	0.45	1.28	58.45	0.50	1.27
May	59.61	0.90	1.56	66.00	0.95	1.57	66.47	1.00	1.65
June	67.09	0.94	1.93	73.80	0.92	1.99	74.41	0.92	1.91
July	73.23	1.06	2.38	80.21	0.76	2.26	80.93	0.76	2.22
August	71.18	1.12	2.49	78.07	1.08	2.41	78.75	1.10	2.44
September	66.29	1.08	2.29	72.97	1.22	2.42	73.57	1.17	2.47
October	85.55	0.87	1.64	63.25	0.74	1.36	63.67	0.67	1.32
November	46.19	0.70	1.57	51.99	0.74	1.66	52.22	0.79	1.66
December	39.68	0.63	1.66	45.20	0.66	1.56	45.30	0.62	1.56
Annual	57.49	0.81	1.77	61.27	0.77	1.71	61.66	0.77	1.70
	Oroville Air Temperature			**Folsom Air Temperature**			**New Melones Air Temperature**		
	Historical	**ELT Increase**	**LLT Increase**	**Historical**	**ELT Increase**	**LLT Increase**	**Historical**	**ELT Increase**	**LLT Increase**
January	45.54	0.77	1.69	45.69	0.88	1.82	42.64	0.89	1.80
February	50.33	0.89	1.69	50.47	0.89	1.78	48.40	0.93	1.75
March	54.16	0.59	1.49	54.17	0.63	1.54	52.88	0.68	1.59
April	59.12	0.59	1.44	58.93	0.56	1.49	58.32	0.81	1.68
May	66.65	1.12	1.85	65.69	1.21	2.01	65.13	1.22	2.03
June	73.83	1.17	2.27	72.41	1.34	2.51	71.74	1.29	2.37
July	79.22	1.30	2.50	77.73	1.58	2.85	76.06	1.31	2.35
August	77.18	1.28	2.63	76.49	1.41	2.80	74.69	1.21	2.47
September	72.69	1.08	2.53	72.90	1.12	2.66	71.10	1.15	2.52
October	64.19	0.94	2.03	64.90	0.96	2.05	62.70	0.96	2.01
November	53.70	0.75	1.87	54.18	0.79	1.89	51.40	0.84	1.92
December	46.41	0.69	1.75	46.75	0.75	1.82	43.31	0.75	1.83
Annual	61.92	0.93	1.98	61.69	1.01	2.10	59.86	1.00	2.03

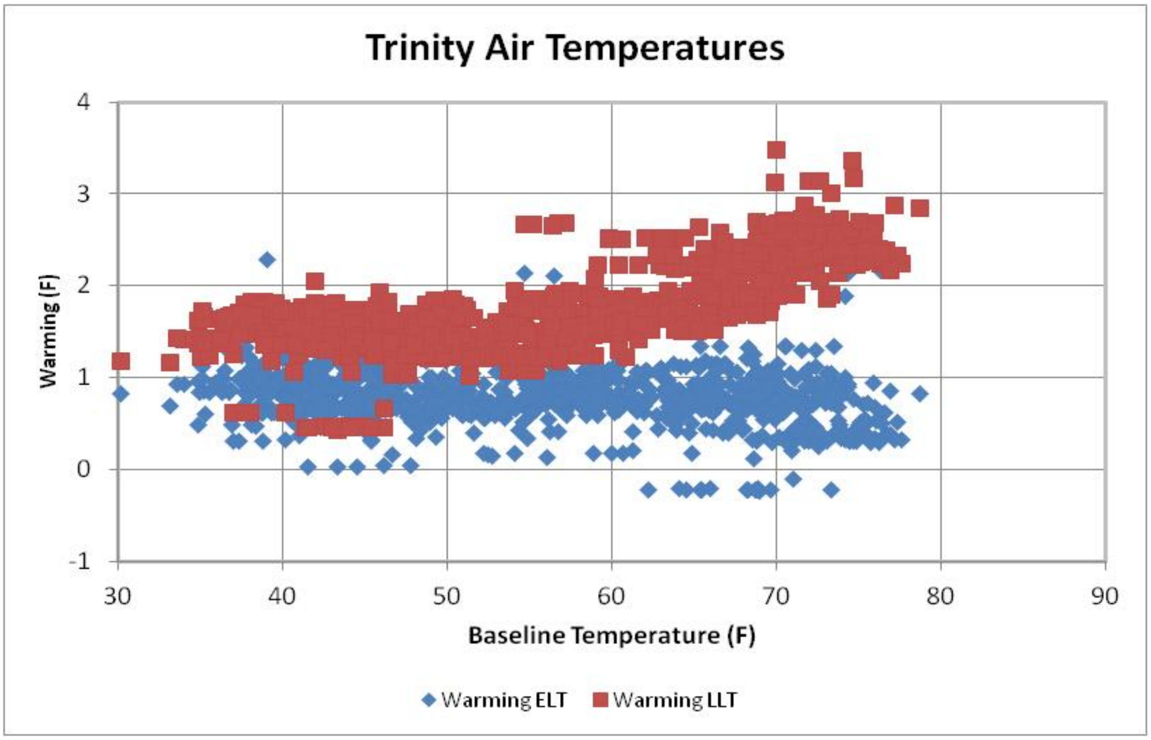


Figure 5.A.2.3-4a. Trinity Reservoir

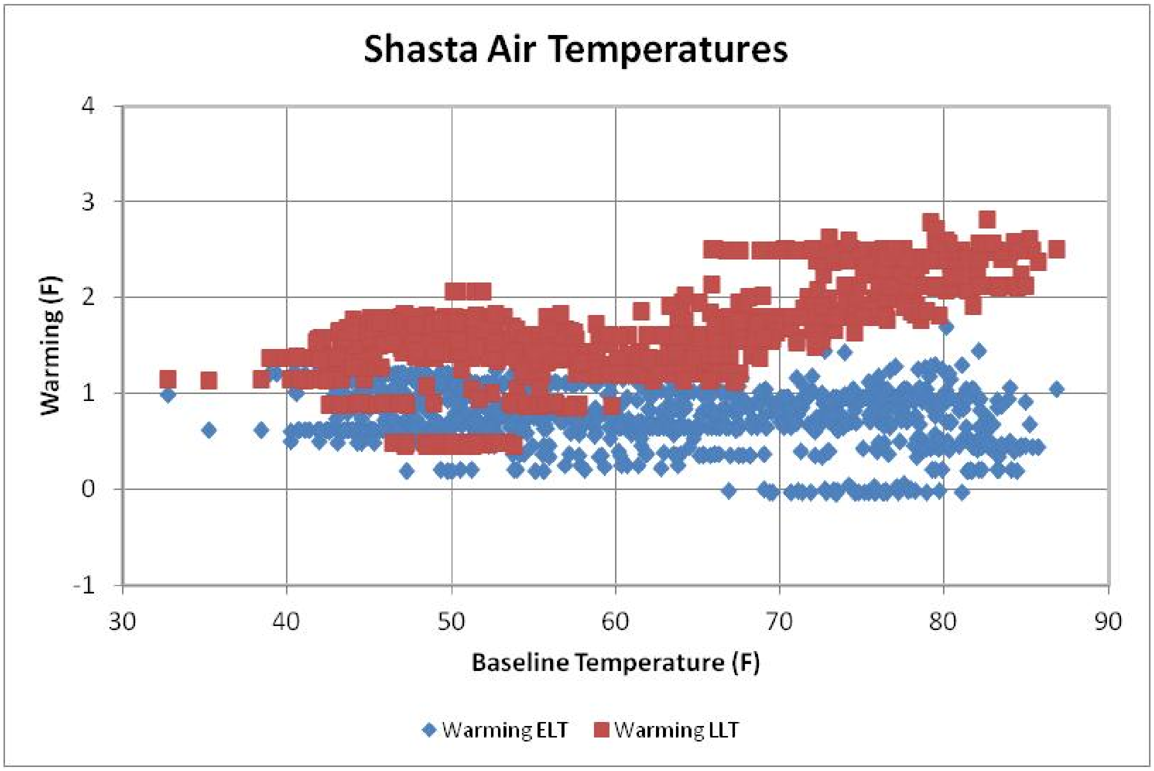


Figure 5.A.2.3-4b. Shasta Reservoir

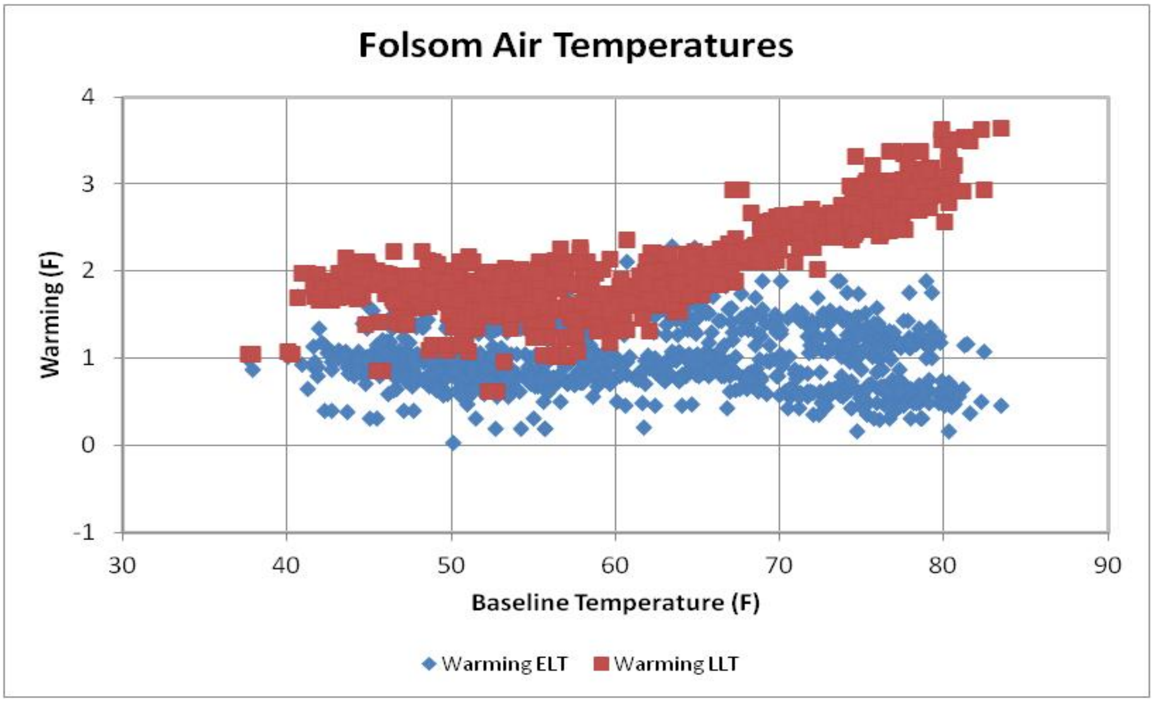


Figure 5.A.2.3-4c. Folsom Reservoir

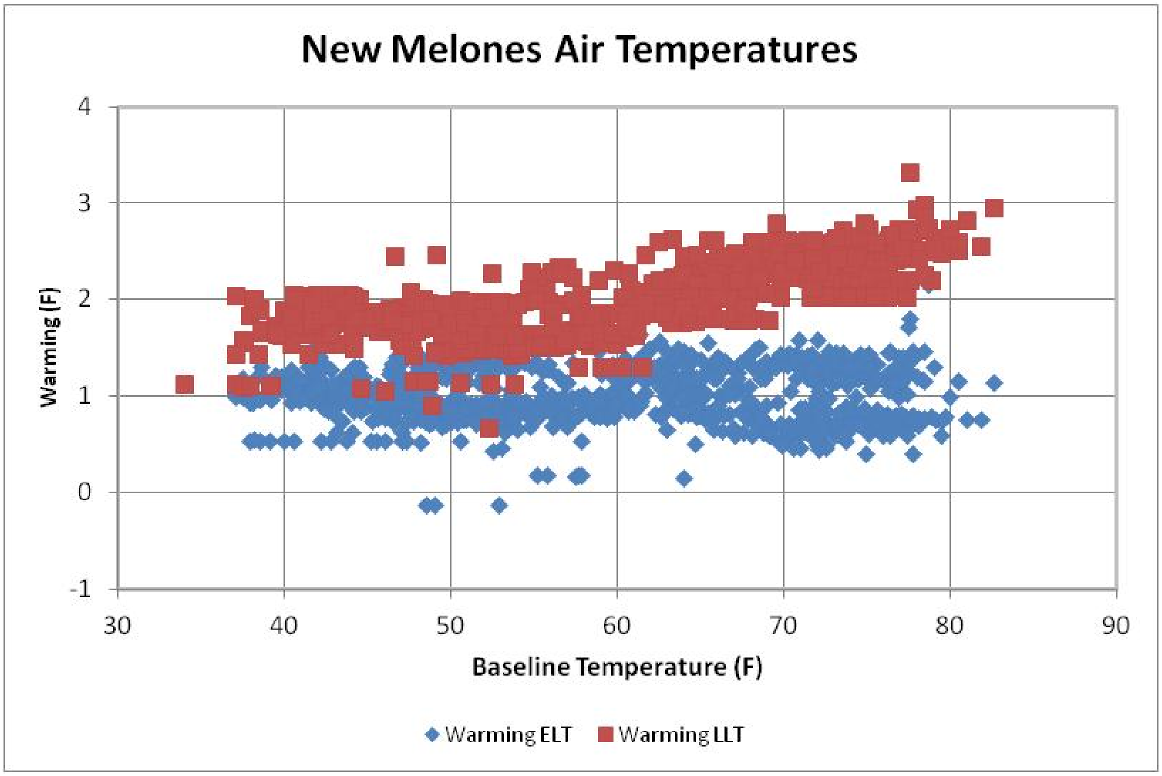


Figure 5.A.2.3-4d. New Melones Reservoir

Figure 5.A.2.3-4. Estimated Climate Change Shifts in Monthly Air Temperatures for ELT (2025) and LLT (2060) at (a) Trinity, (b) Shasta, (c) Folsom and (d) New Melones Reservoirs

5.A.2.3.4 Upstream Methods

Methods for evaluating the effects of climate change on upstream areas include the use of VIC and CALSIM to describe runoff and reservoir inflows and the use of the Reclamation monthly water temperature model and Sacramento River Water Quality Model (SRWQM) to describe reservoir stratification and river warming, and establishing temperature for upstream habitat. These are described below.

5.A.2.3.4.1 Runoff and Reservoir Inflows

The VIC modeling described above (Section 5.A.2.3.2, *Precipitation and Runoff*) was used to estimate the shifts in the monthly runoff and reservoir inflows for the ELT and LLT. The results from the VIC modeling were used in the CALSIM model and are shown as the primary comparison between the existing (historical) and the ELT and LLT runoff patterns. The expected changes in precipitation and runoff were incorporated into the monthly CALSIM model inputs (reservoir inflows) for the ELT and LLT timeframes to identify the change in existing reservoir operations and Delta inflows in the project area. The assumed changes in monthly and annual runoff from future climate change generally reflect the expected shift from snowpack runoff (in April, May, and June) to rainfall runoff (in January, February, and March).

5.A.2.3.4.2 Reservoir Temperature Stratification

Seasonal meteorology (equilibrium temperatures) and seasonal inflow temperatures along with the reservoir geometry and operations (seasonal drawdown of storage) control the reservoir release temperatures. Although the summer equilibrium temperatures are 70–75°F (Table 5.A.2.3-1), the reservoir release temperatures are generally less than 50°F throughout the summer, and the release temperatures from the regulating reservoirs (Lewiston, Keswick, Natoma) are usually less than 55°F. This seasonal "ice box" effect is caused by the stratification of the storage reservoirs, with colder (more dense) water remaining in the lower depths and the warmer (less dense) water remaining near the surface. The seasonal releases from the power plant intakes (generally low in the reservoir) will cause the temperatures in the deeper water to slowly increase throughout the summer months. The release temperatures usually reach a maximum in September or October, prior to the fall cooling and mixing of the reservoir. The seasonal release temperatures at each reservoir will depend on the annual hydrology (i.e., filling and summer drawdown) and the reservoir geometry and outlet elevations (or selective withdrawal facilities).

The Reclamation monthly water temperature model and the SRWQM both were used to simulate the effects of climate change on water temperatures in areas upstream of the Plan Area. The Reclamation temperature model includes the CVP or SWP reservoirs as a one-dimensional (vertical layered) heat budget model, the regulating reservoirs as a one-dimensional longitudinal (vertically mixed segments) heat budget model, and the downstream rivers as a one-dimensional (vertically mixed segments) model. The Reclamation monthly temperature model was used to simulate Trinity Reservoir and Trinity River temperatures, Oroville Reservoir and Feather River temperatures, Folsom Reservoir and American River temperatures, and New Melones Reservoir and Stanislaus River temperatures. The Reclamation temperature model and calibration results are described more fully in the Central Valley Project Improvement Act (CVPIA) *Fish Habitat Methodology/Modeling Technical Appendix* (Bureau of Reclamation 1997).

The SRWQM daily temperature model includes Shasta Reservoir as a one-dimensional (vertical layered) heat budget model, Whiskeytown and Keswick Reservoirs as one-dimensional longitudinal (vertically mixed segments) heat budget models, and the Sacramento River downstream of Keswick Dam to Red Bluff and Hamilton City as a one-dimensional (vertically mixed segments) model. The SRWQM uses a 6-hour time step for daily temperature results, but the seasonal temperatures and the effects of Shasta Reservoir storage volume on Keswick release temperatures were summarized with monthly average temperatures, just like the monthly Reclamation temperature model results.

5.A.2.3.4.3 River Warming

The storage reservoir release temperatures of 50–55°F are much cooler than the equilibrium temperatures in the summer and fall months. The warming in the regulating reservoirs and the downstream warming in the rivers will be controlled by the equilibrium temperature (and heat exchange rate) and the river flow, which controls the travel time and river depth. The surface heat exchange in the regulating reservoirs and downstream rivers is dependent on the surface area and the flow rate. The monthly Reclamation temperature model and the daily SRWQM both use equilibrium temperature and heat exchange calculations to estimate the downstream warming. The water temperatures in the Sacramento River were calculated with the monthly Reclamation temperature model or the daily SRWQM temperature model. The warming equation used in the Reclamation water temperature model is:

$$\text{Warming (°F)} = [\text{T equilibrium} - \text{T release}] \times [1 - \exp(-K \times \text{area (acres)}/\text{flow (cfs)} \times 0.0081)]$$

where K is the heat exchange rate (BTU/[ft^2-day-°F]), 0.0081 is the appropriate conversion, BTU = British thermal units, and cfs = cubic feet per second.

As an example, the warming in Keswick Reservoir and between Keswick and Red Bluff (60 miles downstream) can be calculated with the following information for an example flow of 10,000 cfs. The surface area of Keswick Reservoir is 620 acres, and the downstream river area is about 2,400 acres. The warming in Keswick Reservoir would be about 8% of the initial temperature difference (i.e., equilibrium minus Shasta), and the warming to Red Bluff would be about 34% of the initial temperature difference. Climate change effects on downstream water temperatures would be the result of the increased equilibrium temperatures.

5.A.2.3.5 Delta Methods

The DSM2 1D tidal flow and water quality model was used to estimate changes in Delta water temperatures and the UnTRIM 3D model, CALSIM, ANN, and DSM2 were used to describe changes in salinity and the relationships between tidal flows and salinity and between Delta outflow and salinity under climate change conditions. The general methods using these models are described below.

5.A.2.3.5.1 Water Temperature

Because the Delta water temperatures are controlled by equilibrium temperatures (meteorological conditions), the effects of climate change on air temperatures are expected to warm Delta water temperatures directly. Therefore, adjusted (increased) monthly air temperatures would raise Delta water temperatures by about the same amount. If the assumed warming is uniform in all months, the monthly average water temperatures all may increase by the same amount. The methods used for the BDCP analysis assumed that the cumulative distribution of air temperatures will be shifted so that some months will have much warmer air temperatures, and some months will have similar temperatures. The DSM2 1D tidal flow and water quality model was used to estimate the changes in Delta water temperatures that might be expected from climate change. The water temperature changes were nearly identical to the monthly air temperature changes that were assumed for the metrological inputs. The DSM2 water quality model was used to simulate daily temperatures for Water Years (WY) 1976–1991.

5.A.2.3.5.2 Tidal Flows and Salinity

The UnTRIM 3D model of the San Francisco Bay and Delta was used to accurately simulate the potential effects of sea level rise on tidal flows and salinity intrusion (i.e., a deeper estuary will allow greater seawater intrusion) (MacWilliams and Gross 2010). This model includes the effects of salinity gradients and density effects on the tidal flows and allows the "gravitational circulation" during moderate outflow events to be evaluated. During moderately high outflows, the fresh water (lower density) will flow near the surface of the estuary while seawater (higher density) will tend to move upstream along the bottom of the channel. This increases the net upstream mixing of seawater and increases the seawater intrusion effects in Suisun Bay and the Delta. The simulated changes in the salinity gradient caused by the deeper estuary were incorporated into the RMA 2D model of San Francisco Bay and the Delta, as well as the DSM2 1D (branched) model of the Delta. The effects of tidal habitat restoration were simulated with the RMA 2D model and incorporated into the DSM2 1D modeling and the CALSIM modeling (ANN) of required Delta outflows for salinity control in the western Delta.

The ANN equations in the monthly CALSIM model were adjusted based on the DSM2 results for the two climate change timeframes (ELT and LLT). The Delta outflow required to meet X2 (salinity gradient) objectives or meet salinity (EC) objectives at Emmaton, Jersey Point, and Rock Slough were increased moderately for the ELT case and substantially for the LLT case. This was the major effect of sea level rise on the CALSIM results; increased Delta outflow may become a limitation on future Delta exports.

5.A.2.4 Upstream Inflow Modeling Results

The projected changes in monthly and annual runoff from future projected climate change conditions generally reflect a shift from snowpack runoff (in April, May, and June) to rainfall runoff (in January, February, and March). The overall effects of these changes in runoff on reservoir flood control operations might cause differences in downstream river flows and Delta inflows, and affect how the BDCP is operated and its effects. The projected changes in the major reservoir inflows with future projected climate change (ELT and LLT) are described for each reservoir and river. In general, the annual runoff was not changed much, but the seasonal patterns of runoff were shifted. These seasonal shifts can cause biological effects as discussed in Appendix 5.A.1, *Climate Change Implications for Natural Communities and Terrestrial Species*.

Existing and future projected runoff are summarized as monthly tables showing the cumulative distribution of flows, with 10% increments. The minimum, 10%, 20%, 30% … 90% and maximum monthly flow values and the monthly average flow are given for each inflow location. The projected CALSIM inflows for existing conditions and for ELT and LLT are described from the north (Trinity River) to the south (San Joaquin River at Friant Dam).

5.A.2.4.1 Trinity Reservoir Inflows

The Trinity Reservoir inflow from the upper Trinity River watershed in northern California is included in CALSIM because water can be diverted to the Sacramento River as part of the CVP. There are no upstream diversions of water, so the historical inflow is the unimpaired runoff. Table 5.A.2.4-1.A shows the monthly distributions of existing Trinity Reservoir runoff for 1922–2003 (2010 climate). Table 5.A.2.4-1.B shows the projected shifts in monthly inflow assumed for the ELT (2025 climate), and Table 5.A.2.4-1.C shows the projected shifts in monthly Trinity Reservoir inflow for the LLT (2060 climate). Figure 5.A.2.4-1 shows the monthly median Trinity Reservoir inflow for existing conditions compared to the projected ELT (2025) and projected LLT (2060) conditions.

The annual Trinity Reservoir inflow was projected to change very little with climate change, based on the VIC watershed modeling described above. Table 5.A.2.4-1 indicates the average runoff for existing conditions (historical) was 1,277 thousand acre-feet (TAF), the projected average runoff for ELT (2025) conditions would be 1,279 TAF, and the projected average runoff for LLT (2060) conditions would be 1,300 TAF. The projected effects of LLT (2060) climate change on the Trinity Reservoir inflow would be a slight increase of 2% (23 TAF). The seasonal pattern of runoff would shift from the existing peak in April and May to a more uniform runoff in January–May in the future. Summarizing the monthly runoff in quarterly periods, the runoff fraction in October–December would increase by 3 percentage points from 13% to 16%. The runoff fraction in January–March would increase by 9 percentage points from 36% to 45%. The runoff fraction in April–June would decrease from 46% to 37%, and the runoff fraction in July–September would decrease from 5% to 3%.

Table 5.A.2.4-1.D and Table 5.A.2.4-1.E give the cumulative distribution of the monthly ratios of future runoff to current runoff for the ELT and LLT timeframes. This table illustrates that each month had a different range of assumed shifts in runoff. For example, one of the February runoff values for the ELT was reduced to 0.87 of the existing runoff, and one of the February runoff values was increased to 1.47 times the existing runoff. The average change was an increase to 1.1 times the existing February runoff. The effects of climate change on Trinity River flows or exports to the Sacramento River likely will be small because the Trinity River flows are controlled (i.e., specified) by the Trinity River Restoration Plan. Flood management spills from Trinity Reservoir are infrequent.

Table 5.A.2.4-1. Projected Climate Change Effects on Trinity Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
A. Existing Conditions (Historical) Monthly Distributions for Trinity Reservoir Inflow (TAF)													
Min	6	7	9	9	16	20	38	27	7	3	3	2	225
10%	9	9	16	27	45	79	104	111	41	14	7	6	680
20%	9	11	24	34	57	95	145	152	59	19	9	7	781
30%	9	15	37	46	81	125	160	171	77	22	10	9	878
40%	11	23	43	69	110	144	188	198	84	24	10	9	1,039
50%	12	30	58	95	130	162	213	224	97	27	11	9	1,139
60%	14	43	80	119	153	174	231	264	109	34	13	10	1,421
70%	16	54	115	150	167	198	257	288	162	39	16	11	1,584
80%	18	80	164	211	233	229	262	336	204	55	19	13	1,678
90%	28	125	236	320	286	320	329	400	253	73	24	15	2,013
Max	133	407	535	539	645	472	377	554	501	239	73	36	2,885
Avg	19	52	100	130	151	178	210	244	129	40	14	10	1,277
B. Projected Early Long-Term (2025) Monthly Distributions for Trinity Reservoir Inflow (TAF)													
Min	5	7	9	9	15	19	36	24	6	3	2	2	212
10%	9	9	17	27	47	81	94	91	31	11	6	6	612
20%	9	11	24	36	56	91	130	126	47	13	8	7	746
30%	9	15	37	50	92	127	151	152	59	16	9	8	834
40%	10	23	45	74	118	153	185	170	64	18	9	8	1,017
50%	12	32	60	113	145	161	203	193	75	19	10	9	1,100
60%	13	43	87	134	163	181	222	241	89	23	11	9	1,479
70%	16	57	142	172	201	209	236	275	120	27	12	10	1,616
80%	17	87	212	230	263	240	267	329	169	35	15	12	1,724
90%	42	137	295	362	357	324	308	397	203	50	20	14	2,065
Max	174	510	616	660	745	550	378	532	465	167	51	33	3,028
Avg	21	57	116	149	171	184	202	224	105	28	12	10	1,279
C. Projected Late Long-Term (2060) Monthly Distributions for Trinity Reservoir Inflow (TAF)													
Min	5	7	8	9	16	20	37	23	6	2	2	2	211
10%	8	9	16	32	48	87	90	79	22	9	6	5	635
20%	9	11	25	42	69	100	127	112	35	10	8	7	756
30%	9	15	41	57	108	132	152	125	43	13	8	8	871
40%	10	22	53	85	133	162	180	145	49	14	9	8	1,017
50%	12	32	65	140	160	173	195	158	53	15	9	8	1,122
60%	13	44	96	171	198	192	212	202	63	16	10	9	1,491
70%	15	57	151	209	233	231	240	232	92	20	11	10	1,617
80%	17	85	247	276	300	281	271	293	122	23	14	12	1,768
90%	31	127	322	438	416	356	311	378	153	30	18	14	2,146
Max	174	518	576	737	962	614	403	516	389	107	24	32	3,054
Avg	20	56	127	180	200	201	201	197	79	19	10	9	1,300

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
D. Projected Monthly Ratios of ELT to Existing (Historical) Trinity Reservoir Inflows													
Min	0.87	0.88	0.80	0.93	0.87	0.83	0.82	0.72	0.57	0.53	0.51	0.69	0.88
10%	0.92	0.95	0.97	1.01	0.97	0.93	0.88	0.82	0.70	0.63	0.72	0.90	0.92
20%	0.94	0.96	1.00	1.03	1.00	0.96	0.90	0.85	0.73	0.64	0.83	0.92	0.95
30%	0.95	0.97	1.01	1.04	1.03	0.97	0.92	0.87	0.75	0.66	0.87	0.93	0.96
40%	0.96	0.98	1.03	1.08	1.04	1.01	0.94	0.87	0.76	0.67	0.89	0.94	0.98
50%	0.97	1.00	1.06	1.10	1.09	1.02	0.95	0.89	0.78	0.70	0.90	0.95	0.99
60%	0.97	1.03	1.10	1.13	1.12	1.04	0.96	0.91	0.80	0.73	0.92	0.96	1.01
70%	0.98	1.05	1.14	1.17	1.17	1.06	0.98	0.94	0.83	0.77	0.93	0.97	1.02
80%	1.00	1.09	1.17	1.21	1.20	1.07	1.00	0.96	0.86	0.82	0.94	0.98	1.02
90%	1.18	1.16	1.29	1.26	1.27	1.11	1.02	0.99	0.90	0.88	0.96	0.99	1.04
Max	1.63	1.54	1.54	1.34	1.47	1.27	1.11	1.05	1.01	0.97	0.99	1.01	1.10
Avg	1.01	1.03	1.10	1.12	1.10	1.02	0.95	0.90	0.79	0.73	0.87	0.94	0.99
E. Projected Monthly Ratios of LLT to Existing (Historical) Trinity Reservoir Inflows													
Min	0.79	0.84	0.89	0.95	0.87	0.84	0.67	0.57	0.39	0.31	0.30	0.59	0.89
10%	0.86	0.90	0.98	1.07	1.03	0.97	0.80	0.63	0.47	0.35	0.53	0.84	0.94
20%	0.91	0.93	1.01	1.11	1.09	1.01	0.85	0.70	0.51	0.37	0.74	0.87	0.95
30%	0.93	0.96	1.04	1.18	1.12	1.04	0.89	0.72	0.52	0.42	0.78	0.89	0.97
40%	0.94	0.98	1.08	1.22	1.19	1.09	0.90	0.75	0.57	0.47	0.82	0.91	0.99
50%	0.96	1.01	1.14	1.27	1.24	1.11	0.93	0.77	0.60	0.52	0.84	0.92	1.00
60%	0.97	1.02	1.22	1.33	1.29	1.13	0.96	0.80	0.62	0.57	0.86	0.94	1.01
70%	0.98	1.04	1.29	1.43	1.41	1.16	1.01	0.83	0.66	0.66	0.89	0.95	1.03
80%	1.00	1.08	1.37	1.54	1.48	1.21	1.06	0.86	0.71	0.74	0.91	0.96	1.05
90%	1.05	1.16	1.51	1.59	1.56	1.28	1.11	0.94	0.77	0.82	0.94	0.99	1.08
Max	1.37	1.49	2.20	2.10	2.08	1.45	1.16	1.10	0.89	0.94	0.99	1.01	1.12
Avg	0.97	1.02	1.21	1.33	1.28	1.11	0.95	0.78	0.61	0.56	0.80	0.91	1.00

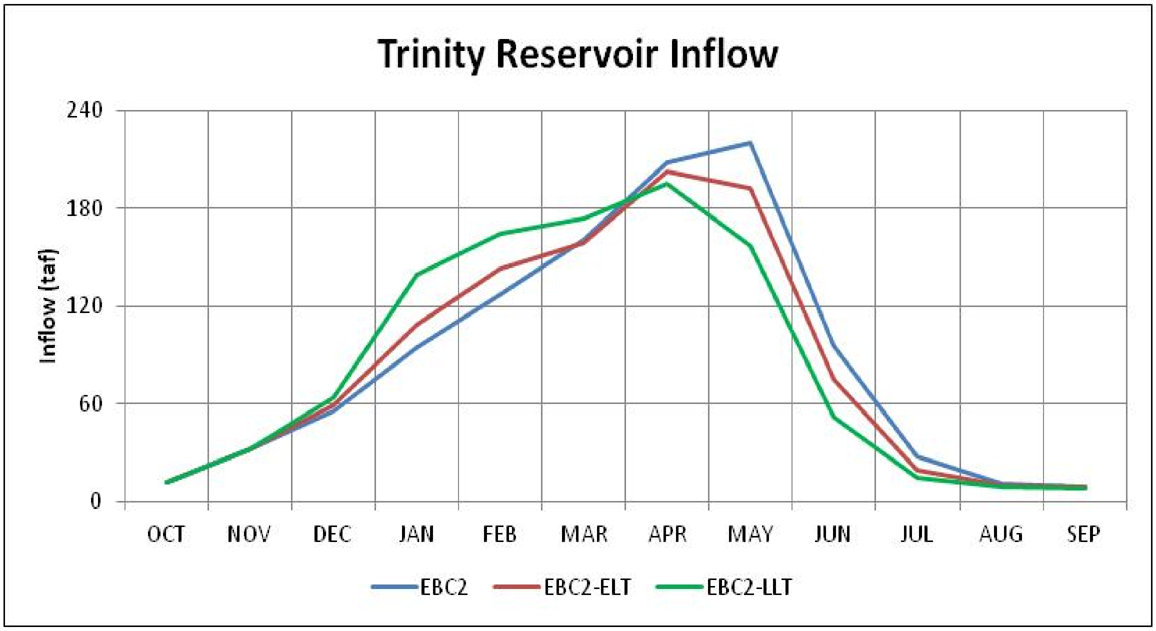


Figure 5.A.2.4-1. Projected Shifts in the Monthly Median Trinity Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.2 Shasta Reservoir Inflows

The Shasta Reservoir inflow from the Upper Sacramento River Watershed, including the McCloud River and the Pit River in northern California, is the major CVP water supply source. There are few upstream diversions of water, and only a couple of reservoirs on the Pit River, so the historical inflow is close to unimpaired runoff. Table 5.A.2.4-2.A shows the monthly distributions of existing Shasta Reservoir inflow for 1922–2003. Table 5.A.2.4-2.B shows the projected shifts in monthly inflow for the ELT (2025), and Table 5.A.2.4-2.C shows the projected shifts in monthly Shasta Reservoir inflow for LLT (2060). Figure 5.A.2.4-2 shows the monthly median (50%) existing Shasta Reservoir inflow compared to the monthly median inflows for the projected ELT (2025) and projected LLT (2060) conditions.

The annual Shasta Reservoir inflow was projected to change very little with climate change. Table 5.A.2.4-2 indicates the average runoff for existing (historical) conditions was 5,690 TAF, the projected average runoff for ELT (2025) conditions would be 5,735 TAF, and the projected average runoff for LLT (2060) conditions would be 5,788 TAF. The projected effects of LLT (2060) climate change on the Shasta Reservoir inflow would be a slight increase of 2% (98 TAF). The existing seasonal runoff is greatest in the months of January–April, and runoff would increase in these high rainfall months. Summarizing the monthly runoff in quarterly periods, the runoff fraction in October–December would increase from 20% to 21%. The runoff fraction in January–March would increase from 42% to 46%. The runoff fraction in April–June would decrease from 27% to 23%, and the runoff fraction in July–September would decrease from 11% to 10%. Table 5.A.2.4-2.D and Table 5.A.2.4-2.E give the cumulative distribution of the monthly ratios of future runoff to current runoff for the ELT and LLT timeframes. This table illustrates that each month had a different range of assumed shifts in runoff. For example, one of the July runoff values for the LLT was reduced to 0.63 times the existing runoff, and one of the July runoff values was reduced to 0.97 times the existing runoff. The average change for July runoff was a reduction to 0.82 times the existing July runoff for the LLT.

Table 5.A.2.4-2. Projected Climate Change Effects on Shasta Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing Conditions (Historical) Monthly Distributions for Shasta Reservoir Inflow (TAF)													
Min	161	164	176	177	213	241	200	193	172	161	152	148	2,533
10%	184	188	224	249	307	382	363	279	206	183	170	167	3,543
20%	197	223	250	318	369	512	430	336	230	196	181	181	3,906
30%	213	234	297	341	493	593	467	367	261	208	197	191	4,117
40%	223	251	338	414	557	658	513	422	275	220	206	201	4,807
50%	232	276	359	553	666	717	604	469	290	234	209	210	5,209
60%	249	304	471	727	848	864	706	496	322	247	227	223	6,258
70%	262	348	632	795	961	943	833	574	348	257	233	229	6,834
80%	276	405	832	1,031	1,173	1,083	984	717	397	279	247	235	7,391
90%	292	563	1,093	1,430	1,494	1,372	1,189	807	491	300	258	260	8,730
Max	658	1,576	1,877	2,923	2,481	2,704	1,637	1,161	942	430	317	298	10,798
Avg	246	340	545	721	803	838	691	514	326	240	215	211	5,690
B. Projected Early Long-Term (2025) Monthly Distributions for Shasta Reservoir Inflow (TAF)													
Min	155	158	177	181	195	232	189	178	159	142	143	141	2,433
10%	179	187	226	255	316	358	341	255	185	168	163	161	3,435
20%	190	220	255	327	359	497	407	307	202	179	174	177	3,809
30%	208	233	301	362	495	578	436	340	230	189	184	184	4,028
40%	217	255	353	427	562	643	479	370	242	202	191	193	4,693
50%	230	284	377	587	690	726	563	425	258	210	199	201	5,284
60%	242	326	488	776	880	844	654	460	283	218	211	211	6,485
70%	256	364	677	906	1,026	935	816	524	299	231	217	219	6,982
80%	271	426	987	1,096	1,331	1,117	946	647	346	246	227	224	7,407
90%	326	616	1,298	1,609	1,709	1,432	1,143	722	431	257	243	246	9,044
Max	765	1,902	2,056	3,306	2,852	2,995	1,681	1,019	813	344	288	277	11,286
Avg	248	356	613	783	872	838	657	465	287	213	201	202	5,735
C. Projected Late Long-Term (2060) Monthly Distributions for Shasta Reservoir Inflow (TAF)													
Min	154	154	181	190	207	236	189	173	154	137	142	140	2,470
10%	180	185	230	272	355	354	335	246	175	157	158	160	3,433
20%	191	215	262	344	392	508	379	279	184	167	169	175	3,860
30%	207	230	309	389	503	580	415	322	210	177	175	181	4,112
40%	219	251	375	473	572	655	458	339	223	188	184	191	4,726
50%	228	278	428	645	743	756	535	383	230	196	191	197	5,305
60%	237	323	527	806	893	869	613	425	260	201	197	204	6,390
70%	255	363	730	1,008	1,099	969	761	474	276	208	203	214	6,951
80%	268	415	1,071	1,229	1,427	1,148	863	589	304	217	215	220	7,576
90%	314	595	1,369	1,978	1,796	1,474	1,115	669	377	233	223	234	8,952
Max	768	1,954	2,172	3,389	2,997	3,040	1,697	923	797	288	265	263	11,437
Avg	245	351	643	860	929	857	634	427	259	195	191	198	5,788

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
D. Projected Monthly Ratios of ELT to Existing (Historical) Shasta Reservoir Inflows													
Min	0.94	0.96	0.97	0.96	0.90	0.89	0.84	0.84	0.83	0.79	0.88	0.88	0.95
10%	0.96	0.98	1.00	1.00	0.96	0.93	0.89	0.87	0.85	0.84	0.90	0.94	0.96
20%	0.96	0.99	1.01	1.01	0.98	0.94	0.92	0.88	0.86	0.87	0.92	0.95	0.97
30%	0.96	1.00	1.02	1.03	0.99	0.95	0.93	0.89	0.87	0.88	0.93	0.95	0.98
40%	0.97	1.00	1.04	1.04	1.01	0.97	0.94	0.90	0.87	0.89	0.93	0.96	0.98
50%	0.97	1.02	1.05	1.05	1.04	0.98	0.95	0.91	0.89	0.90	0.94	0.96	1.00
60%	0.97	1.03	1.07	1.07	1.07	1.00	0.95	0.91	0.89	0.90	0.95	0.97	1.01
70%	0.98	1.04	1.10	1.10	1.10	1.01	0.96	0.92	0.90	0.91	0.95	0.97	1.02
80%	0.98	1.06	1.14	1.13	1.12	1.03	0.97	0.93	0.90	0.92	0.96	0.97	1.03
90%	1.14	1.08	1.21	1.15	1.18	1.05	0.99	0.94	0.91	0.93	0.97	0.97	1.04
Max	1.37	1.30	1.41	1.27	1.28	1.12	1.06	1.01	0.93	0.97	0.99	1.01	1.10
Avg	1.00	1.03	1.08	1.07	1.05	0.99	0.94	0.91	0.88	0.89	0.94	0.96	1.00
E. Projected Monthly Ratios of LLT to Existing (Historical) Shasta Reservoir Inflows													
Min	0.91	0.93	0.97	1.00	0.89	0.86	0.72	0.72	0.69	0.63	0.80	0.82	0.96
0.10	0.94	0.95	1.02	1.04	1.00	0.93	0.81	0.78	0.74	0.74	0.82	0.89	0.97
0.20	0.96	0.97	1.03	1.06	1.02	0.94	0.87	0.80	0.76	0.78	0.84	0.91	0.98
0.30	0.96	0.98	1.05	1.09	1.04	0.96	0.89	0.81	0.77	0.80	0.86	0.93	0.99
0.40	0.97	0.99	1.08	1.11	1.06	0.98	0.90	0.82	0.78	0.82	0.88	0.94	1.00
0.50	0.97	1.00	1.12	1.14	1.09	1.00	0.92	0.84	0.80	0.83	0.90	0.95	1.00
0.60	0.98	1.01	1.15	1.16	1.12	1.02	0.93	0.85	0.82	0.84	0.92	0.95	1.01
0.70	0.99	1.02	1.17	1.20	1.18	1.04	0.94	0.86	0.83	0.85	0.93	0.96	1.02
0.80	1.00	1.04	1.24	1.26	1.22	1.07	0.96	0.88	0.84	0.86	0.94	0.97	1.04
0.90	1.06	1.10	1.29	1.32	1.30	1.10	0.98	0.90	0.88	0.88	0.95	0.97	1.06
Max	1.24	1.24	1.54	1.54	1.42	1.20	1.08	0.98	0.94	0.97	0.97	1.00	1.07
Avg	0.99	1.01	1.14	1.16	1.12	1.01	0.91	0.84	0.80	0.82	0.89	0.94	1.01

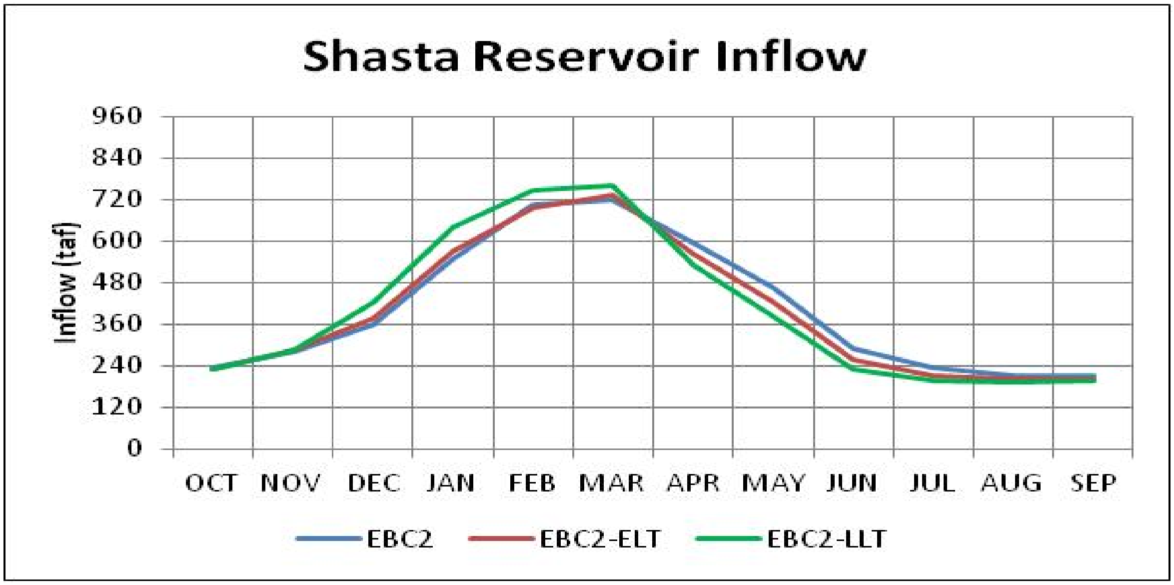


Figure 5.A.2.4-2. Projected Shifts in Monthly Median Shasta Reservoir Inflow (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.3 Sacramento River Tributaries Inflows

There are several Sacramento River tributary streams, including Clear Creek, Battle Creek, Mill Creek, Deer Creek, and Butte Creek. These inflows are included in CALSIM, and the climate change shifts in runoff were projected to be similar to the Shasta inflow adjustments. The average historical annual Clear Creek inflow to Whiskeytown Reservoir was about 150 TAF. The average historical annual inflow from Battle Creek was about 365 TAF; the annual inflow from Mill Creek was about 200 TAF; the annual inflow from Deer Creek was also about 200 TAF; and the annual inflow from Butte Creek was about 300 TAF.

5.A.2.4.4 Oroville Reservoir Inflows

The Oroville Reservoir inflow from the Upper Feather River watershed is the major SWP water supply source. The major upstream reservoir is Lake Almanor (operated by The Pacific Gas and Electric Company [PG&E]), which is operated for seasonal storage for hydropower energy generation at the six PG&E North Fork Feather River hydropower stations. There are few upstream diversions of water for consumptive use, but the seasonal inflow pattern is quite different from the unimpaired flows. Table 5.A.2.4-3.A shows the monthly distributions of the existing Oroville Reservoir inflow for 1922–2003, assuming the current operations of Lake Almanor (2010). Table 5.A.2.4-3.B shows the projected shifts in monthly inflow for the ELT (2025), and Table 5.A.2.4-3.C shows the projected shifts in monthly Oroville Reservoir inflow for the LLT (2060). Figure 5.A.2.4-3 shows the monthly median (50%) existing Oroville Reservoir inflow compared to the monthly median inflows for the projected ELT (2025) and projected LLT (2060) conditions.

Table 5.A.2.4-3. Projected Climate Change Effects on Oroville Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing (Historical) Monthly Distributions for Oroville Reservoir Inflow (TAF)													
Min	49	43	41	48	50	74	61	72	45	29	31	65	751
10%	54	61	83	147	169	248	236	166	108	84	88	76	1,823
20%	60	77	108	178	213	308	303	244	136	104	98	83	2,297
30%	62	98	156	203	271	348	369	300	177	111	107	89	2,675
40%	107	141	186	262	351	389	432	351	195	120	112	95	2,882
50%	122	155	208	320	430	443	510	407	227	139	128	104	3,457
60%	141	170	244	386	531	515	557	482	266	168	147	128	4,140
70%	154	188	312	527	630	623	670	566	307	186	161	150	4,953
80%	159	245	497	677	716	754	773	738	400	217	180	158	5,657
90%	173	294	738	1,139	1,012	1,165	991	944	558	270	197	167	6,659
Max	740	993	1,718	2,499	2,361	2,080	1,598	1,573	881	371	245	217	8,860
Avg	124	185	343	477	511	567	562	506	280	159	137	119	3,967
B. Projected Early Long-Term (2025) Monthly Distributions for Oroville Reservoir Inflow (TAF)													
Min	44	38	39	47	47	69	55	62	38	26	28	56	690
10%	50	61	86	156	184	249	215	141	83	75	78	69	1,763
20%	54	74	111	190	235	315	296	207	114	87	87	76	2,239
30%	58	98	164	216	310	362	345	260	137	92	97	80	2,662
40%	105	136	194	289	366	417	411	299	153	100	101	87	2,852
50%	116	155	231	342	484	470	475	344	175	119	118	93	3,430
60%	133	169	266	413	601	520	542	413	202	139	136	118	4,343
70%	147	198	374	595	731	676	648	488	227	153	147	135	5,108
80%	153	240	595	755	938	805	760	685	295	174	160	145	5,803
90%	183	308	929	1,301	1,167	1,214	1,007	880	418	193	175	151	6,913
Max	792	1,238	1,988	2,798	2,729	2,454	1,706	1,404	711	239	190	237	9,441
Avg	119	194	397	544	598	608	551	449	217	127	122	108	4,036
C. Projected Late Long-Term (2060) Monthly Distributions for Oroville Reservoir Inflow (TAF)													
Min	43	36	34	46	48	69	54	60	35	25	27	54	669
10%	47	53	81	159	200	266	203	131	71	66	75	65	1,759
20%	51	67	108	199	262	324	276	173	98	80	85	72	2,207
30%	55	95	163	248	340	376	327	228	112	85	90	76	2,591
40%	97	124	192	316	399	435	378	255	127	91	96	83	2,857
50%	112	142	241	379	518	485	446	282	144	102	109	88	3,411
60%	123	156	291	452	671	575	520	363	158	123	127	107	4,211
70%	138	187	401	690	783	692	618	402	177	135	136	129	5,152
80%	144	225	680	884	1,027	884	744	589	219	150	146	137	5,762
90%	175	293	938	1,486	1,253	1,213	982	720	319	158	157	142	7,026
Max	957	1,159	1,918	2,952	2,914	2,584	1,769	1,239	555	196	172	280	9,444
Avg	117	180	409	612	660	636	531	381	170	110	113	103	4,022

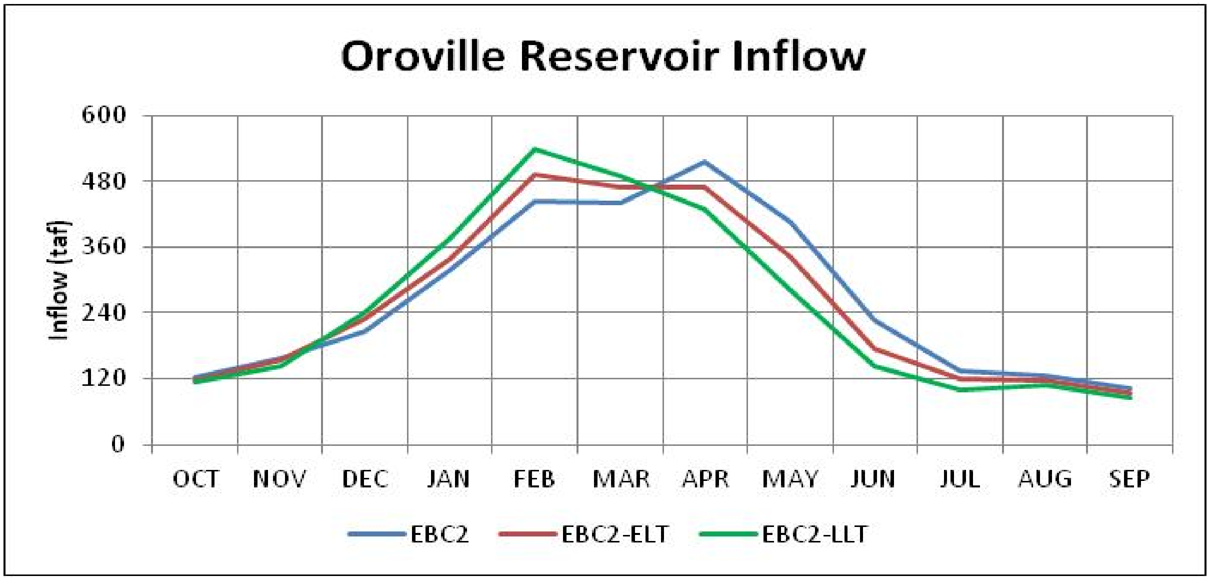


Figure 5.A.2.4-3. Projected Shifts in the Monthly Median Oroville Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

The annual Oroville Reservoir inflow was projected to change very little with climate change. Table 5.A.2.4-3 indicates the average inflow for existing (historical) conditions was 3,967 TAF, the projected average inflow for ELT (2025) conditions would be 4,036 TAF, and the projected average inflow for LLT (2060) conditions would be 4,022 TAF. The projected effects of LLT (2060) climate change on the Oroville Reservoir inflow would be a slight increase of 1.5% (55 TAF). The existing seasonal pattern of runoff is greatest in the months of January–May, and runoff would increase in the months of December–March (rainfall) and decrease in the months of April–June (snowmelt). About 25% of the watershed (with 970 TAF average runoff) is upstream of Lake Almanor, so some of the increased rainfall runoff in December–March would be regulated for hydropower releases. The changes in Oroville Reservoir inflows include the possible changes in Lake Almanor operations. Summarizing the monthly inflow in quarterly periods, the inflow fraction in October–December would increase from 16% to 18%. The inflow fraction in January–March would increase from 39% to 47%. The inflow fraction in April–June would decrease from 34% to 27%, and the inflow fraction in July–September would decrease from 10% to 8%. The projected shifting of about 8% of the snowmelt runoff from April–June to rainfall runoff in December–March was greater than the projected shifting of the inflow to Shasta Reservoir.

5.A.2.4.5 Yuba River Inflows

The Yuba River flows and upstream reservoir operations were separately modeled, and the flow at Marysville was specified for the CALSIM model. A similar shifting of the runoff patterns was projected from the VIC watershed modeling. The average unimpaired runoff for the Yuba River at Engelbright Dam for 1922–2003 was about 2,170 TAF/year. Several water supply diversions are located below Engelbright Dam, so the average river flow at Marysville was simulated for CALSIM to be about 1,450 TAF/year (67% of runoff, with an average of 715 TAF/year diverted) The simulated change in the Yuba River inflow for the ELT was an average increase of 10 TAF/year (0.7%) and the simulated change for the LLT was an average decrease of 22 TAF/year (-1.5%).

5.A.2.4.6 Folsom Reservoir Inflows

Several major upstream reservoirs control the majority of inflow to Folsom Reservoir, so the CALSIM inflow is estimated from separate modeling of these upstream reservoir storage and hydropower projects. The projected inflows to Folsom Reservoir are therefore the combination of projected changes in rainfall and snowmelt runoff (from the VIC watershed modeling) together with possible changes in the operations of these upstream storage projects. There are few upstream diversions of water for consumptive use, but the seasonal inflow pattern is quite different from the unimpaired flows. Table 5.A.2.4-4.A shows the monthly distributions of the existing Folsom Reservoir inflow for 1922–2003, assuming the current operations of upstream storage projects (2010). Table 5.A.2.4-4.B shows the projected shifts in monthly inflow for the ELT (2025), and Table 5.A.2.4-4.C shows the projected shifts in monthly Folsom Reservoir inflow for the LLT (2060). Figure 5.A.2.4-4 shows the monthly median (50%) existing Folsom Reservoir inflow compared to the monthly median inflows for the projected ELT (2025) and projected LLT (2060) conditions.

The annual Folsom Reservoir inflow was projected to change very little with climate change. Table 5.A.2.4-4 indicates the average inflow for existing (historical) conditions was 1,332 TAF, the projected average inflow for ELT (2025) conditions would be 1,336 TAF, and the projected average runoff for LLT (2060) conditions would be 1,302 TAF. The projected effects of LLT (2060) climate change on the Folsom Reservoir inflow would be a slight decrease of 2% (-30 TAF). The existing seasonal pattern of runoff is greatest in the months of February–May, and runoff would increase in the months of December–March (rainfall), remain constant in April, and decrease in the months of May–July (snowmelt). Summarizing the monthly inflow in quarterly periods, the inflow fraction in October–December would increase from 18% to 20%. The inflow fraction in January–March would increase from 34% to 40%. The inflow fraction in April–June would decrease from 33% to 29%, and the inflow fraction in July–September would decrease from 15% to 12%. The projected shifting of about 5% of the runoff from April–June to rainfall runoff in December–March was less than the projected shifting of the inflow to Oroville Reservoir.

Table 5.A.2.4-4. Projected Climate Change Effects on Folsom Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing (Historical) Monthly Distributions for Folsom Reservoir Inflow (TAF)													
Min	22	21	9	12	11	11	14	17	11	6	9	14	201
10%	43	47	54	40	40	55	64	55	23	10	24	42	602
20%	47	54	57	50	53	77	80	70	36	15	47	62	698
30%	49	56	64	63	64	94	107	93	53	33	66	64	833
40%	51	61	73	75	80	105	134	132	61	48	70	66	1,077
50%	53	64	83	94	110	136	156	182	76	67	72	68	1,253
60%	54	72	89	116	156	158	176	204	96	88	73	70	1,419
70%	58	79	105	162	190	179	194	225	137	99	75	72	1,649
80%	65	89	135	230	231	217	225	243	175	109	81	74	1,955
90%	71	115	211	304	280	284	258	306	230	126	87	78	2,248
Max	131	350	491	832	705	521	484	403	415	229	113	119	3,216
Avg	56	78	112	144	146	158	157	172	107	70	66	66	1,332
B. Projected Early Long-Term (2025) Monthly Distributions for Folsom Reservoir Inflow (TAF)													
Min	23	25	9	12	10	9	11	13	8	5	7	13	180
10%	40	46	54	40	39	54	60	47	17	9	22	38	580
20%	44	53	60	51	54	76	73	59	28	12	44	57	666
30%	47	56	64	66	65	95	104	83	43	24	56	59	797
40%	49	61	77	81	88	112	134	118	47	38	59	61	1,078
50%	51	68	92	97	127	138	154	169	63	50	62	63	1,222
60%	52	71	99	126	162	160	178	187	80	64	63	65	1,428
70%	56	84	115	176	215	187	192	204	106	73	65	66	1,720
80%	65	93	160	260	259	227	226	232	147	83	67	68	1,947
90%	72	132	311	332	356	296	258	299	191	97	70	72	2,337
Max	171	404	574	1010	818	574	539	379	338	162	86	90	3,290
Avg	55	83	130	160	166	164	157	161	90	53	56	61	1,336
C. Projected Late Long-Term (2060) Monthly Distributions for Folsom Reservoir Inflow (TAF)													
Min	22	22	7	10	8	9	11	12	8	4	7	13	165
10%	39	45	48	39	41	58	58	43	15	8	21	36	564
20%	44	49	53	51	57	81	72	53	23	11	41	55	642
30%	46	53	61	64	68	98	103	76	37	20	47	57	799
40%	47	55	72	86	90	117	128	106	41	33	52	58	1,009
50%	49	57	87	102	135	145	143	140	54	42	55	60	1,180
60%	51	63	104	129	170	171	175	161	65	48	57	62	1,388
70%	55	71	119	185	223	201	190	182	82	59	59	64	1,708
80%	63	81	161	291	287	241	227	199	119	62	62	65	1,963
90%	72	110	284	369	382	321	268	279	154	75	65	70	2,274
Max	205	349	583	1061	866	634	533	359	260	117	80	106	3,345
Avg	55	73	127	174	177	173	157	143	73	41	50	59	1,302

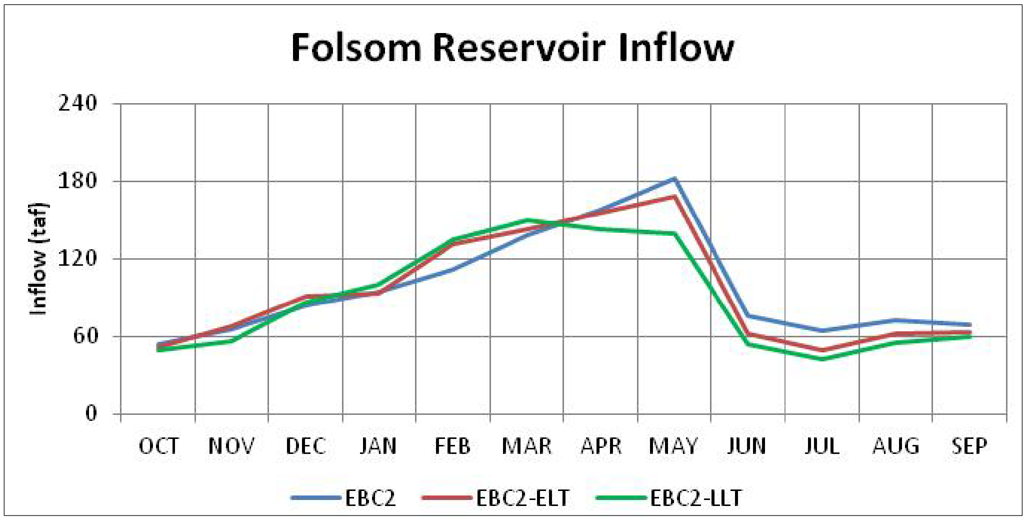


Figure 5.A.2.4-4. Projected Shifts in the Monthly Median Folsom Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.7 Mokelumne River and Cosumnes River Inflows

The Mokelumne River and Cosumnes River both enter the north Delta near Lodi. The Cosumnes River has only a few small reservoirs and the winter-spring runoff enters the Delta along with the Mokelumne River releases from Camanche Reservoir. The Mokelumne River runoff is modified by several upstream reservoirs. The average annual unimpaired runoff for the Cosumnes River is about 365 TAF/year. The average annual Mokelumne River unimpaired runoff is about 725 TAF/year, but an average of about 200 TAF/year is diverted from Pardee Reservoir to the EBMUD aqueduct, and about 200 TAF/year is diverted for irrigation along the river below Camanche Reservoir and the Woodbridge Dam. The combined inflow from the Cosumnes and Mokelumne Rivers to the Delta is specified in the CALSIM model with an average of 665 TAF/year (61% of runoff, with an average of 425 TAF/year diverted). The projected effects of climate change were small because the Cosumnes River watershed has little snowpack, and most of the projected Mokelumne River runoff shifts would have been modified through reservoir operations; very little change in the CALSIM inflows was projected for the ELT or the LLT.

5.A.2.4.8 New Melones Reservoir Inflows

The annual New Melones Reservoir inflow from the Stanislaus River was projected to decrease slightly with climate change. The projected inflow was a combination of VIC watershed modeling and upstream reservoir operations modeling. Table 5.A.2.4-5 indicates the average inflow for existing (historical) conditions was 1,087 TAF, the projected average inflow for ELT (2025) conditions would be 1,066 TAF, and the projected average runoff for LLT (2060) conditions would be 1,018 TAF. The projected effects of LLT (2060) climate change on the New Melones Reservoir inflow would be a decrease of 6% (-69 TAF). The existing seasonal pattern of runoff is greatest in the months of April–June, and runoff would increase in the months of January–March (rainfall), remain constant in April and May, and decrease in the months of June–August. Summarizing the monthly inflow in quarterly periods, the annual inflow fraction in October–December would increase from 12% to 13%. The inflow fraction in January–March would increase from 27% to 33%. The inflow fraction in April–June would decrease from 46% to 44%, and the inflow fraction in July–September would decrease from 15% to 10%. (Figure 5.A.2.4-5.)

Table 5.A.2.4-5. Projected Climate Change Effects on New Melones Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing (Historical) Monthly Distributions for New Melones Reservoir Inflow (TAF)													
Min	2	7	13	11	12	17	28	21	25	20	19	19	271
10%	21	21	27	25	29	44	58	45	41	43	37	27	497
20%	26	26	31	29	36	58	74	84	55	45	39	30	594
30%	29	30	35	37	45	69	90	97	71	49	42	33	660
40%	31	32	36	44	59	75	105	164	117	52	43	35	857
50%	33	34	41	58	77	91	118	207	149	59	45	37	1,063
60%	34	36	48	70	96	106	128	247	184	67	47	40	1,196
70%	36	39	56	84	111	132	148	279	208	77	48	42	1,305
80%	38	44	68	114	139	149	181	317	235	92	55	46	1,533
90%	53	55	99	183	184	184	206	341	321	118	59	56	1,843
Max	86	283	393	601	474	397	361	510	625	285	98	71	2,900
Avg	34	41	62	85	95	112	128	204	164	75	47	39	1,087
B. Projected Early Long-Term (2025) Monthly Distributions for New Melones Reservoir Inflow (TAF)													
Min	2	7	14	10	11	15	24	18	17	16	17	15	235
10%	19	20	25	24	28	44	55	37	33	29	28	24	446
20%	24	25	29	28	36	58	72	71	41	33	29	26	547
30%	26	28	34	37	46	68	85	91	54	34	31	28	605
40%	28	30	37	42	62	75	106	156	98	37	32	30	783
50%	30	32	40	57	80	92	113	196	139	42	34	31	1,014
60%	31	34	48	74	105	109	126	249	165	47	35	33	1,185
70%	34	38	55	89	127	135	151	285	191	53	37	36	1,299
80%	36	45	77	123	150	156	183	317	219	74	39	41	1,484
90%	46	57	120	210	223	191	207	365	329	96	48	47	1,900
Max	83	348	511	848	607	420	380	575	633	242	70	68	2,877
Avg	31	42	69	93	105	115	127	206	153	57	35	34	1,066
C. Projected Late Long-Term (2060) Monthly Distributions for New Melones Reservoir Inflow (TAF)													
Min	2	6	14	10	11	15	23	15	14	15	15	12	223
10%	18	18	25	25	30	45	53	33	26	21	19	21	422
20%	22	23	29	29	37	62	72	63	32	23	21	24	516
30%	24	25	32	37	48	70	84	83	46	25	24	26	587
40%	26	27	36	43	62	77	104	138	74	29	27	27	728
50%	28	29	40	58	85	93	112	177	102	32	29	28	932
60%	30	31	47	75	107	117	126	221	141	34	32	30	1,089
70%	32	33	54	99	130	134	144	256	163	40	33	33	1,256
80%	36	41	73	131	158	169	181	305	191	50	35	38	1,427
90%	43	51	117	223	223	219	208	354	283	68	41	43	1,807
Max	88	286	506	874	596	478	390	574	582	203	52	97	2,880

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
Avg	29	37	67	100	110	121	129	191	132	42	29	31	1,018

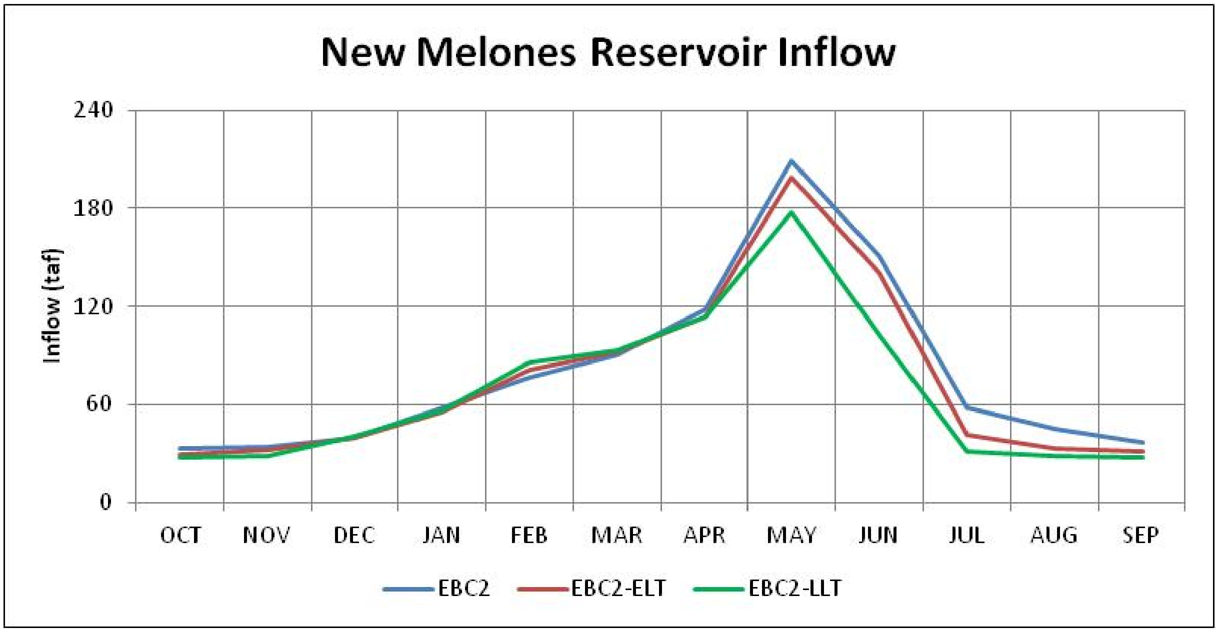


Figure 5.A.2.4-5. Projected Shifts in the Monthly Median New Melones Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.9 New Don Pedro Reservoir Inflows

The annual New Don Pedro Reservoir inflow from the Tuolumne River was assumed to decrease slightly with climate change. Table 5.A.2.4-6 indicates the average inflow for existing (historical) conditions was 1,586 TAF, the projected average inflow for ELT (2025) conditions would be 1,559 TAF, and the projected average runoff for LLT (2060) conditions would be 1,474 TAF. The projected effects of LLT (2060) climate change on the New Don Pedro Reservoir inflow would be a decrease of 7% (-112 TAF). The existing seasonal pattern of runoff is greatest in the months of April–June, and runoff would increase in the months of January–April (rainfall) and decrease in the months of May–August. Summarizing the monthly inflow in quarterly periods, the annual inflow fraction in October–December would increase from 9% to 10%. The annual inflow fraction in January–March would increase from 27% to 33%. The annual inflow fraction in April–June would decrease from 50% to 46%, and the annual inflow fraction in July–September would decrease from 11% to 7%. (Figure 5.A.2.4-6.)

Table 5.A.2.4-6. Projected Climate Change Effects on New Don Pedro Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing (Historical) Monthly Distributions for New Don Pedro Reservoir Inflow (TAF)													
Min	5	5	7	6	9	11	20	31	9	9	12	10	223
10%	9	9	18	23	44	73	99	105	40	18	16	21	601
20%	11	11	23	30	64	101	126	169	76	21	18	22	829
30%	13	13	38	39	79	116	154	215	156	26	21	23	902
40%	14	15	43	55	100	140	173	261	210	35	24	25	1,146
50%	16	17	54	67	141	163	191	286	279	52	28	28	1,496
60%	17	26	63	96	172	198	224	315	325	80	29	31	1,742
70%	19	29	82	134	205	230	247	354	371	119	32	33	1,931
80%	23	48	106	188	243	248	270	448	452	166	36	34	2,255
90%	29	66	191	262	313	306	290	528	555	278	41	38	2,804
Max	162	430	578	978	547	559	576	852	965	615	184	94	4,438
Avg	20	37	90	123	160	186	200	308	294	107	31	29	1,586
B. Projected Early Long-Term (2025) Monthly Distributions for New Don Pedro Reservoir Inflow (TAF)													
Min	5	4	7	5	9	10	17	24	7	8	11	9	192
10%	8	8	17	22	44	72	82	79	34	15	15	19	549
20%	10	10	23	29	63	104	123	137	60	17	16	20	742
30%	11	12	36	38	83	117	150	183	124	23	18	21	834
40%	13	14	42	55	101	141	170	233	152	27	21	23	1,060
50%	14	16	54	65	156	172	199	280	215	43	23	25	1,444
60%	15	25	63	99	186	208	229	301	256	62	25	27	1,661
70%	18	28	87	137	235	248	254	348	290	97	28	29	1,941
80%	22	51	115	209	275	283	278	456	380	124	31	31	2,298
90%	29	72	222	318	367	335	297	509	465	216	32	33	2,793
Max	172	538	703	1,346	732	620	593	949	937	432	143	92	4,490
Avg	19	39	102	139	182	198	205	299	240	83	26	27	1,559
C. Projected Late Long-Term (2060) Monthly Distributions for New Don Pedro Reservoir Inflow (TAF)													
Min	5	4	6	5	9	10	16	22	7	7	10	9	181
10%	8	7	16	23	45	76	80	63	30	14	14	18	514
20%	9	9	23	30	65	110	125	114	50	15	15	19	707
30%	11	11	35	41	85	120	145	144	87	19	16	19	797
40%	12	14	43	55	106	147	177	196	128	24	18	21	980
50%	13	14	53	69	159	177	197	226	148	34	21	23	1,340
60%	14	23	64	102	200	210	234	257	179	49	23	25	1,581
70%	17	26	88	157	239	250	265	288	206	72	24	27	1,880
80%	22	41	114	238	311	300	290	413	276	94	28	29	2,157
90%	28	62	231	356	394	361	316	493	325	162	29	32	2,769
Max	196	483	676	1,430	730	668	626	947	844	298	107	105	4,419
Avg	18	35	100	153	191	208	210	262	185	62	22	26	1,474

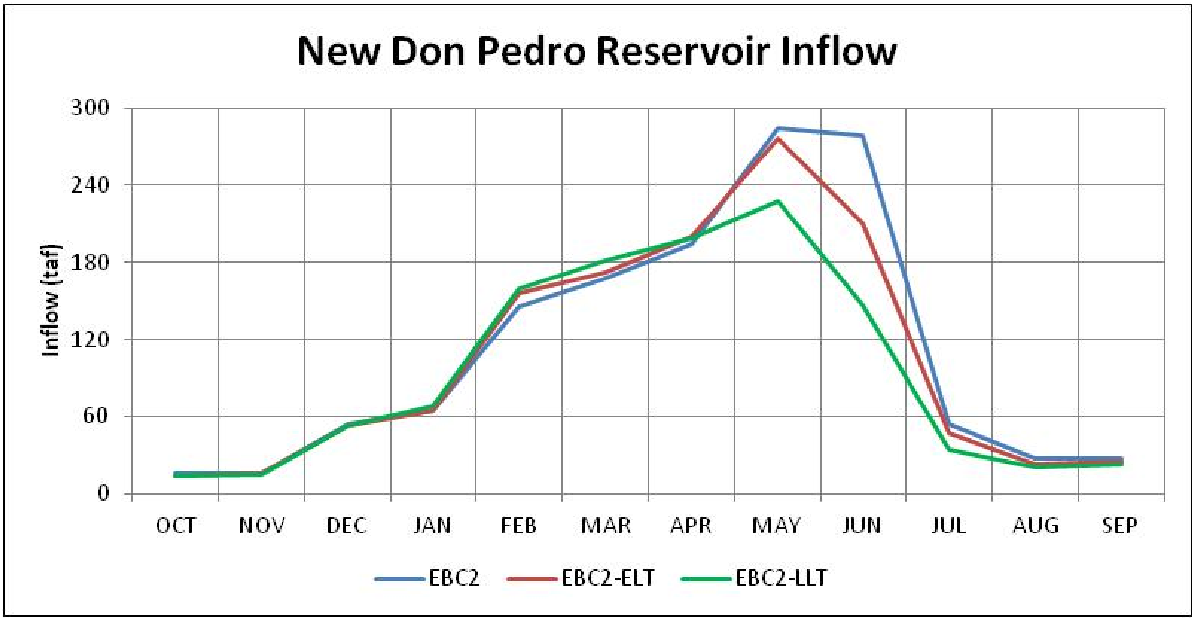


Figure 5.A.2.4-6. Projected Shifts in the Monthly Median New Don Pedro Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.10New Exchequer Reservoir Inflows

The annual New Exchequer Reservoir inflow from the Merced River was projected to decrease slightly with climate change. Table 5.A.2.4-7 indicates the average inflow for existing (historical) conditions was 965 TAF, the projected average inflow for ELT (2025) conditions would be 942 TAF, and the projected average runoff for LLT (2060) conditions would be 878 TAF. The projected effects of LLT (2060) climate change on the New Exchequer Reservoir inflow would be a decrease of 9% (-112 TAF). The existing seasonal pattern of runoff is greatest in the months of April–June, and runoff would increase in the months of January–April (rainfall) and decrease in the months of May–August. Summarizing the monthly inflow in quarterly periods, the annual inflow fraction in October–December would increase from 7% to 9%. The annual inflow fraction in January–March would increase from 26% to 33%. The annual inflow fraction in April–June would decrease from 58% to 53%, and the annual inflow fraction in July–September would decrease from 9% to 5%. (Figure 5.A.2.4-7.)

Table 5.A.2.4-7. Projected Climate Change Effects on New Exchequer Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing (Historical) Monthly Distributions for New Exchequer Reservoir Inflow (TAF)													
Min	0	2	1	3	3	5	30	37	14	3	0	0	142
10%	2	4	6	9	19	35	79	99	44	7	2	1	384
20%	3	5	8	13	24	49	89	123	56	14	3	2	507
30%	3	6	11	19	32	57	107	170	86	22	6	2	575
40%	4	7	16	24	42	63	124	200	119	30	7	3	680
50%	5	10	22	35	54	79	134	245	146	42	10	5	884
60%	7	12	27	46	69	91	159	269	166	50	14	6	1,054
70%	8	16	34	64	104	113	171	290	210	68	18	9	1,179
80%	10	22	53	95	148	147	185	321	273	98	29	12	1,399
90%	17	39	102	158	202	164	212	396	338	133	43	20	1,700
Max	61	259	372	616	359	390	445	565	649	359	103	71	2,871
Avg	8	19	43	65	84	98	145	240	173	62	19	9	965
B. Projected Early Long-Term (2025) Monthly Distributions for New Exchequer Reservoir Inflow (TAF)													
Min	0	2	1	2	3	6	23	27	7	2	0	0	118
10%	1	3	5	9	18	32	77	68	24	6	2	1	319
20%	2	5	8	12	26	44	86	91	32	11	3	1	438
30%	3	6	10	18	30	57	110	138	58	13	5	2	519
40%	3	7	15	24	46	63	123	181	91	16	6	3	633
50%	5	9	22	36	56	77	140	238	111	20	8	5	811
60%	6	12	31	53	67	91	155	267	128	27	10	5	1,012
70%	8	15	37	68	114	115	176	303	165	38	12	7	1,216
80%	10	21	66	112	171	150	197	350	234	59	16	11	1,373
90%	15	46	149	196	222	171	227	433	317	96	18	16	1,734
Max	106	312	474	742	463	405	456	651	669	268	84	71	2,917
Avg	8	21	55	76	93	100	147	237	143	40	13	8	942
C. Projected Late Long-Term (2060) Monthly Distributions for New Exchequer Reservoir Inflow (TAF)													
Min	0	2	1	2	3	7	23	26	6	2	0	0	113
10%	1	3	5	8	18	34	74	46	14	5	2	1	298
20%	2	5	7	13	26	49	92	73	21	7	3	1	412
30%	3	6	9	19	31	60	109	94	30	9	4	2	448
40%	3	7	14	25	46	72	130	150	59	11	5	3	569
50%	5	8	22	35	59	84	139	189	73	12	6	4	741
60%	6	11	28	47	73	100	160	219	83	14	8	5	954
70%	7	14	37	75	117	122	182	256	118	23	9	7	1,064
80%	9	19	61	100	182	153	211	325	166	32	13	10	1,321
90%	15	34	141	221	233	195	251	420	234	56	16	15	1,707
Max	167	306	430	797	467	440	479	672	581	184	86	83	2,872
Avg	8	18	51	82	97	108	155	210	104	25	11	9	878

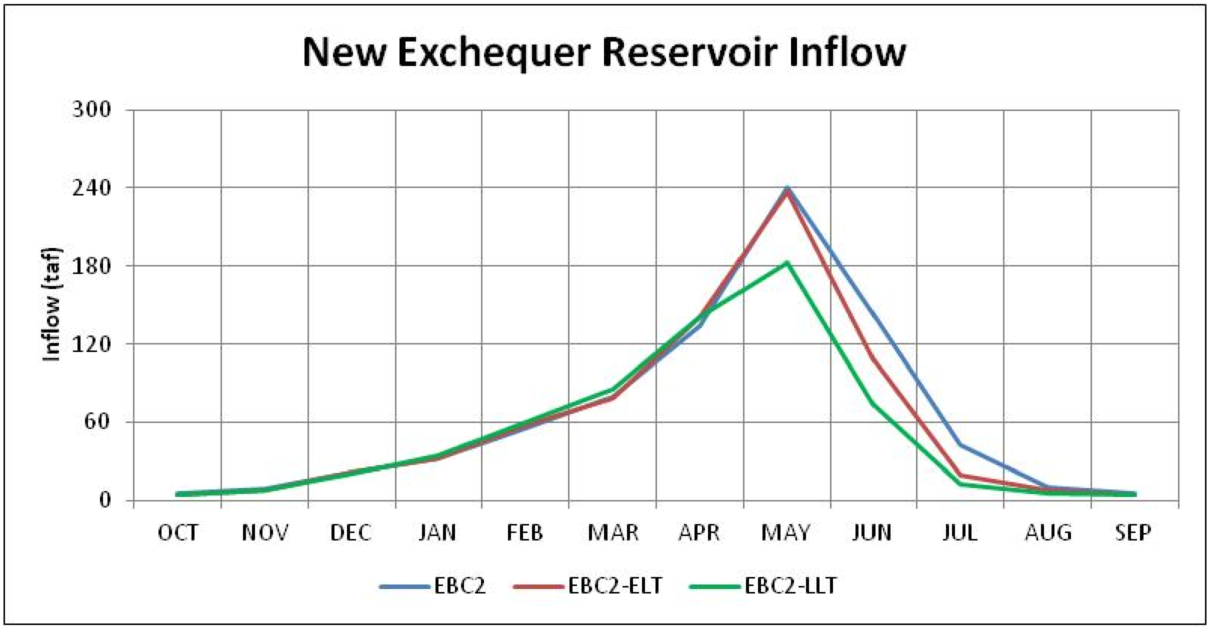


Figure 5.A.2.4-7. Projected Shifts in the Monthly Median New Exchequer Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.11Millerton Reservoir Inflows

The projected future Millerton Reservoir inflow from the San Joaquin River with climate change would be the combination of shifted runoff as projected with the VIC watershed modeling and seasonal storage changes for hydropower in the upstream reservoirs. These upstream reservoirs are modeled separately, so the projected runoff shifts from climate change may be slightly different from the changes in the Millerton inflows. The average inflow was 1,730 TAF for existing conditions, and was reduced to 1,660 for the ELT (2025) and to 1,561 TAF for the LLT (2060) conditions (Table 5.A.2.4-8). This is a reduction of about 10% (-169 TAF). Summarizing the monthly inflow in quarterly periods, the annual inflow fraction in October–December would remain the same at 12%. The annual inflow fraction in January–March would increase from 21% to 27%. The annual inflow fraction in April–June would increase from 43% to 44%, and the annual inflow fraction in July–September would decrease from 24% to 17%. (Figure 5.A.2.4-8.)

Table 5.A.2.4-8. Projected Climate Change Effects on Millerton Reservoir Inflow

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
A. Existing (Historical) Monthly Distributions for Millerton Reservoir Inflow (TAF)													
Min	25	15	21	24	24	21	45	10	5	37	36	62	383
10%	32	29	34	37	47	76	100	81	67	68	77	80	855
20%	40	38	41	45	66	85	128	120	107	74	82	93	1,082
30%	49	43	45	59	74	103	140	148	138	82	91	98	1,220
40%	61	50	54	64	83	113	166	197	199	111	101	100	1,292
50%	67	56	61	72	95	129	195	223	228	138	110	103	1,528
60%	74	61	67	90	120	146	218	266	276	165	118	105	1,793
70%	77	66	76	107	135	169	243	316	363	192	127	107	2,022
80%	82	76	89	140	178	200	264	390	486	268	147	112	2,286
90%	90	109	145	199	235	241	284	465	588	347	215	123	2,922
Max	225	191	319	606	325	393	454	836	1,119	752	332	216	4,688
Avg	65	63	78	101	119	146	198	254	291	187	124	105	1,730
B. Projected Early Long-Term (2025) Monthly Distributions for Millerton Reservoir Inflow (TAF)													
Min	23	14	19	21	21	20	40	8	3	26	31	54	328
10%	30	27	32	34	46	76	100	69	45	48	64	71	777
20%	37	36	37	41	67	87	126	99	74	53	68	79	948
30%	45	41	42	54	73	105	144	150	99	59	72	85	1,100
40%	56	46	50	61	84	118	167	178	166	68	78	88	1,188
50%	61	52	58	68	97	135	202	217	194	80	84	90	1,386
60%	66	56	66	89	130	152	231	277	237	104	89	93	1,690
70%	69	61	74	104	156	180	265	336	315	134	99	94	1,957
80%	73	76	93	152	210	212	292	399	440	227	104	98	2,263
90%	77	104	151	209	277	281	320	543	590	327	131	104	2,977
Max	219	215	352	723	447	455	493	985	1,123	638	279	234	4,791
Avg	59	60	78	106	134	158	210	266	263	142	92	92	1,660
C. Projected Late Long-Term (2060) Monthly Distributions for Millerton Reservoir Inflow (TAF)													
Min	22	13	18	20	20	20	40	7	2	21	29	51	313
10%	28	26	30	33	45	79	109	61	31	37	53	58	724
20%	36	34	35	39	67	92	133	78	49	43	61	71	847
30%	43	38	39	56	73	108	151	127	70	46	64	77	1,015
40%	53	42	48	63	85	120	177	160	126	50	67	81	1,108
50%	57	47	57	67	100	140	206	194	150	55	72	84	1,254
60%	60	51	63	91	141	157	243	243	179	63	77	86	1,626
70%	63	56	73	110	160	200	274	305	250	90	81	88	1,797
80%	66	69	94	157	219	242	314	361	357	141	85	91	2,122
90%	72	98	163	242	290	307	361	529	518	255	92	97	2,778
Max	220	191	375	747	478	514	500	1063	966	528	196	322	4,598
Avg	55	55	78	113	139	168	223	251	215	103	74	87	1,561

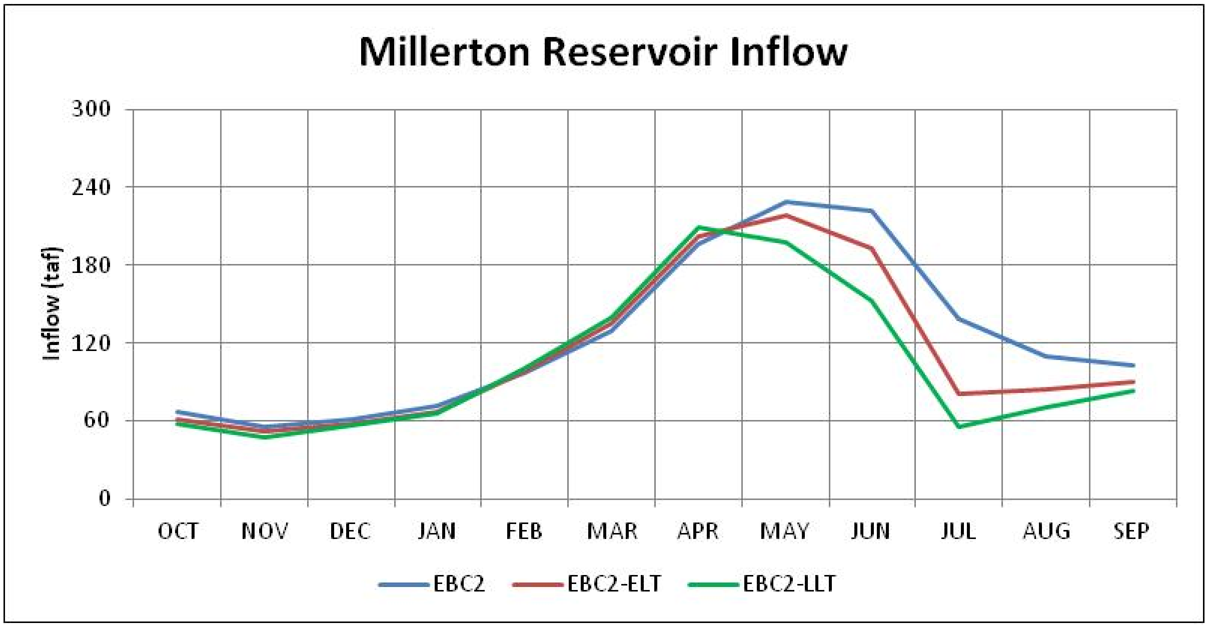


Figure 5.A.2.4-8. Projected Shifts in the Monthly Median Millerton Reservoir Runoff (TAF) from Existing Conditions to Early Long-Term (2025) to Late Long-Term (2060)

5.A.2.4.12 Summary of Projected Runoff Changes

The projected climate change effects on rainfall and runoff in the Central Valley of California and the estimated inflows to the major CVP and SWP reservoirs required several steps that necessitated many assumptions and used several models in sequence. The runoff and resulting reservoir inflow for each of the CVP and SWP reservoirs were adjusted separately, based on the GCM and VIC results, as described in the methods. Each of the months in the historical sequence from 1922 to 2003 was adjusted with a slightly different number. The climate change adjustments to runoff and reservoir inflow did not modify the historical sequence of conditions; the annual runoff sequence remained similar to the historical record with only incremental changes in each month. Figure 5.A.2.4-9 shows an example of the monthly shifts in the historical Shasta Reservoir inflow (runoff from the upper Sacramento River, including the Pit and Shasta Rivers) for the second half of the CALSIM period, WY 1963–2003. These projected changes in the Central Valley runoff might be considered moderate; more extreme variations from the historical sequence of annual runoff conditions or greater variation within the months of each runoff year likely would provide a stronger test of the ability of the CVP and SWP reservoir operations to provide flood control and water supply.

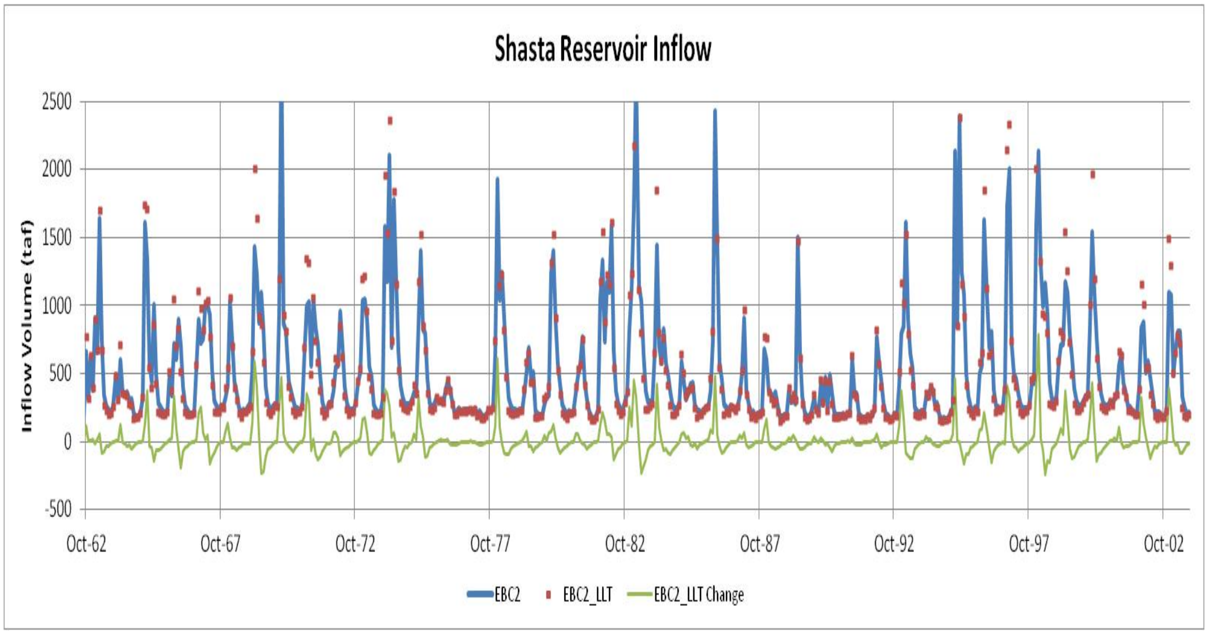


Figure 5.A.2.4-9. Projected Shifts in the Monthly Shasta Reservoir Inflow (TAF) from Existing Conditions (2010, EBC2) to Late Long-Term (2060, EBC2_LLT) for Water Years 1963–2003

5.A.2.5 Upstream Water Temperatures Modeling Results

The upstream water temperatures in the rivers below each major CVP and SWP reservoir (e.g., spawning and rearing habitat) were simulated with the Reclamation water temperature models. The results for each of the climate cases (existing, ELT, and LLT) are shown in the following graphs and discussed in this appendix. The three climate change cases incorporated different runoff, sea level rise, and air temperature conditions and are referenced as existing biological conditions "two" (EBC2 with historical sea level and climate, EBC2_ELT with 2025 sea level rise and climate change, and EBC2_LLT with 2060 sea level ride and climate change). These different runoff, sea level rise, and air temperature cases were simulated with CALSIM and with the Reclamation temperature models. The major simulated water temperature effects were the result of climate change warming. Although the other BDCP cases added some changes in water temperatures from different reservoir and Delta operations, only the changes attributable to climate change (warming and sea level rise) will be discussed in this appendix. These changes are represented by the shift in water temperatures from the existing conditions EBC2 case to the EBC2_ELT (2025 climate) and the EBC2_LLT (2060 climate) cases.

5.A.2.5.1 Trinity River Water Temperatures

The existing Trinity Reservoir inflow temperatures are 35–45°F in November–May. This provides a large volume of cold water (<50°F) in Trinity Reservoir that maintains a very cool release temperature throughout the summer of most years. The existing inflow temperatures are about 55°F in June, are a maximum of 60–65°F in July–September, and cool to about 55°F in October.

Although the surface water temperatures in Trinity Reservoir reach a maximum of 75–80°F in July–September, the release temperatures remain at 45–50°F unless the storage is reduced to less than 1,000 TAF. The power plant intake is located very low in the reservoir with a minimum storage volume of 250 TAF (below the outlet). The surface heating of the reservoir does not begin to warm the release temperature unless the water surface is reduced to within 50–75 feet of the power plant outlet. This corresponds to a storage of about 750–1,000 TAF.

The simulated existing Trinity Reservoir release temperature from the power plant intake was nearly always about 45°F. The simulated Lewiston release temperature was slightly warmer in the spring and about 5°F warmer in the summer months. During periods of high flow, the release temperature to the Carr Tunnel, the Lewiston Hatchery, and the Trinity River was less than 50°F. Surface temperatures in Lewiston can stratify when the Carr power plant is not operating, with surface temperatures of 60–70°F. The main factor controlling the Trinity Reservoir release temperature and the temperature in the Trinity River below Lewiston Dam is the Trinity Reservoir storage volume. Because the Trinity River flow is controlled at 300–450 cfs in most months, the warming downstream to Douglas City and North Fork is controlled by the difference between the equilibrium temperature and the Lewiston release temperature, as well as the monthly surface heat exchange rate.

Figure 5.A.2.5-1 shows the monthly ranges of the Reclamation temperature model results for the Trinity River at Lewiston Reservoir, Douglas City (15 miles downstream), and North Fork (37 miles downstream) for WY 1922–2003 for existing conditions (EBC2). The 10%, 30%, 50%, 70%, and 90% cumulative river temperatures for each month are shown. Some of the monthly river temperatures were higher than the 90% value and some were lower than the 10% value, but the seasonal pattern is well represented. The established Trinity River temperature criteria are 60°F at Douglas City from July 1 to September 14, 56°F at Douglas City September 15–30, and 56°F at North Fork October 1–December 31. The simulated monthly river temperature ranges for the EBC2 case indicate that these temperature criteria generally are met. Only in years with low simulated Trinity Reservoir storage were the Lewiston release temperatures higher than these summer and fall temperature criteria. The Reclamation monthly water temperature model inputs were adjusted to match the projected climate change air temperature increase of about 1°F for the ELT and about 2°F for the LLT.

Figure 5.A.2.5-2 shows the monthly ranges of the Reclamation temperature model results for the Trinity River at Lewiston Reservoir, Douglas City, and North Fork for WY 1922–2003 for the projected LLT conditions (EBC2_LLT). The increases in water temperatures were greatest in the summer and fall months of some years; a combination of low reservoir storage and low river flows will give the greatest water temperature increases with climate change.

Figure 5.A.2.5-3 shows the Reclamation temperature model results for Lewiston Reservoir, Douglas City, and North Fork temperatures in September, plotted against the September Trinity Reservoir storage volume for the EBC2 climate change cases. The Lewiston release temperatures were 45–55°F in September when the carryover storage was greater than 1,000 TAF. The September release temperatures increased from 55°F with a storage volume of 1,000 TAF to about 60°F with a storage volume of 500 TAF. The September Lewiston temperatures increased to 65°F (or higher) with a simulated September storage volume of 250 TAF. The simulated temperatures at Douglas City were often about 5°F warmer than the release temperatures at Lewiston in September. The simulated temperatures at North Fork were often about 5°F warmer than the temperatures at Douglas City and were generally between 55°F and 65°F (average of 60°F) in September. The Lewiston

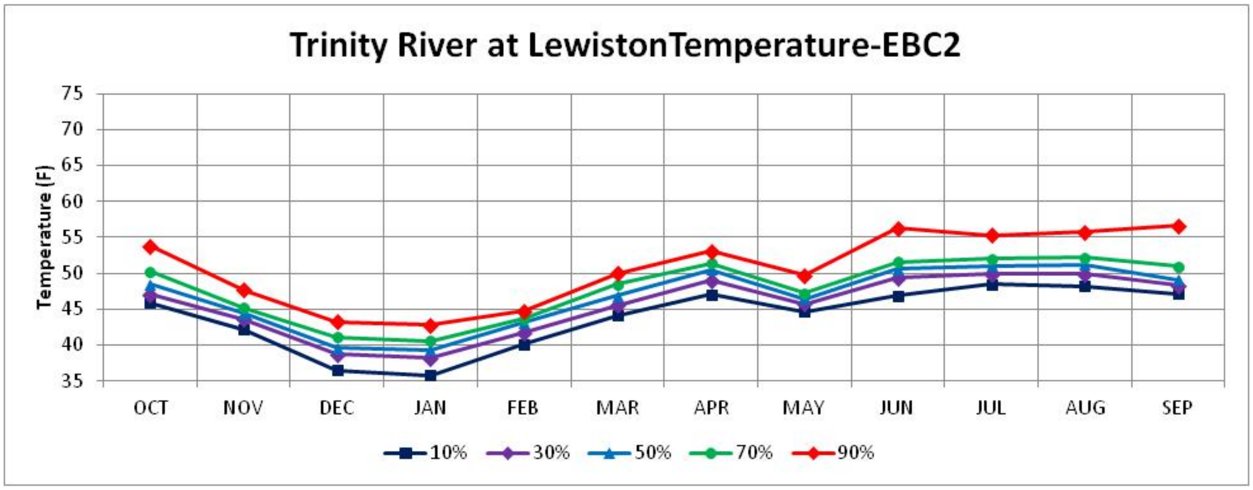
temperatures of 55–65°F in September did not increase at Douglas City or at North Fork, suggesting that the equilibrium temperature was about 55–65°F in September. The ELT temperatures were generally 1–2°F warmer, and the LLT temperatures were about 2–3°F warmer than the existing temperatures at each of these Trinity River locations in September.

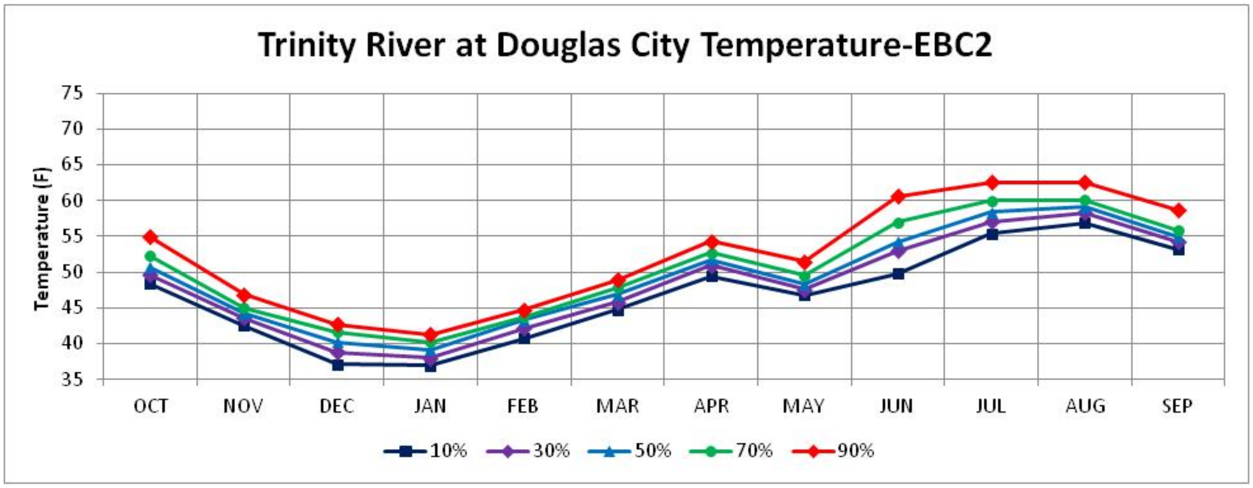
Figure 5.A.2.5-4 shows the Reclamation temperature model results for Lewiston, Douglas City, and North Fork temperatures in October, plotted against the October Trinity Reservoir storage volume for the EBC2 climate change cases. The Lewiston Reservoir release temperatures were similar to the September temperatures, with release temperatures of 45–55°F when October storage volumes were greater than 1,000 TAF. The October release temperatures increased from 55°F with a storage volume of 1,000 TAF to about 60°F with a storage volume of 500 TAF. The release temperatures increased to 60°F (or higher) with a simulated October storage volume of 250 TAF. The simulated temperatures at Douglas City were about 2–3°F warmer than the Lewiston release temperatures, when the release temperatures were less than 55°F in October. October Lewiston temperatures greater than 60°F were cooled slightly at Douglas City, suggesting that the equilibrium temperature was about 55–60°F in October. The existing North Fork temperatures were generally 50–55°F in October and almost always met the 56°F temperature objective. The ELT temperatures were generally 1–2° F warmer and the LLT temperatures were about 2–3°F warmer than the existing temperatures at each of these Trinity River locations in October.

These results from the Reclamation temperature model for the Trinity Reservoir and Trinity River indicate that a Trinity Reservoir storage volume greater than 750 TAF would maintain Lewiston release temperatures of less than 60°F in September and October. A minimum Trinity Reservoir storage volume of 1,000 TAF would provide a Lewiston Reservoir release temperature of about 55°F. The Trinity River temperatures for the ELT and LLT cases remain relatively cool compared to the summer temperature criteria of 60°F at Douglas City. The simulated Trinity River temperatures also generally remained below the 56°F spawning temperature criteria in October and November. It therefore does not appear likely that the simulated increase in average air temperature of 2°F would be sufficient to cause the Trinity River temperatures to exceed the water temperature criteria for summer rearing or fall-run Chinook salmon spawning in October and November.

Figure 5.A.2.5-5 shows the historical Trinity Reservoir storage compared to the simulated Trinity Reservoir storage for the EBC2 climate change cases for WY 1963–2003 (second half of the CALSIM simulation period). The historical operations reduced the storage to less than 750 TAF only in 1977 and 1991. The simulated storage of the EBC2 case was similar to historical storage, although more of the reservoir releases now goes to the Trinity River, with less water being exported to the Sacramento River.

Figure 5.A.2.5-6 shows the simulated Lewiston Dam release temperatures for the EBC2 cases for WY 1963–2003 for the EBC2 climate change cases. The EBC2 release temperatures generally vary seasonally from less than 40°F in the winter months to more than 50°F in the summer and fall months of most years. However, in years with reduced storage of less than 750 TAF, the simulated EBC2 Lewiston Dam release temperatures (and hatchery temperatures) were greater than 55°F in September and October. Because the simulated Trinity Reservoir storage would be reduced in many years for EBC2_LLT climate change conditions, the simulated Lewiston Dam release temperatures for the EBC2_LLT climate change conditions were generally warmer and were greater than 55°F in September and October more often.





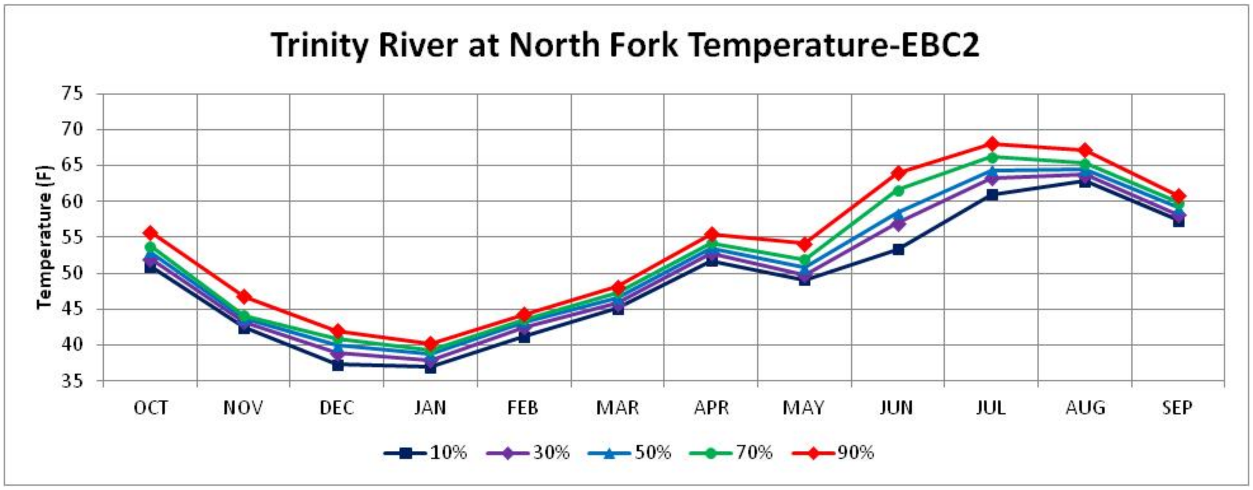
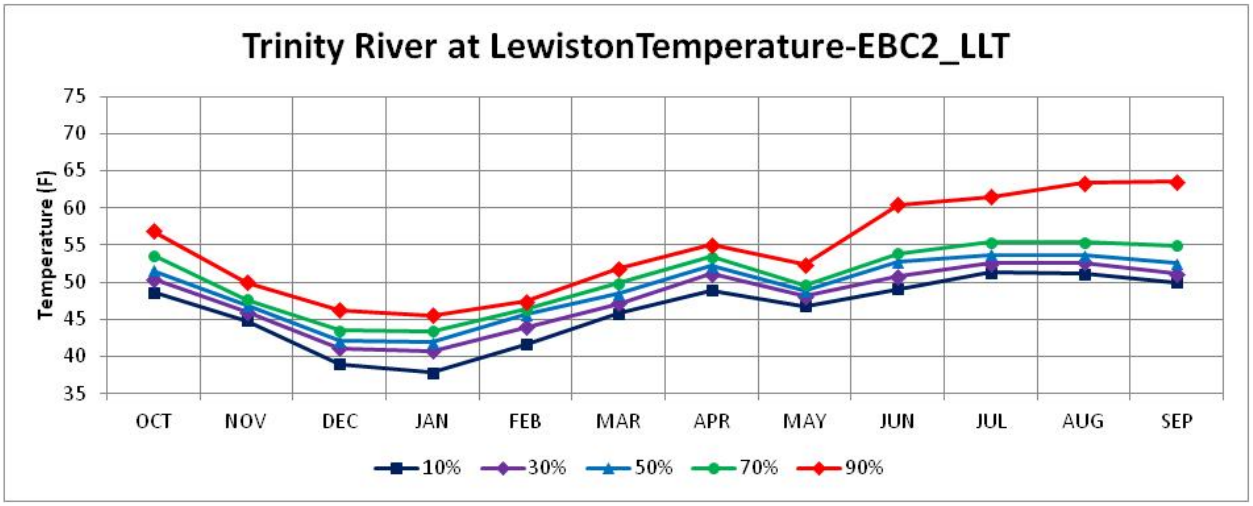
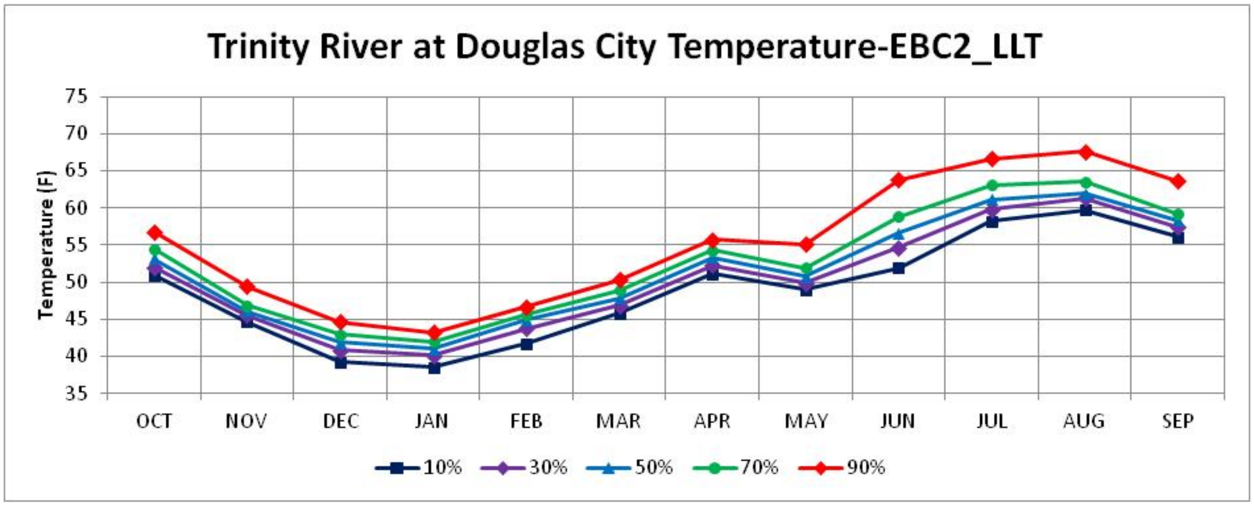


Figure 5.A.2.5-1. Reclamation Temperature Model Monthly Ranges for Trinity River Temperatures at Lewiston Reservoir, Douglas City, and North Fork for WY 1922–2003 for EBC2





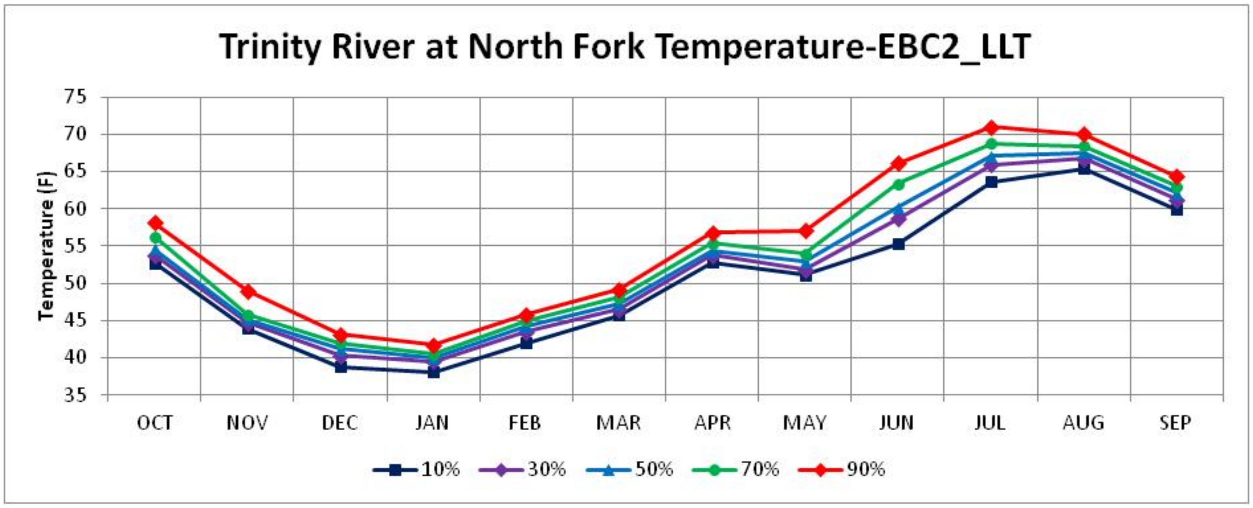
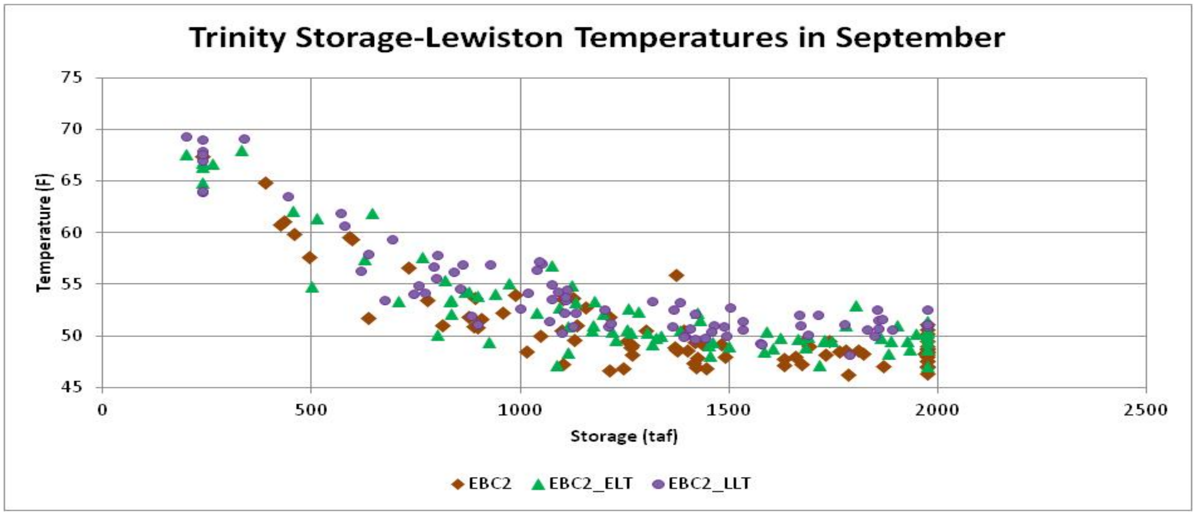
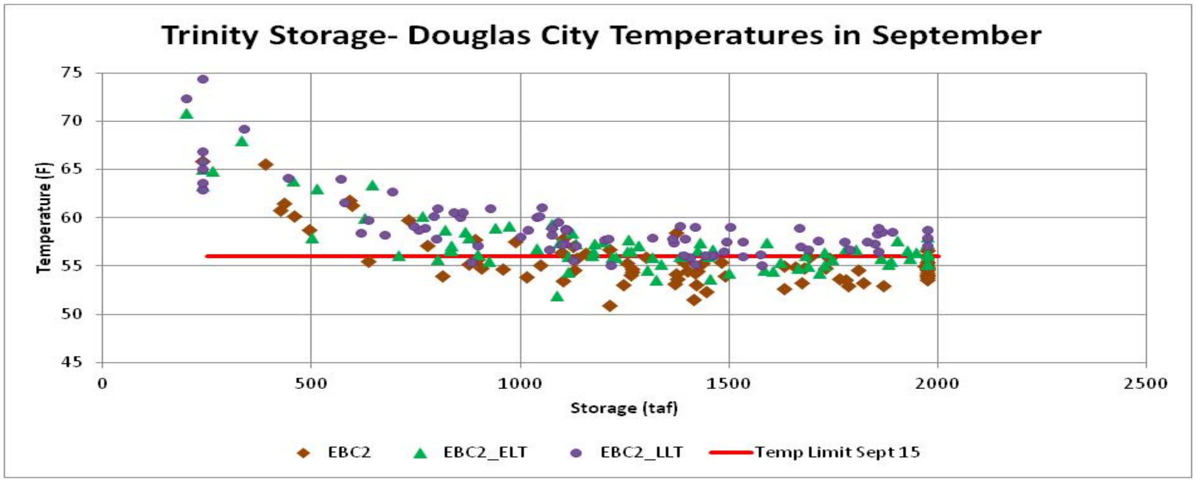


Figure 5.A.2.5-2. Reclamation Temperature Model Monthly Ranges for Trinity River Temperatures at Lewiston Reservoir, Douglas City, and North Fork for WY 1922–2003 for EBC2_LLT





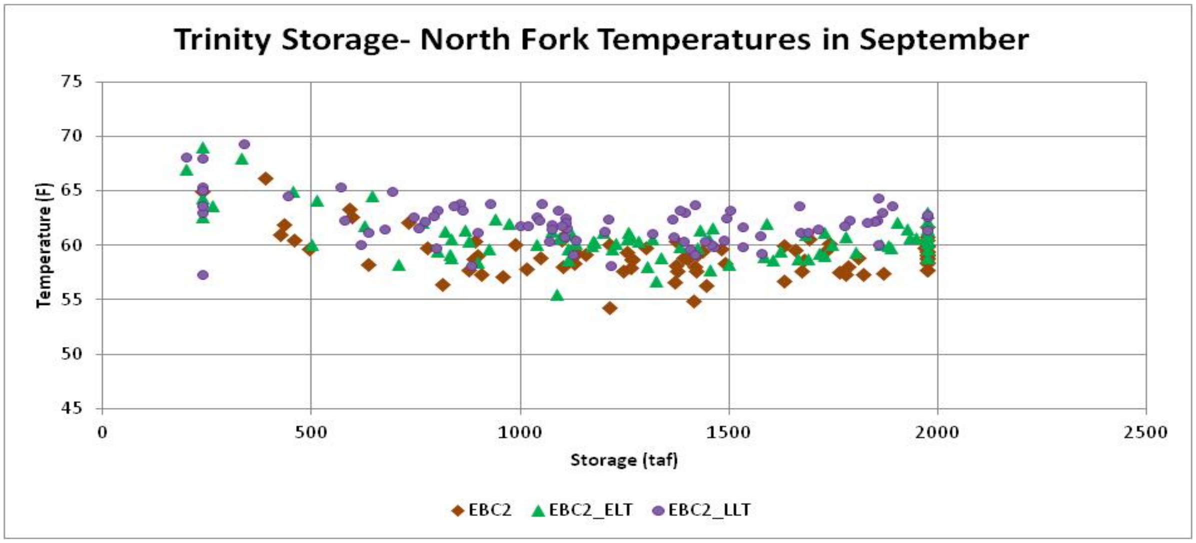
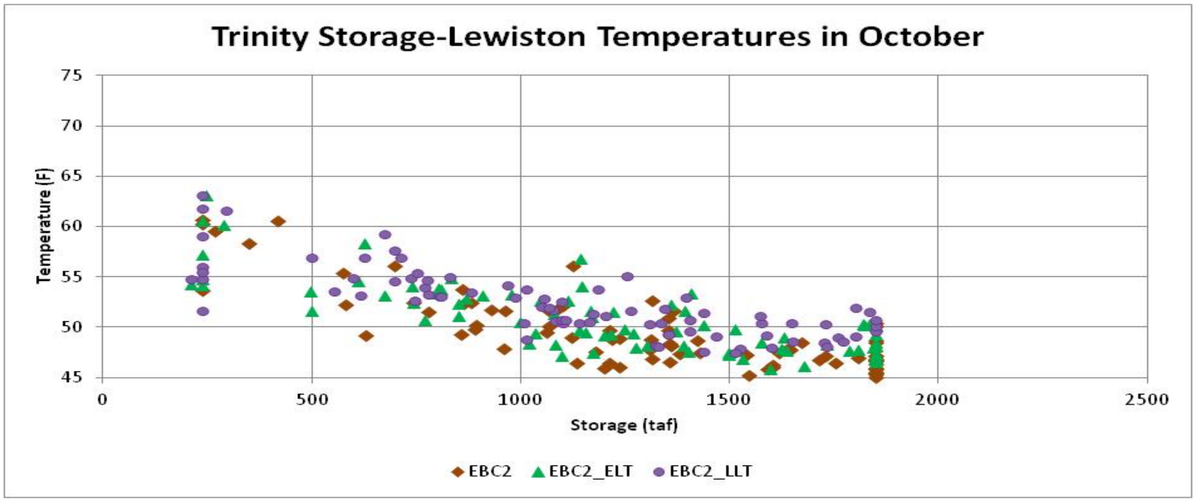
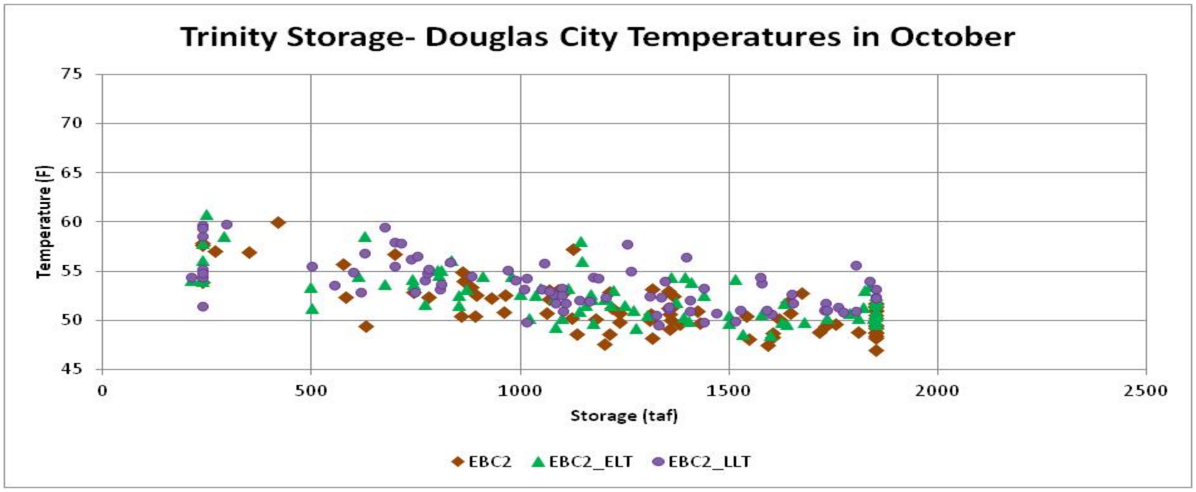


Figure 5.A.2.5-3. Trinity Reservoir Storage (TAF) and Lewiston, Douglas City, and North Fork Temperatures (°F) in September for the EBC2, EBC2_ELT and EBC2_LLT Cases for WY 1922–2003





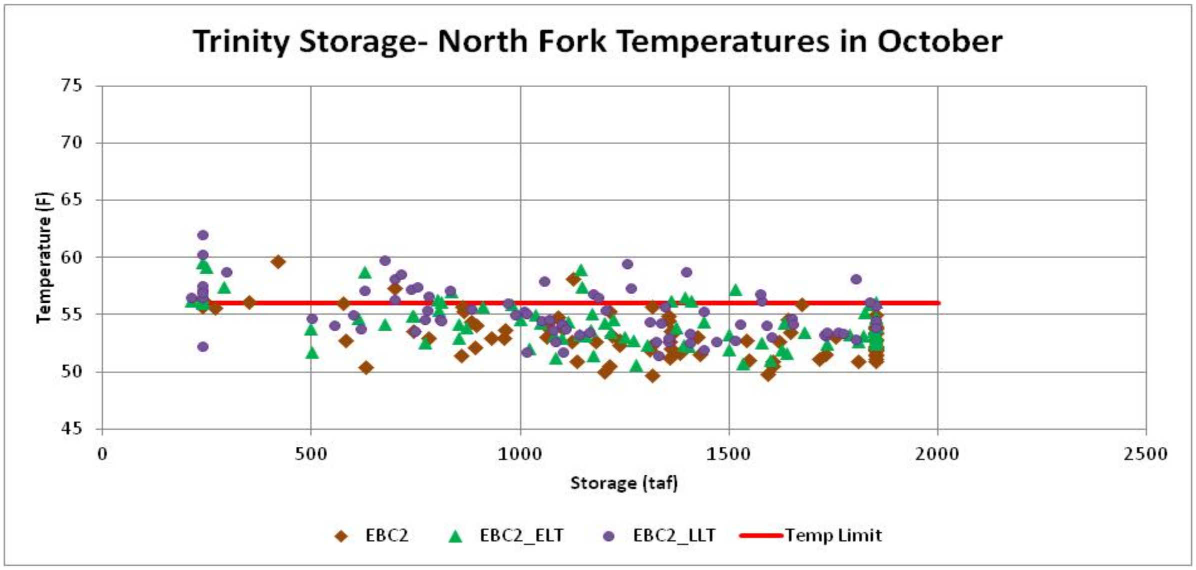


Figure 5.A.2.5-4. Trinity Reservoir Storage (TAF) and Lewiston, Douglas City, and North Fork Temperature (°F) in October for the EBC2, EBC2_ELT and EBC2_LLT Cases for WY 1922–2003

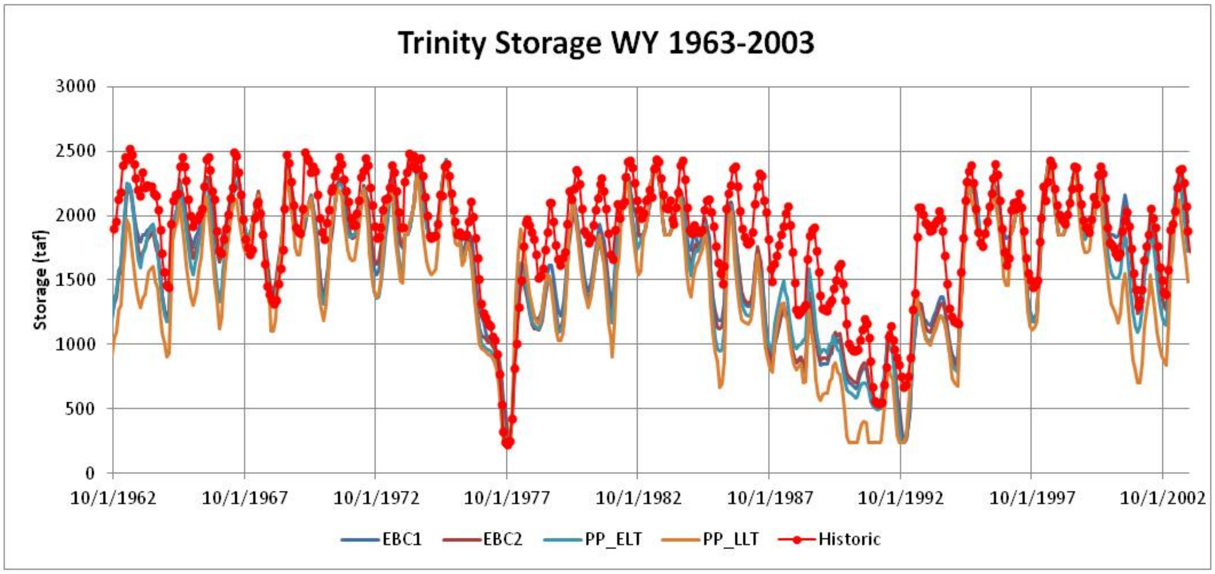


Figure 5.A.2.5-5. Historical and CALSIM-Simulated Trinity Reservoir Storage for the EBC2, EBC2_ELT and EBC2_LLT Cases for WY 1963–2003

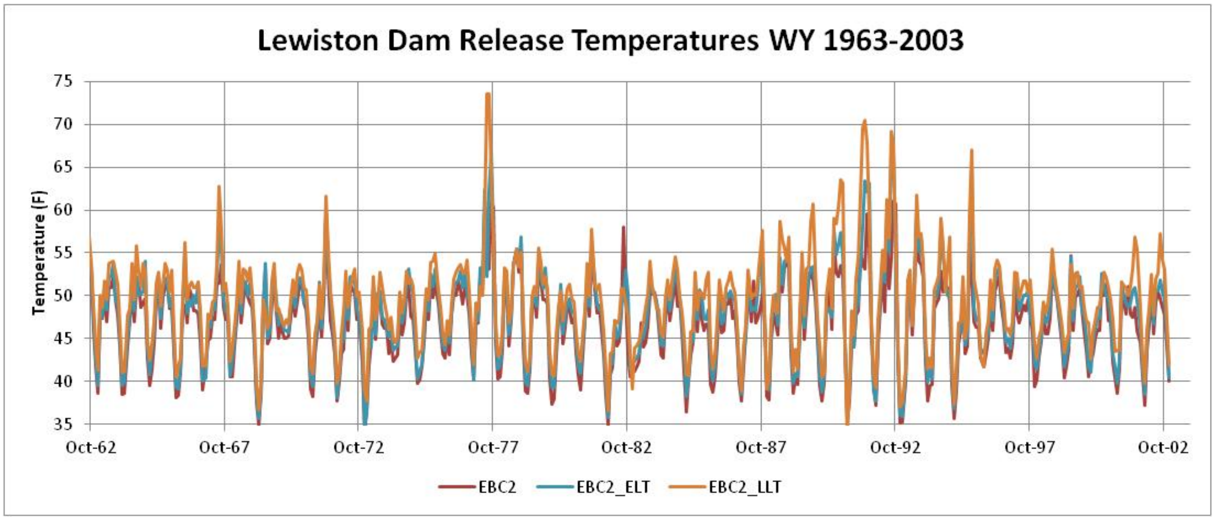


Figure 5.A.2.5-6. Reclamation Temperature Model-Simulated Lewiston Dam Release Temperatures for the EBC2 Climate Change Cases for WY 1963–2003

5.A.2.5.2 Sacramento River Water Temperatures

The Shasta Reservoir inflow temperatures are about 5°F warmer than the Trinity Reservoir inflow temperatures, with a minimum of 45–50°F in November–April (Table 5.A.2.4-1). This provides a large volume of cold water (<50°F) in Shasta Reservoir that maintains a cool release temperature of 45–50°F throughout the summer of most years. The inflow temperatures are about 55°F in May, 60°F in June, and 65°F in July and August. Inflow temperatures cool to about 60°F in September, 55°F in October, and 50°F in November. Although the surface water temperatures in Shasta Reservoir reach a maximum of 75–80°F in July–September, the release temperatures remain at 45–50°F unless the storage is reduced to less than 1,500 TAF. The power plant intake is located low in the reservoir with a minimum storage volume of 500 TAF (below the outlet). The surface heating of the reservoir does not begin to warm the release temperature unless the water surface is reduced to within 75–100 feet of the power plant outlet. This corresponds to a storage volume of about 1,000–1,500 TAF.

Figure 5.A.2.5-7 shows the monthly ranges for the SRWQM temperature model results of Sacramento River temperatures at Keswick Reservoir, Red Bluff (55 miles downstream), and Hamilton City (100 miles downstream) for existing conditions (EBC2) for WY 1922–2003. Figure 5.A.2.5-8 shows the monthly ranges for the SRWQM temperature model results of Sacramento River temperatures for the LLT conditions (EBC2_LLT) for WY 1922–2003. Generally, the simulated Sacramento River temperatures are about 2–3°F warmer in the summer months than simulated for EBC2 conditions.

The established Sacramento River temperature criteria are 56°F at Bend Bridge (45 miles downstream) or the designated compliance location (upstream at Ball's Ferry or Jelly's Ferry) from April 15 to September 30 to protect winter-run spawning and egg incubation, and 60°F in October to protect holding adults prior to fall-run spawning in November. The simulated monthly temperature ranges indicate that these Sacramento River temperature criteria are generally met, but not always, at Bend Bridge. Only in years with low Shasta Reservoir storage were the simulated Keswick release temperatures higher than these summer and fall temperature criteria.

Figure 5.A.2.5-9 shows the SRWQM temperature model results for Keswick release temperatures and downstream Sacramento River temperatures in August, plotted against the August Shasta Reservoir storage volume for the EBC2 climate change cases. The Keswick release temperatures were 50–55°F when the carryover storage was greater than 1,500 TAF. The Keswick temperatures increased from 55°F with a storage volume of 1,500 TAF to about 60°F with a storage volume of 1,000 TAF. The release temperatures increased to 65°F (or higher) with an August storage volume of 500 TAF. The simulated temperatures at Bend Bridge (45 miles downstream) in August were about 5°F warmer than the Jelly's Ferry temperatures.

The simulated effects of climate change increased at the downstream stations because of increased equilibrium temperatures and heat exchange rates. The simulated changes in water temperatures at Bend Bridge between the existing conditions cases (brown symbols) and the ELT cases (green symbols) were about 1–3°F. The simulated changes in water temperatures between the existing conditions and the LLT cases (purple symbols) at Bend Bridge were about 2–5°F. The simulated Keswick flows in August were about 10,000 cfs for each of the EBC2 cases. Therefore, the increased variation in water temperatures at Bend Bridge was caused by estimated increases in equilibrium temperature and heat exchange rates, rather than changes in river flow. About half of the simulated temperatures at Bend Bridge in August for the EBC2 cases exceed the established temperature criteria of 56°F. Almost all of the simulated August temperatures for the future cases (ELT and LLT) would exceed the 56°F criteria. The simulated effects of climate change warming will reduce the portion of the Sacramento River that would remain below the 56°F temperature criteria.

Figure 5.A.2.5-10 shows the SRWQM temperature model results for Keswick release temperatures and Bend Bridge temperatures in September, plotted against the September Shasta Reservoir storage volume for the EBC2 climate change cases. The Keswick release temperatures were 50–55°F when the carryover storage was greater than 2,500 TAF. The Keswick release temperatures increased from 55°F with a storage volume of 2,500 TAF to about 60°F with a storage volume of 1,500 TAF. The release temperatures increased to 65°F (or higher) with a September storage volume of 500 TAF. The simulated temperatures at Bend Bridge (45 miles downstream) were about 5°F warmer than the Keswick temperatures. The September temperatures were simulated to be higher than the August temperatures; only the coolest Keswick release temperatures (with Shasta storage of greater than 2,500 TAF) were below the 56°F temperature criteria at Bend Bridge. The simulated effects of climate change in September were similar to those in August; the Bend Bridge temperatures were 2–3°F warmer for the ELT cases (green symbols) and were 3–5°F warmer for the LLT cases (purple symbols).

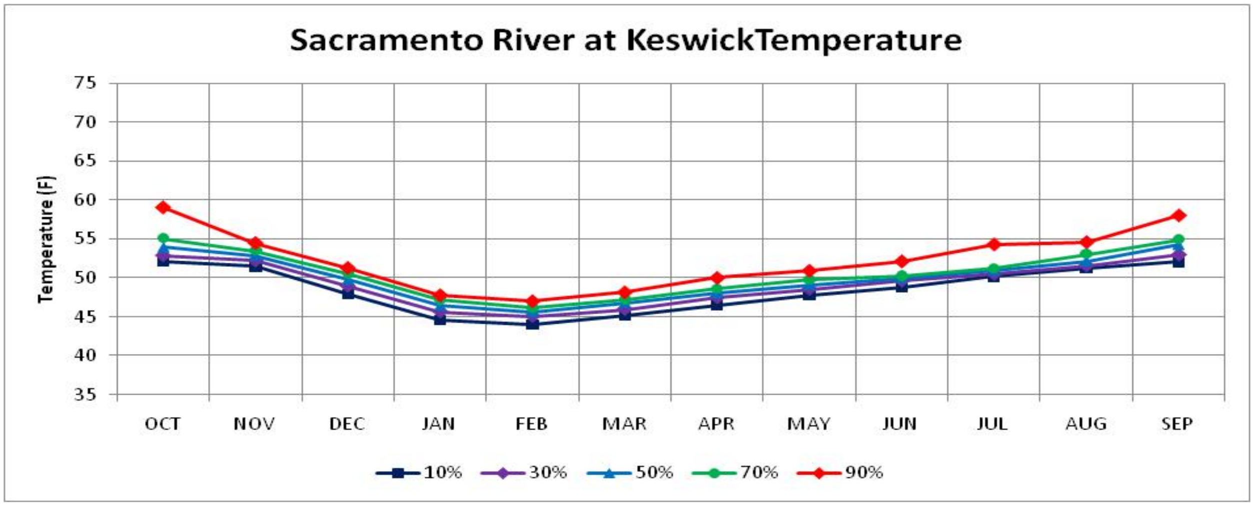
Figure 5.A.2.5-11 shows the SRWQM temperature model results for Keswick release temperatures and Bend Bridge temperatures in October, plotted against the October Shasta Reservoir storage volume for the EBC2 climate change cases. The Keswick temperatures were 50–55°F when the carryover storage was greater than 2,500 TAF. The Keswick temperatures increased from 55°F with a storage volume of 2,500 TAF to about 60°F with a storage volume of 1,500 TAF, and increased to about 65°F with a storage volume of 500 TAF for all three BDCP cases. The simulated temperatures at Bend Bridge (45 miles downstream) were just 1–2°F warmer than the release temperatures at Keswick in October. There was very little warming simulated for release temperatures of 55–60°F, suggesting that the equilibrium temperature was about 55–60°F in October.

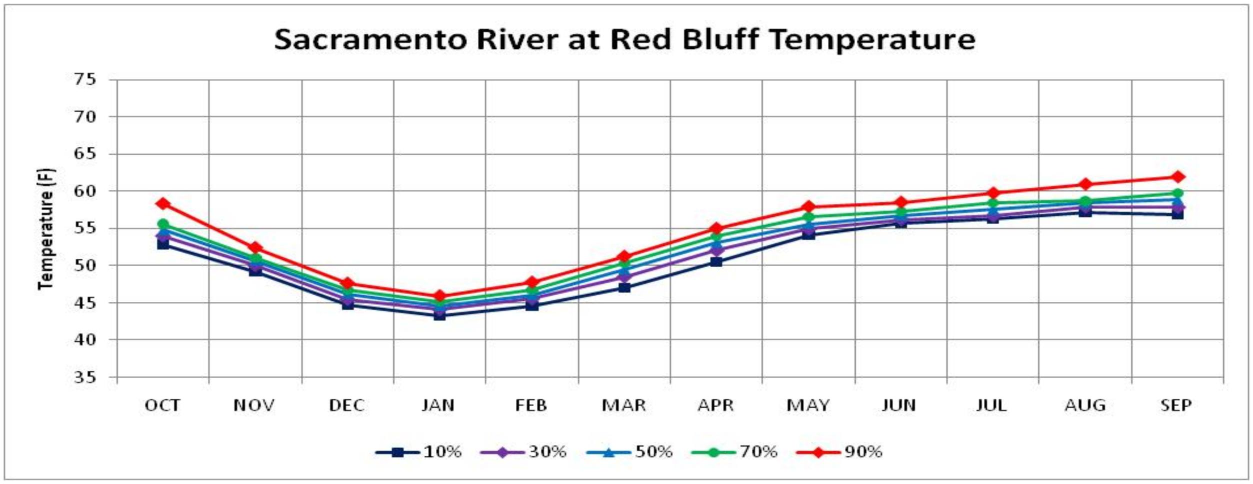
Figure 5.A.2.5-12 shows the SRWQM temperature model results for Keswick release temperatures and Bend Bridge temperatures in November, plotted against the November Shasta Reservoir storage volume for the EBC2 climate change cases. The Keswick temperatures were 50–55°F for all six cases regardless of the storage volume. The Shasta Reservoir temperatures apparently have cooled and mixed to a temperature of about 55°F in November, and the meteorological conditions produce additional cooling downstream at Bend Bridge. The ELT and LLT cases have slightly warmer Keswick release temperatures for storage volumes of less than 2,500 TAF. The simulated temperatures at Bend Bridge (45 miles downstream) were 1–2°F cooler than the release temperatures at Keswick in November. Almost all of the simulated November temperatures at Bend Bridge were less than 55°F for all climate change cases. There was no simulated warming from climate change effects in the Sacramento River in November.

These results from the SRWQM temperature model for Shasta Reservoir and Keswick Reservoir indicate that a Shasta Reservoir storage volume of greater than 1,500 TAF would maintain Keswick release temperatures of less than 55°F in August, less than 60°F in September, less than 60°F in October, and less than 55°F in November for existing conditions. A minimum Shasta Reservoir storage volume of 2,000 TAF would provide a Keswick Reservoir release temperature of about 55°F in September and October.

The simulated August Keswick temperatures were generally less than the 56°F temperature criteria, except for years when the Shasta Reservoir storage volume was less than 1,500 TAF. The simulated Keswick temperatures in September were 2°F warmer for the LLT and were greater than the 56°F temperature criteria in years with storage of less than 2,500 TAF. September temperatures likely will exceed the 56°F criteria with LLT climate change warming. The simulated effects of climate change warming on Keswick temperatures in October and November did not substantially change the water temperatures below Keswick Reservoir. The majority of the October and November temperatures were less than 60°F, and more than half of the simulated temperatures were below 56°F in October and November for all cases. The 56°F temperature criteria in the Sacramento River downstream of Keswick Reservoir would be satisfied in most years in October and November if the Shasta Reservoir storage was greater than 2,000 TAF, regardless of the simulated effects of climate change. A minimum Shasta Reservoir storage of 1,500 TAF would eliminate the warmest October Keswick release temperatures of greater than 60°F. November release temperatures of 55°F were simulated regardless of the Shasta Reservoir storage or the effects of climate change warming.

Figure 5.A.2.5-13 shows the historical Shasta Reservoir storage volumes for WY 1961–2003 along with the simulated Shasta Reservoir storage for four of the EBC2 climate change cases (with existing reservoir operations). The historical operations reduced the Shasta Reservoir storage volume to less than 1,500 TAF only in 1976–1977, 1991, and 2008. Figure 5.A.2.5-14 shows the effects of climate change on Keswick release temperatures would be greatest in the summer months when the Shasta Reservoir storage was less than 2,500 TAF. Keswick temperatures higher than 65°F were simulated when the Shasta storage was reduced to less than 1,000 TAF, and were warmer for the ELT and LLT conditions because the reservoir storage was slightly lower and the Shasta Reservoir temperatures were slightly increased.





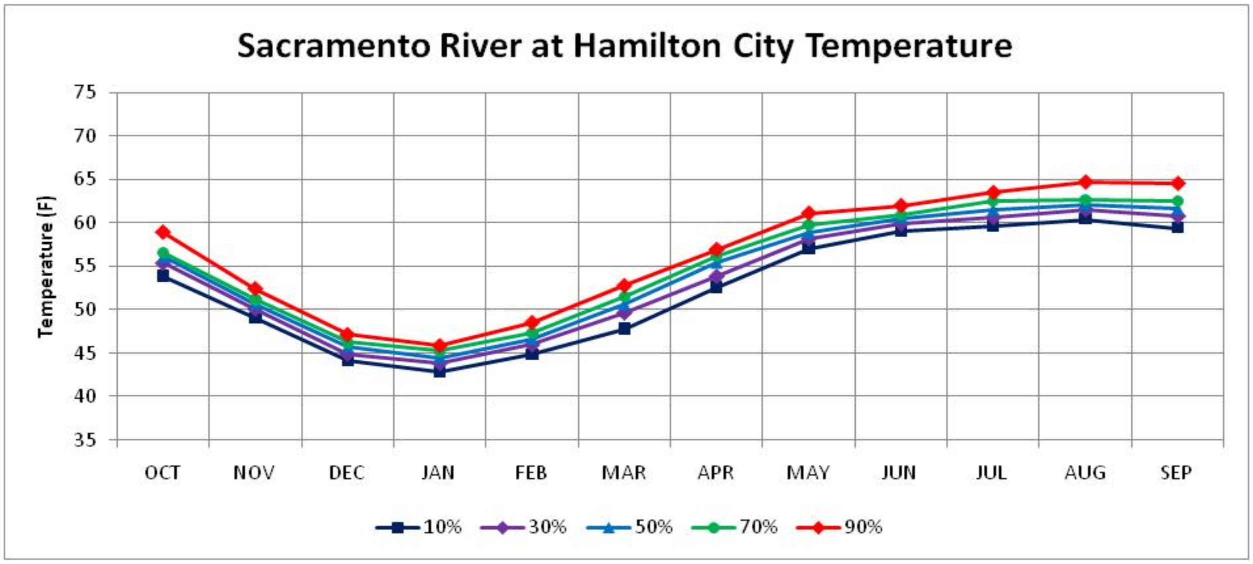
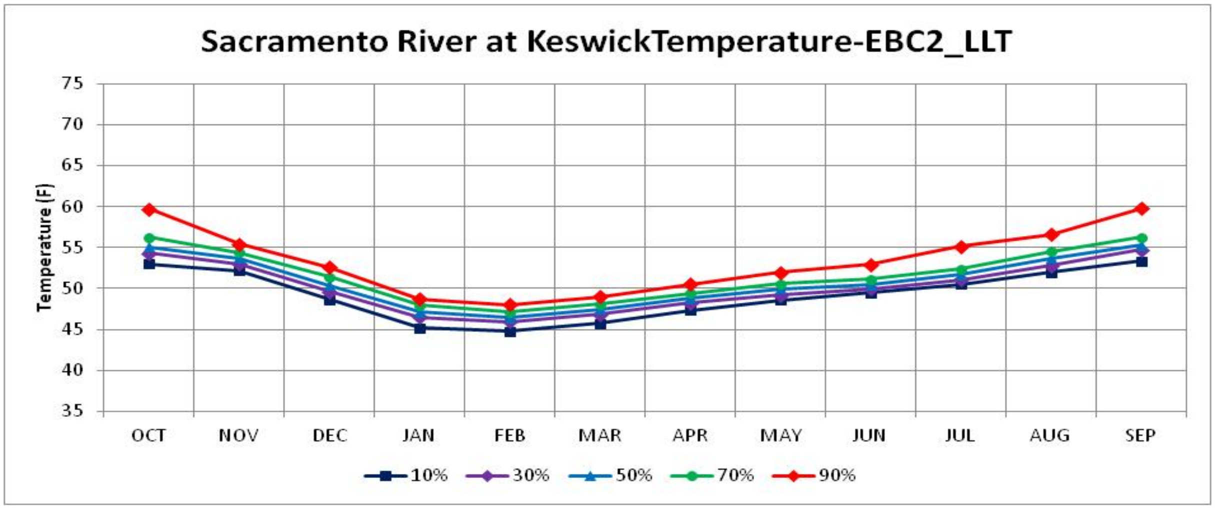
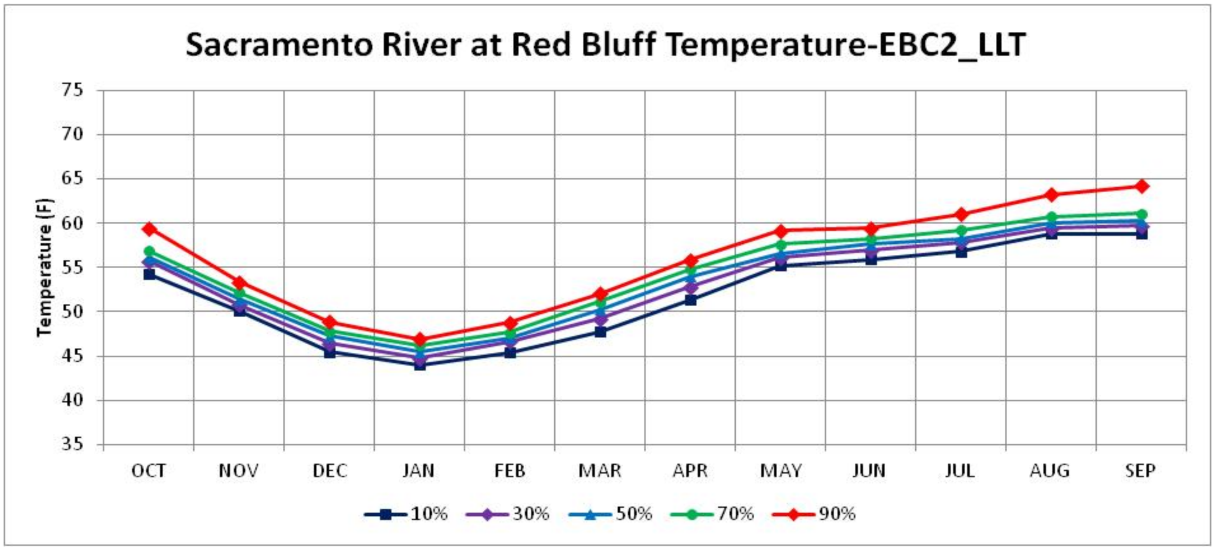


Figure 5.A.2.5-7. SRWQM Monthly Temperature Ranges for the Sacramento River at Keswick Reservoir, Red Bluff, and Hamilton City for WY 1922–2003 for Existing Conditions (EBC2)





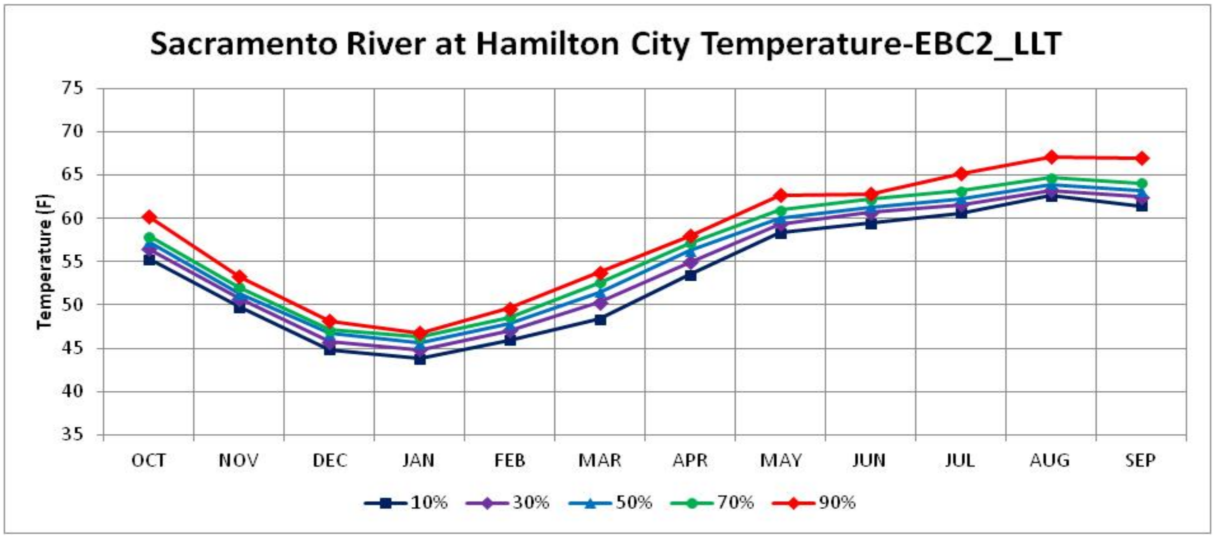


Figure 5.A.2.5-8. SRWQM Monthly Temperature Ranges for the Sacramento River at Keswick Reservoir, Red Bluff, and Hamilton City for WY 1922–2003 for EBC2-LLT

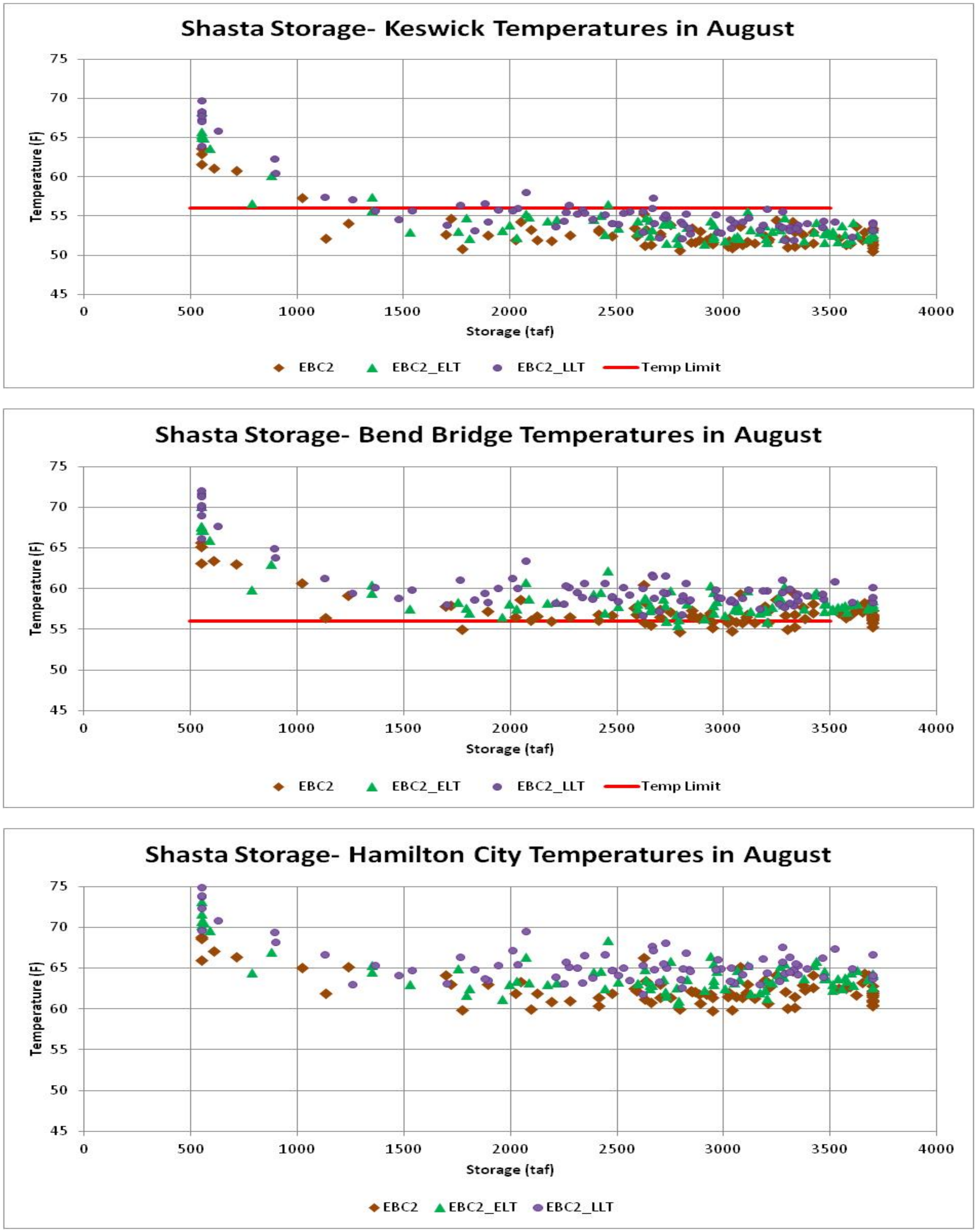
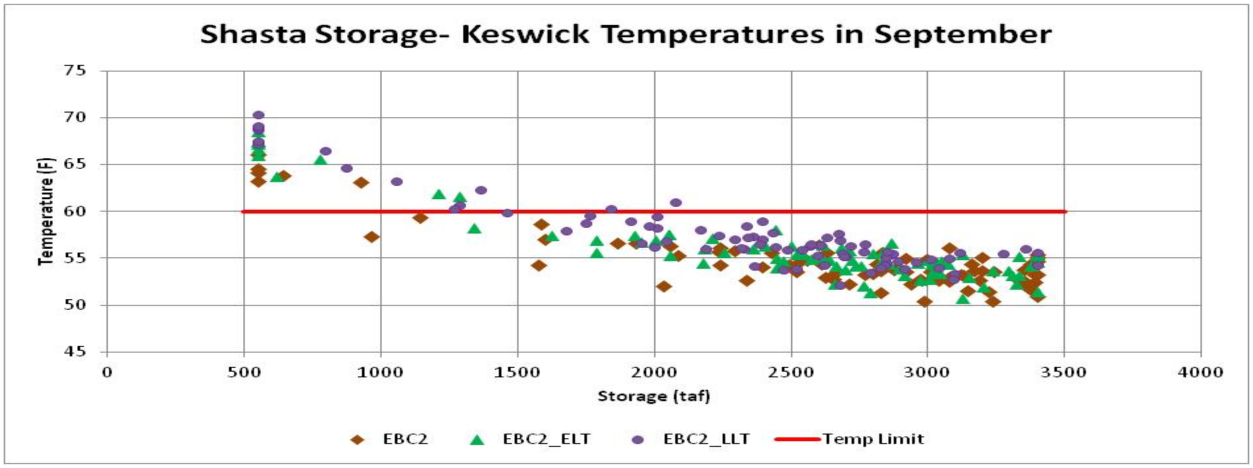
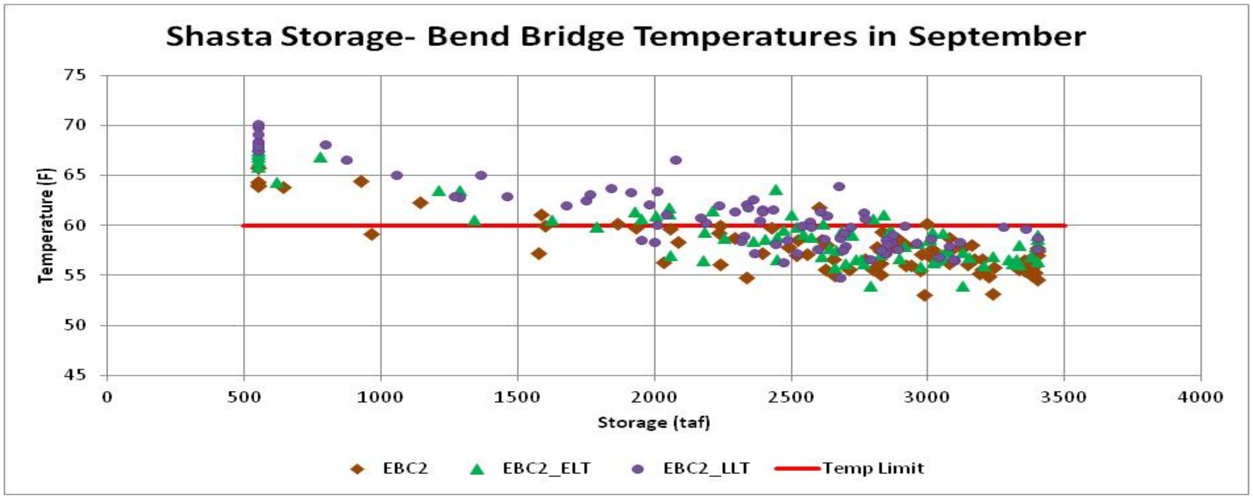


Figure 5.A.2.5-9. Shasta Reservoir Storage (TAF) and Sacramento River Temperatures (°F) at Keswick, Bend Bridge, and Hamilton City in August for the EBC2 Climate Change Cases for WY 1922–2003





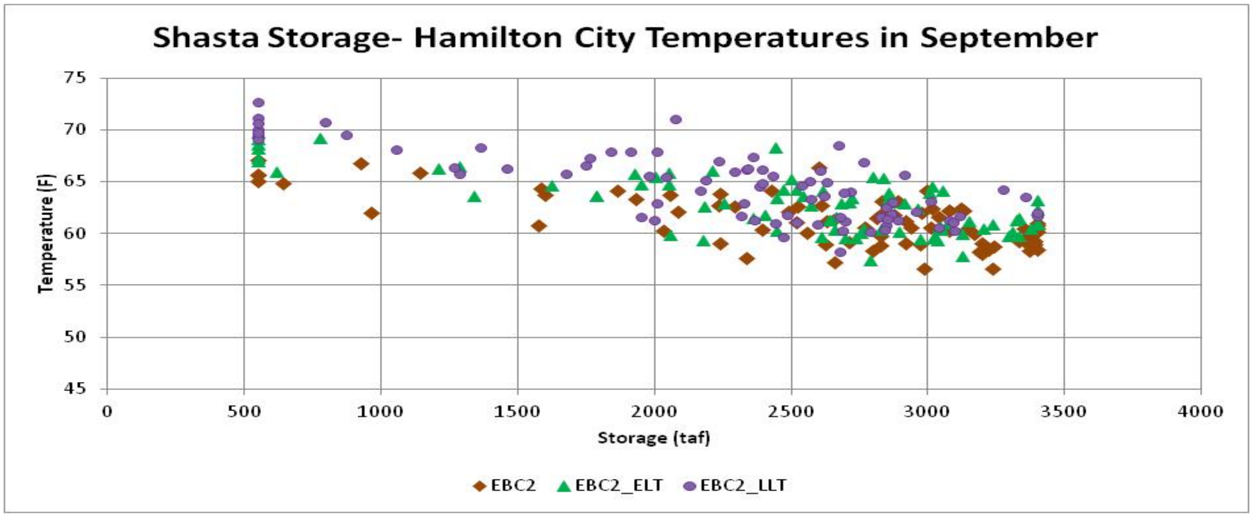
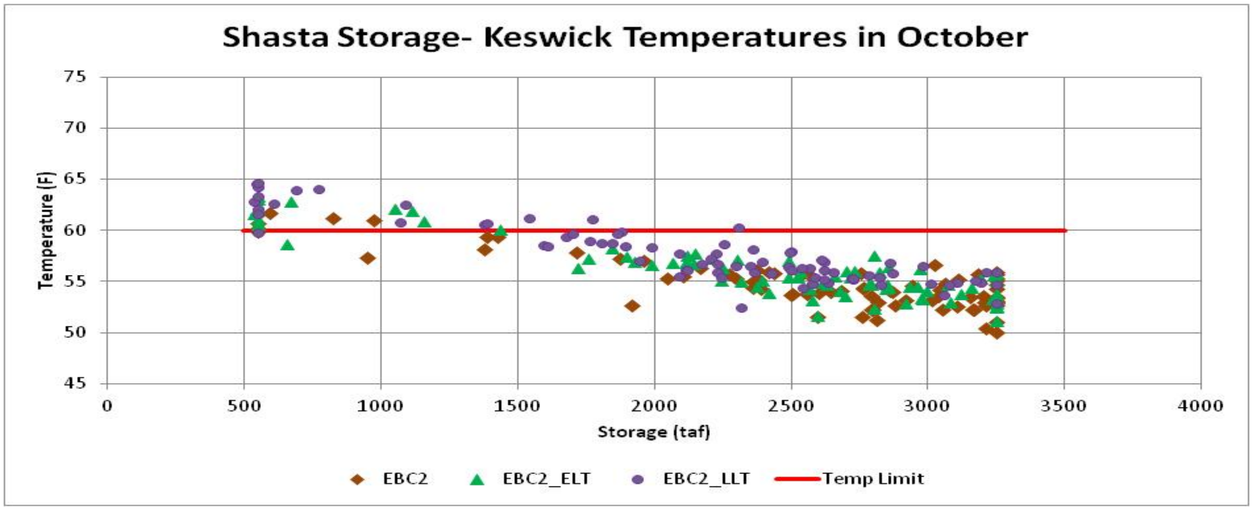
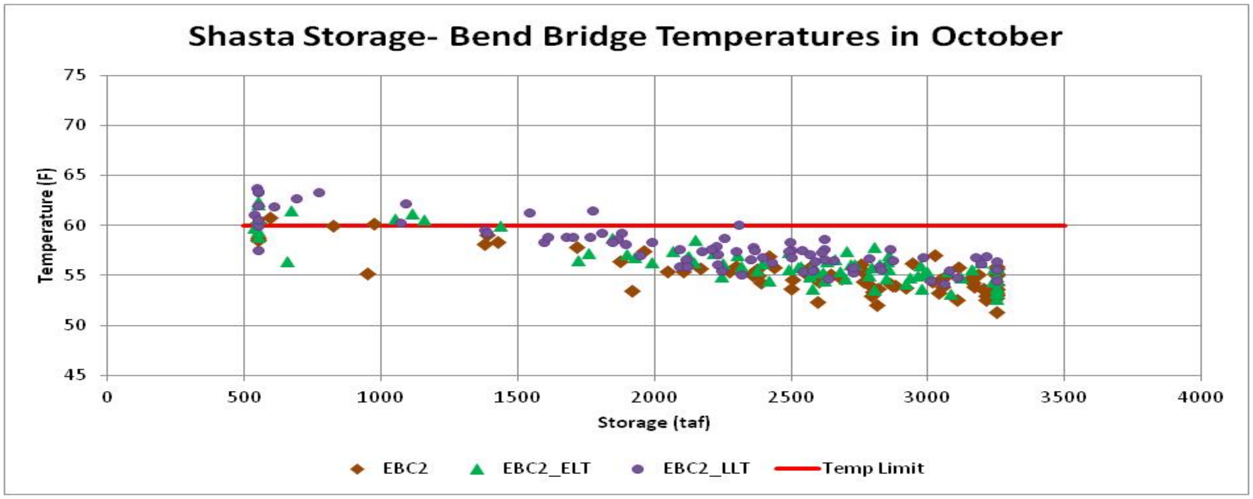


Figure 5.A.2.5-10. Shasta Reservoir Storage (TAF) and Sacramento River Temperatures (°F) at Keswick, Bend Bridge, and Hamilton City in September for the EBC2 Climate Change Cases for WY 1922–2003





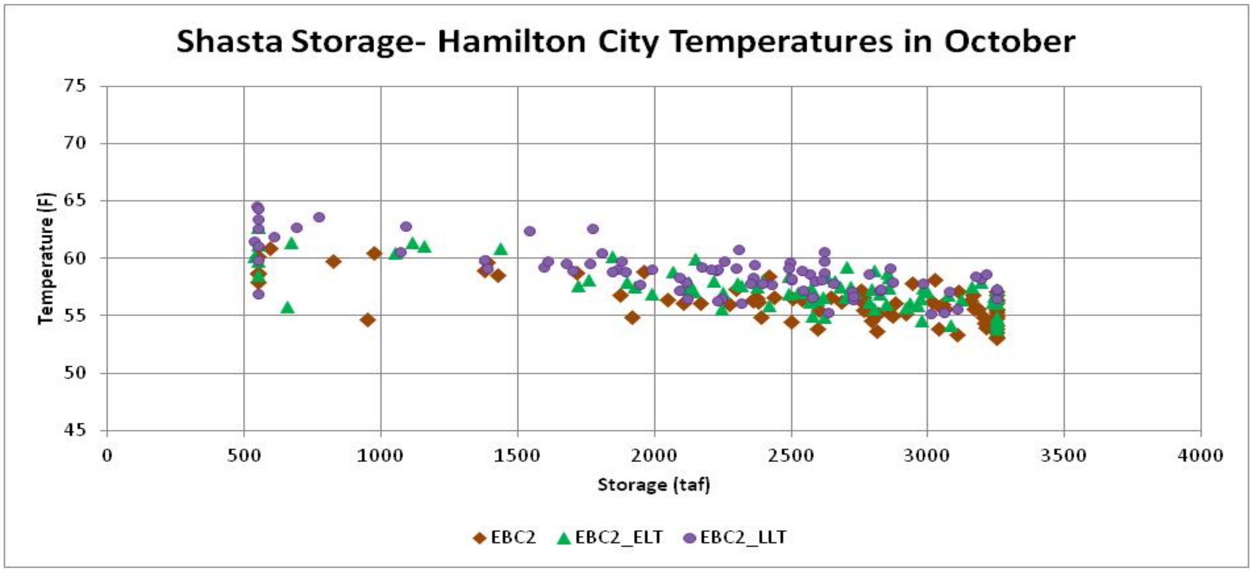


Figure 5.A.2.5-11. Shasta Reservoir Storage (TAF) and Sacramento River Temperatures (°F) at Keswick, Bend Bridge, and Hamilton City in October for the EBC2 Climate Change Cases for WY 1922–2003

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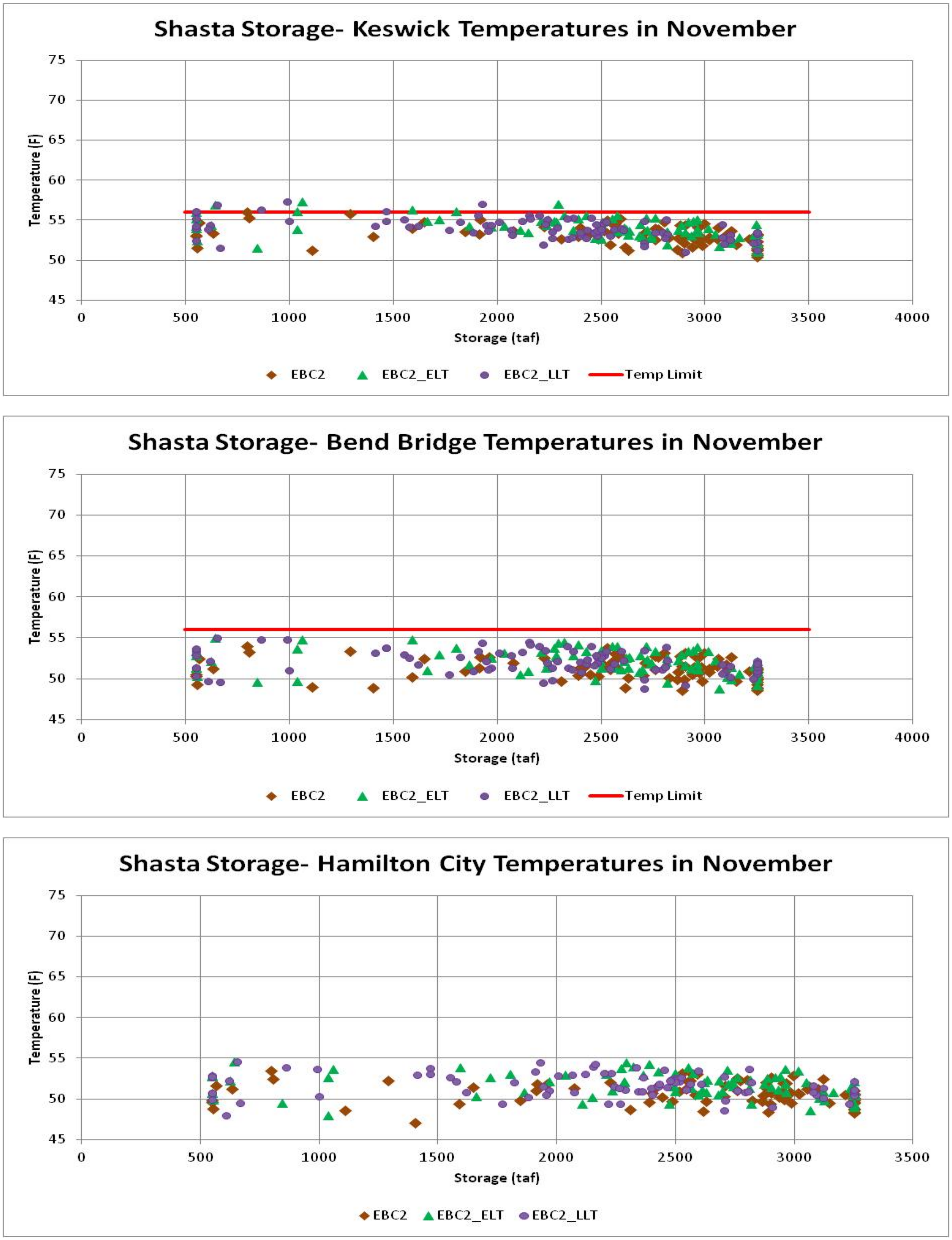

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3

4 **Figure 5.A.2.5-12. Shasta Reservoir Storage (TAF) and Sacramento River Temperatures (°F) at Keswick,**
5 **Bend Bridge, and Hamilton City in November for the EBC2 Climate Change Cases for WY 1922–2003**

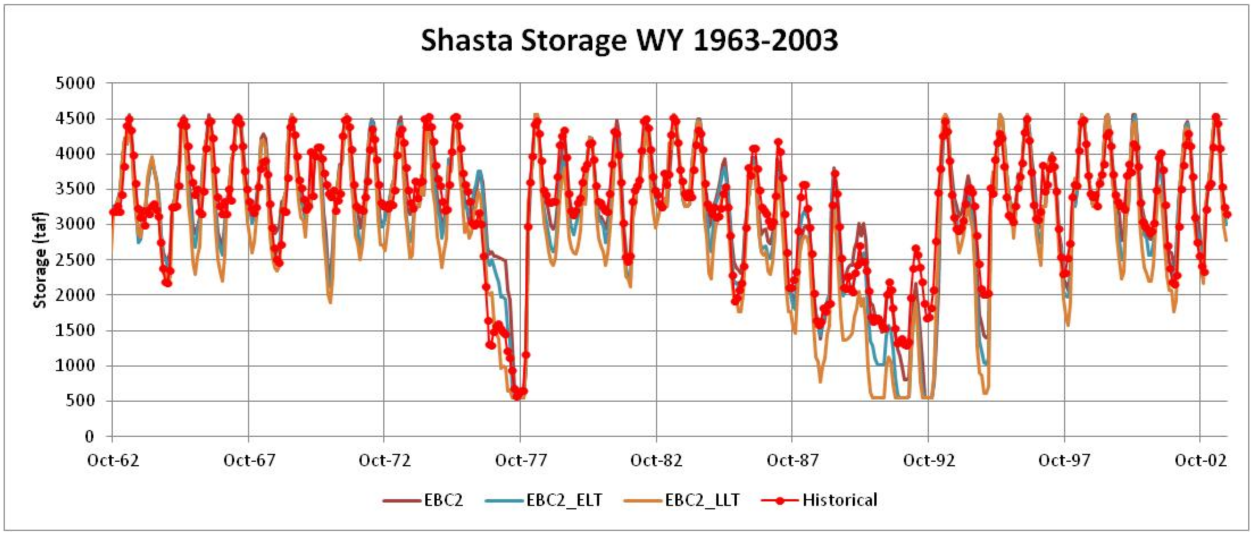


Figure 5.A.2.5-13. Historical and CALSIM-Simulated Shasta Reservoir Storage for the EBC2 Climate Change Cases for WY 1963–2003

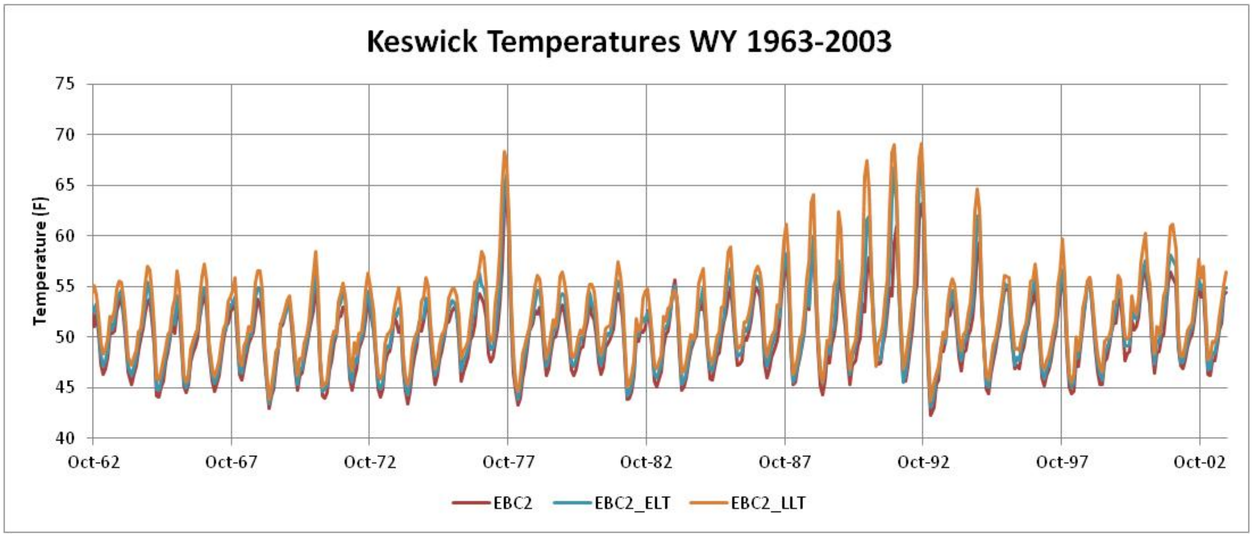


Figure 5.A.2.5-14. SRWQM-Simulated Keswick Reservoir Release Temperature for the EBC2 Climate Change Cases for WY 1963–2003

5.A.2.5.3 Feather River Water Temperatures

The monthly Reclamation water temperature model includes Oroville Reservoir and the Feather River downstream of Oroville Reservoir and the (off-stream) Thermalito Afterbay Reservoir. Oroville Reservoir was built with selective outlets for the power plant, which has two (reversible) pump-turbines. Oroville Reservoir releases water through a main intake structure with adjustable shutters to allow releases from different elevations (temperatures) within the reservoir. The Reclamation temperature model uses target release temperatures to simulate the effects of the shutter elevations on release temperatures (to preserve cool water until August and September). The lowest intake for the power plant is at elevation 615 feet with a minimum storage volume of about 750 TAF (below the outlet).

The Oroville Facilities are operated to meet water temperature objectives at two locations, the intake to the Feather River Fish Hatchery (56°F from September 1 to November 30) and at Robinson Riffle in the low-flow channel, about 5 miles below the Fish Dam (65°F from June 1 to September 30). If temperatures approach the criteria, discontinuing pump-back power operations will reduce the warming in the reservoir. Lowering the intake elevation by removing shutter panels will reduce the release temperature.

Figure 5.A.2.5-15 shows the simulated monthly range of Feather River water temperatures at the Fish Dam (hatchery), at the Thermalito Reservoir release to the Feather River (7 miles downstream from the Fish Dam), and at Gridley (25 miles downstream) for existing conditions (EBC2) for WY 1922–2003. The releases to the Feather River (low-flow channel) between the Fish Dam and the Thermalito Reservoir release locations are a constant flow of about 700–900 cfs. Most of the Oroville release flows are diverted to the Thermalito Forebay and Afterbay Reservoirs and then released to the Feather River about 7 miles downstream. The water temperatures in the low-flow channel portion of the Feather River are almost always less than 60°F, and are less than 55°F in September–November for fall-run spawning and egg incubation. The Feather River temperature criteria are 65°F from June 1 to September 30 in the low-flow channel. This can almost always be satisfied for existing conditions because of the selective withdrawal facilities and because Oroville storage is always maintained above 1,000 TAF. The Thermalito Afterbay has a large surface area of about 5,000 acres with an average depth of about 15 feet, and substantial warming occurs. Therefore, the Feather River water temperatures downstream of the Thermalito Afterbay release (discharge) are 65–70°F in the summer months of June, July, and August. The monthly temperatures at Gridley are similar to the monthly temperatures below the Thermalito Afterbay release because temperatures at both locations are approaching equilibrium temperatures.

Figure 5.A.2.5-16 shows the monthly range of Feather River water temperatures at the Fish Dam, at the Thermalito Reservoir release, and at Gridley for the EBC2_LLT conditions. Fall and winter temperatures at the Fish Dam (hatchery) are warmed in most years relative to existing conditions (EBC2). The target temperatures in the summer are maintained by the adjustable shutters. Downstream temperatures at Thermalito release are generally higher with climate change warming. Water temperatures with climate change conditions at Gridley are similar to the existing water temperatures, which are controlled by meteorological conditions (air temperatures), which are only slightly warmer.

Figure 5.A.2.5-17 shows the monthly Reclamation temperature model results for Feather River temperatures in September at the Fish Dam, above the Thermalito release (Robinson Riffle), and at Gridley in September, plotted against the September Oroville Reservoir storage volume for the three

EBC2 cases. The Fish Dam release temperatures to the low-flow channel (and hatchery) were about 55°F for EBC2 when the September Oroville storage was greater than 1,500 TAF. The Fish Dam temperatures increased from 55°F with a storage volume of 1,500 TAF to about 60°F with a storage volume of 750 TAF. The Fish Dam temperatures for the ELT case (green symbols) were about 1°F warmer, and the release temperatures for the LLT case (purple symbols) were about 2°F warmer. The simulated September temperatures at the downstream end of the low-flow channel (Robinson Riffle—above the afterbay discharge) were about 60°F for Oroville storage volumes of more than 1,000 TAF. This was about 5°F warmer than the release temperatures at the Fish Dam in September. The ELT and LLT September temperatures were 3–5°F warmer than the existing condition temperatures at Robinson Riffle. The September temperatures at Gridley were generally warmer than the temperatures above the Thermalito release, ranging from 60 to 70°F. The simulated ELT and LLT temperatures were somewhat warmer and more variable at this downstream location, ranging 65–75°F in September. The effects of meteorology and flow in the Feather River were more variable than for the Sacramento River because the range of simulated September Feather River temperatures at Gridley (60–70°F) was greater than the 5°F range of simulated Sacramento River temperatures at Hamilton City.

Figure 5.A.2.5-18 shows the monthly Reclamation temperature model results in October at the Fish Dam, upstream of the Thermalito Afterbay release, and at Gridley, plotted against the October Oroville Reservoir storage volume for the three EBC2 climate change cases. The baseline Fish Dam temperatures (brown symbols) were less than 55°F for Oroville storage volume greater than 1,000 TAF, and increased to 60°F (or more) with a simulated Oroville storage volume of 750 TAF. The simulated Fish Dam October temperatures for the ELT cases (green symbols) were similar to the baseline temperatures, but the simulated LLT temperatures were 2–4°F warmer than the baseline temperatures when the Oroville storage volume was less than 1,500 TAF. The water temperatures upstream of Thermalito (Robinson Riffle) were increased by only 1–2°F because the equilibrium temperatures (60–65°F) were not much higher than the release temperatures in October. Water temperatures at Robinson Riffle were less than 60°F for Oroville storage volume of more than 1,000 TAF for the baseline and ELT cases. Some temperatures higher than 60°F were simulated for the LLT case even when storage volume was greater than 1,000 TAF. All cases showed increased October temperatures when the Oroville storage volume was less than 1,000 TAF. Water temperatures at Gridley in October ranged from 55 to 60°F unless the reservoir storage was less than 1,000 TAF. The ELT temperatures at Gridley were 1–3°F warmer, and the LLT temperatures at Gridley were 2–5°F warmer than EBC2.

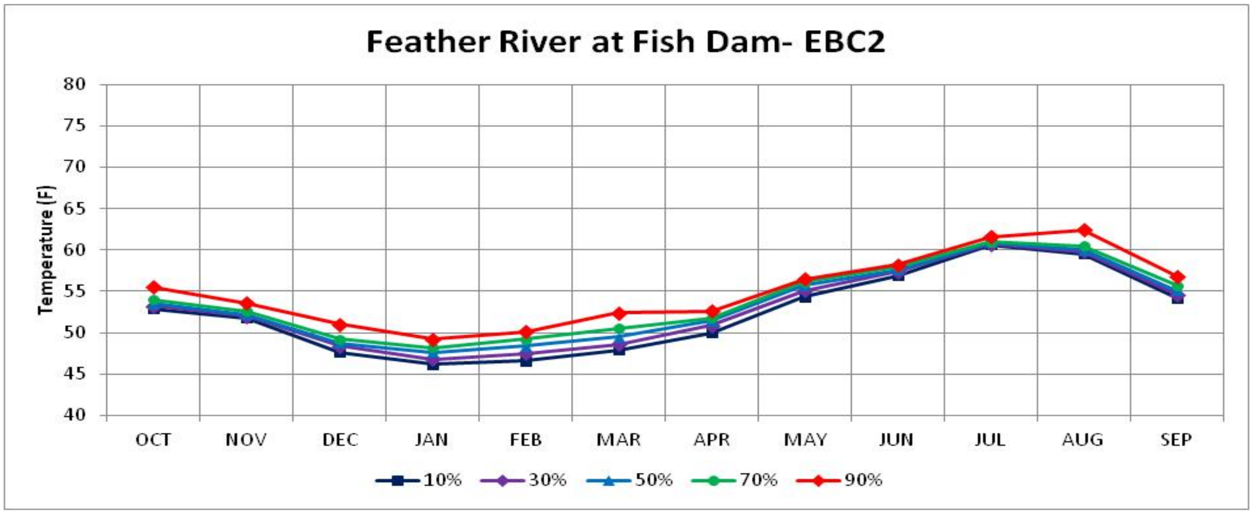
Figure 5.A.2.5-19 shows the monthly Reclamation temperature model results in November at the Fish Dam, upstream of the Thermalito Afterbay release, and at Gridley, plotted against the November Oroville Reservoir storage volume for the three EBC2 climate change cases. The Fish Dam baseline temperatures (brown symbols) were about 50–55°F for Oroville storage volume greater than 1,000 TAF, and increased to about 60°F with an Oroville storage volume of 750 TAF. The simulated November temperatures for the ELT case (green symbols) were similar to the baseline temperatures, but the simulated LLT temperatures were 5–7°F warmer than the baseline temperatures when the Oroville storage volume was less than 2,000 TAF. The water temperatures upstream of the Thermalito Afterbay release (Robinson Riffle) were increased only by 1–2°F because the equilibrium temperatures (60–65°F) were not much higher than the release temperatures in November. Water temperatures at Robinson Riffle were less than 60°F for Oroville storage volume more than 1,000 TAF for the baseline and ELT cases. Some temperatures higher than 60°F were simulated for the LLT case even when storage volume was greater than 1,000 TAF.

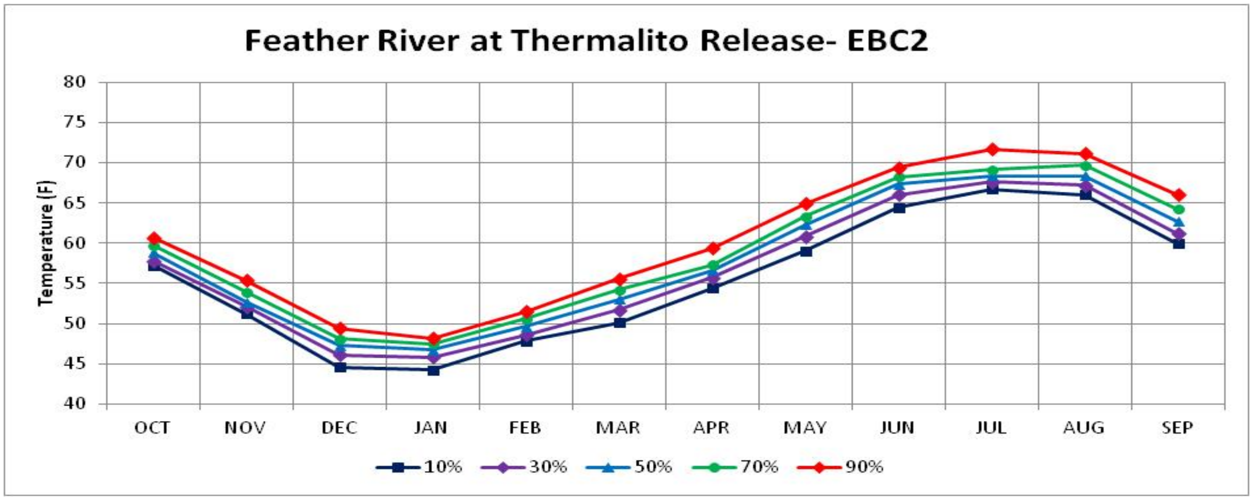
All cases showed increased November temperatures with an Oroville storage volume less than 1,000 TAF.

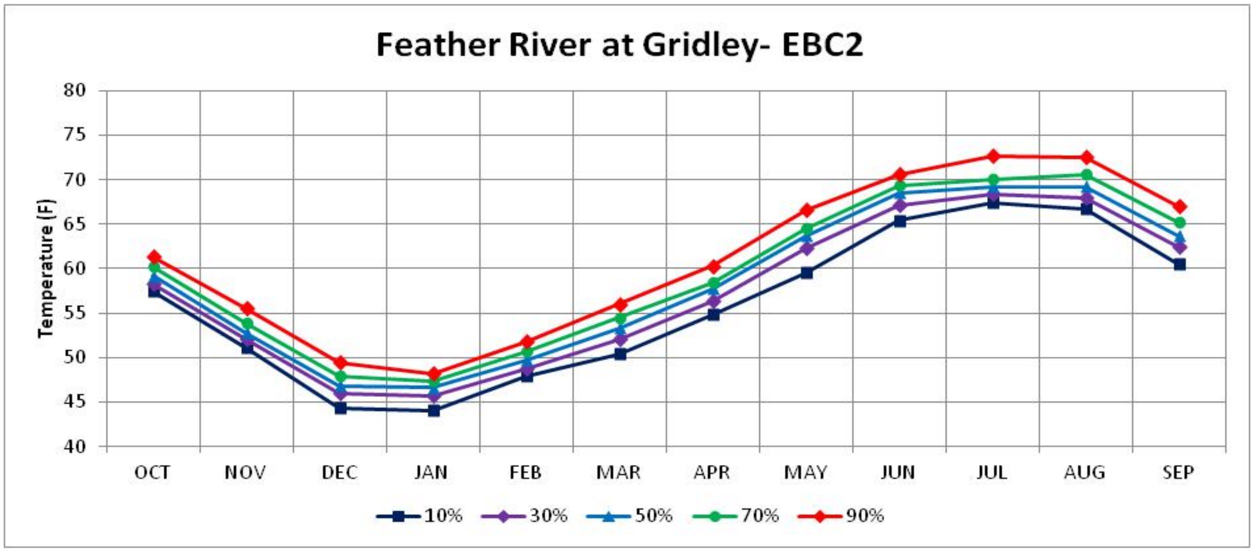
The simulated effects of climate change (warming) increased the Oroville Reservoir release temperatures in the months of October and November. The simulated October Fish Dam release temperatures to the low-flow channel were generally less than the 56°F temperature criteria, except for years when the Oroville Reservoir storage volume was less than 1,000 TAF. The simulated Fish Dam release temperatures in October were often 2–5°F warmer for the LLT cases. The simulated November temperatures for the baseline and ELT cases were less than 56°F in the low-flow channel, except when the Oroville storage volume was less than 1,000 TAF. The November temperatures for the LLT were often higher than 56°F when the storage volume was less than 2,000 TAF. The 56°F temperature criteria at the Feather River hatchery and in the low-flow channel would be satisfied in most years in October and November if the Oroville Reservoir storage was greater than 1,000 TAF.

Figure 5.A.2.5-20 shows the historical Oroville Reservoir storage volumes for WY 1962–2010 along with the simulated Oroville Reservoir storage for the three EBC2 climate change cases. The historical operations reduced the Oroville Reservoir storage volume to slightly less than 1,000 TAF only in 1977 and 1991. The years with simulated storage less than 1,000 TAF had higher Fish Dam release temperatures in September, October, and November.

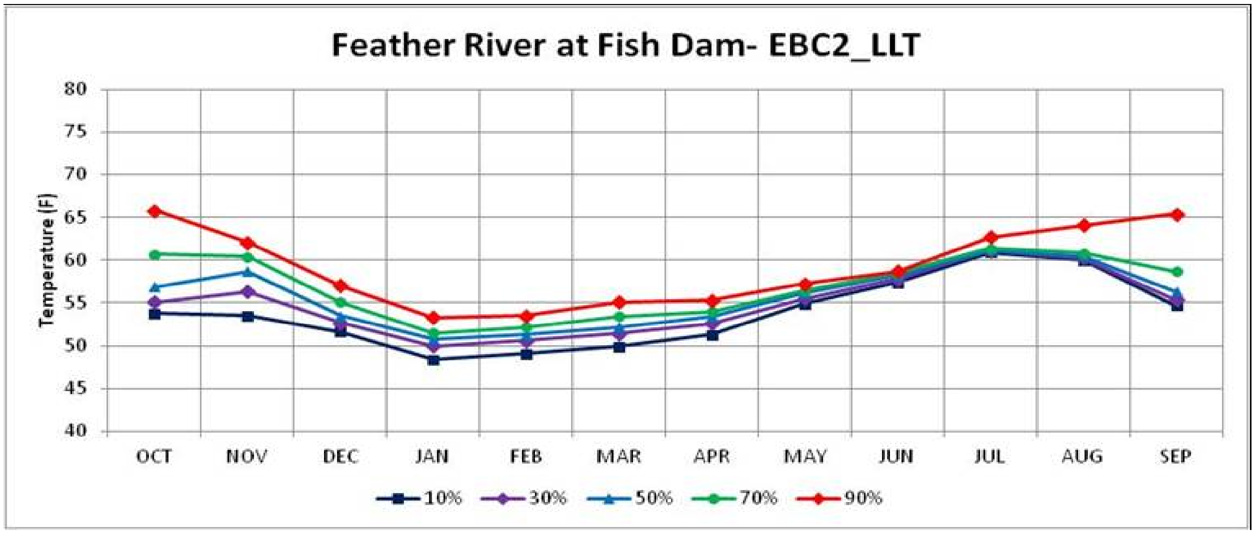
Figure 5.A.2.5-21 shows Reclamation temperature model results for the Feather River at the Fish Dam for the EBC2 climate change cases for WY 1963–2003. The seasonal pattern of Oroville Reservoir release temperatures is very similar each year. Because the simulated carryover storage for the existing conditions was almost always above 1,000 taf, the maximum simulated Feather River temperatures at the Fish Dam remained less than 60°F. Because the simulated carryover storage for the climate change cases would be less than 1,000 taf in more years, the Fish Dam temperatures were increased to 65°F in several more years.

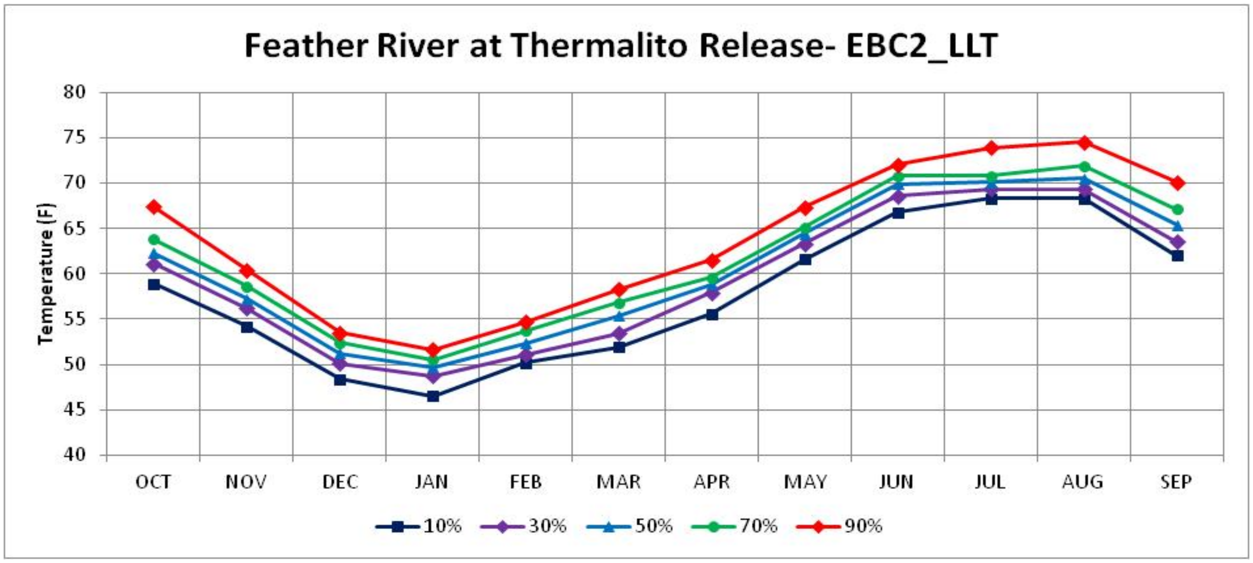
1 

2 

3 

4 **Figure 5.A.2.5-15. Reclamation Temperature Model Monthly Temperature Ranges for Feather River at**
5 **the Fish Dam, Thermalito Afterbay Release, and Gridley for WY 1922–2003 for EBC2**





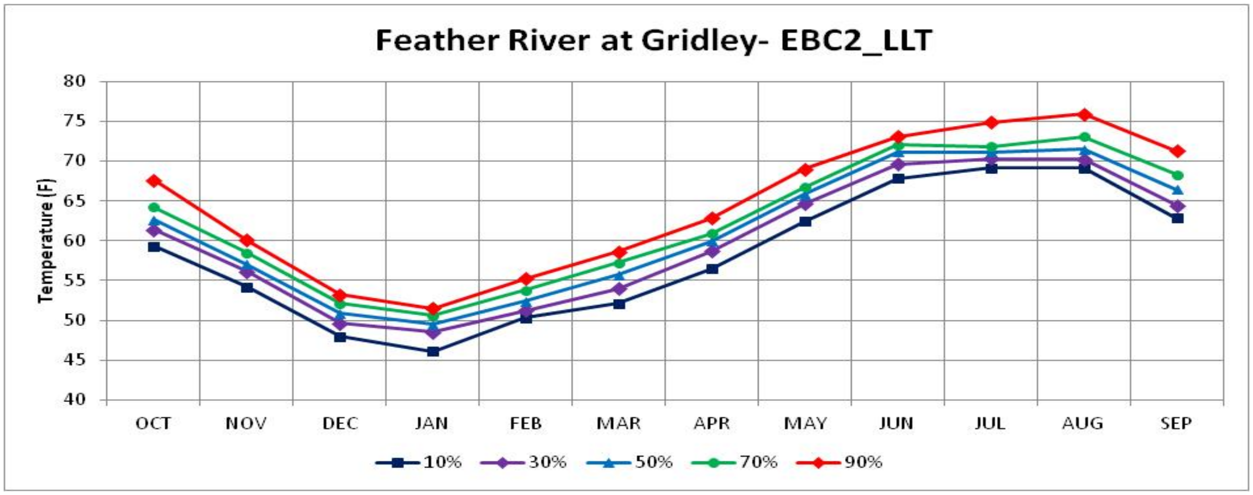
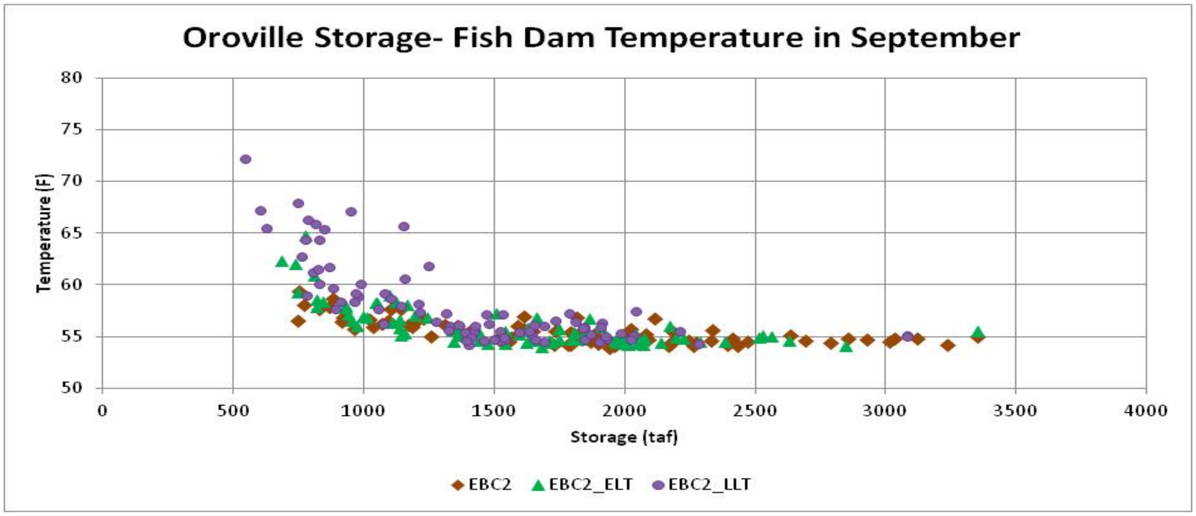
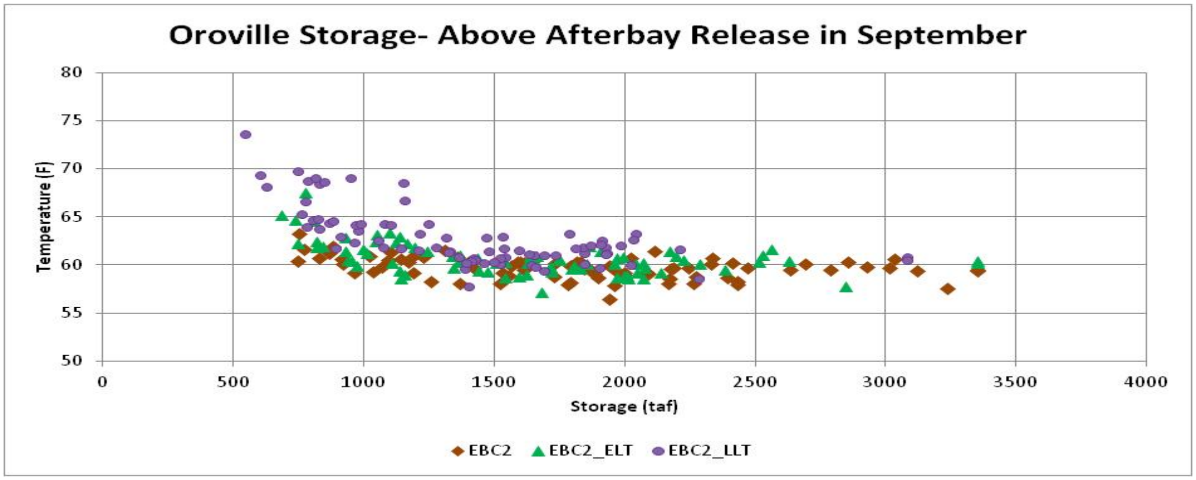


Figure 5.A.2.5-16. Reclamation Temperature Model Monthly Temperature Ranges for Feather River at the Fish Dam, Thermalito Afterbay Release, and Gridley for WY 1922–2003 for EBC2_LLT





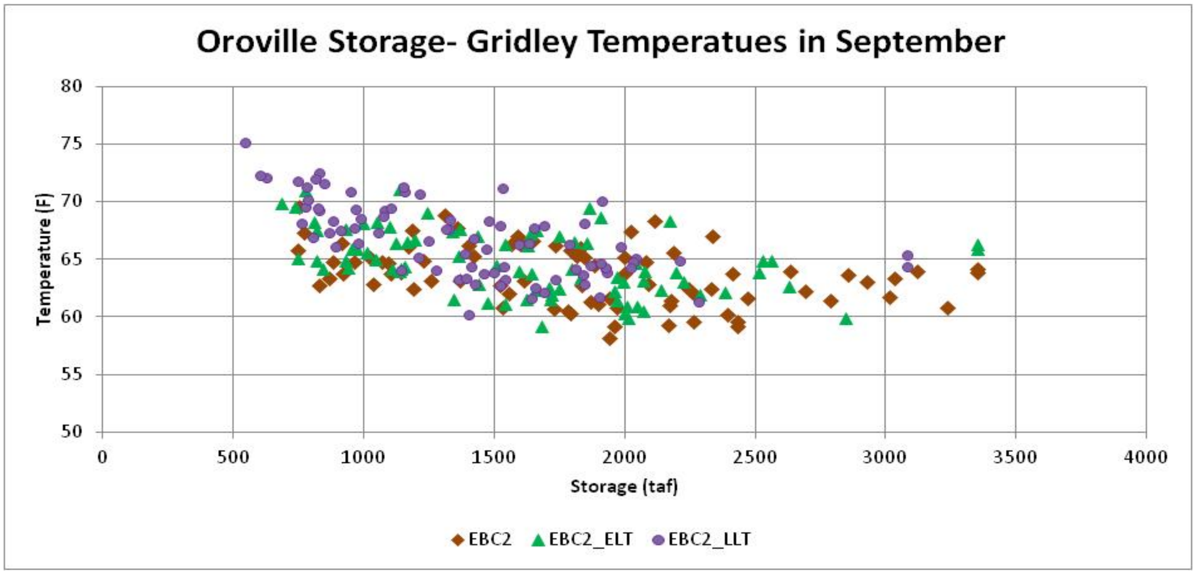


Figure 5.A.2.5-17. Oroville Reservoir Storage (TAF) and Feather River Temperatures (°F) at the Fish Dam, upstream of Thermalito Release (Robinson Riffle), and Gridley in September for the EBC2 Climate Change Cases for WY 1922–2003

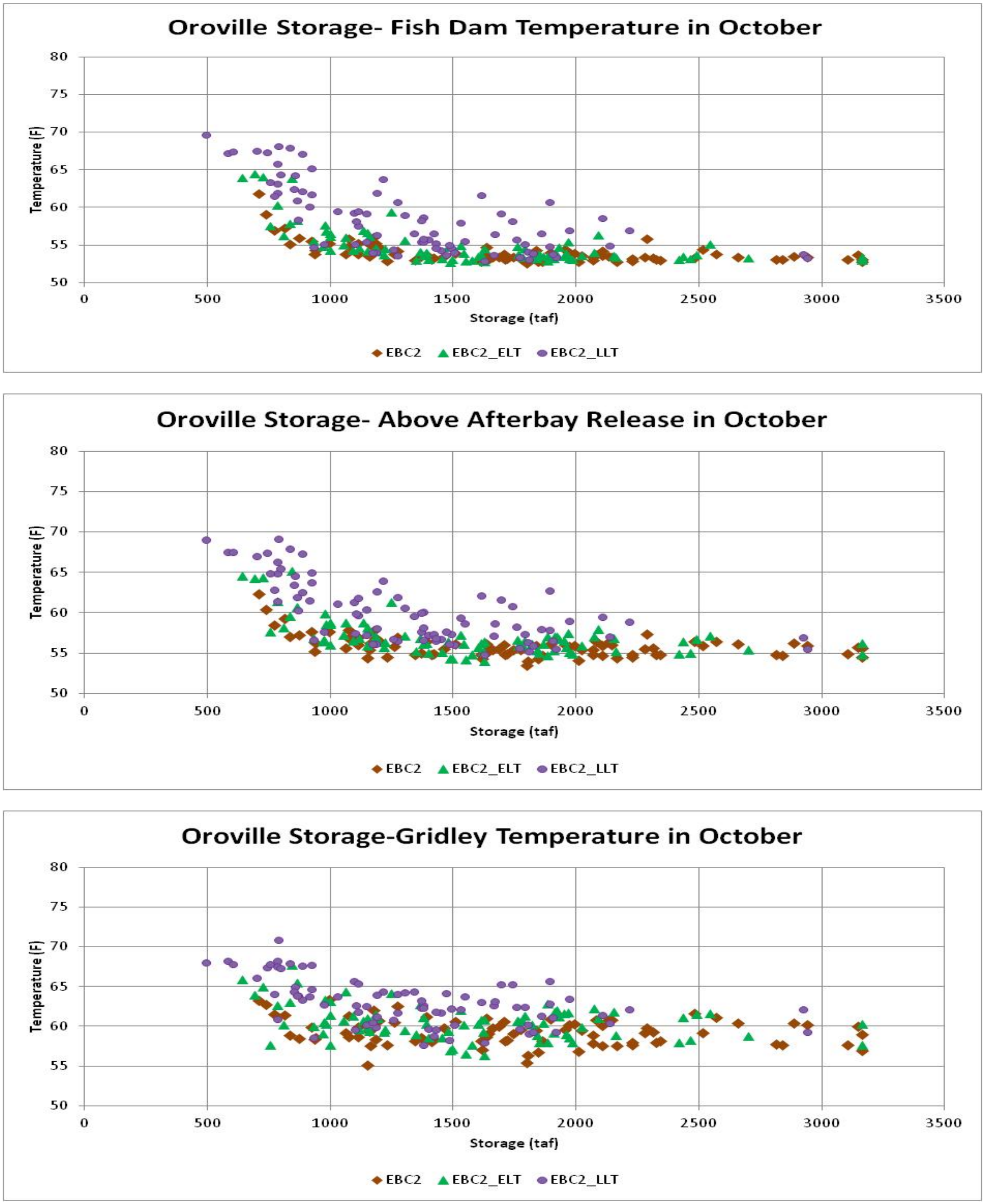
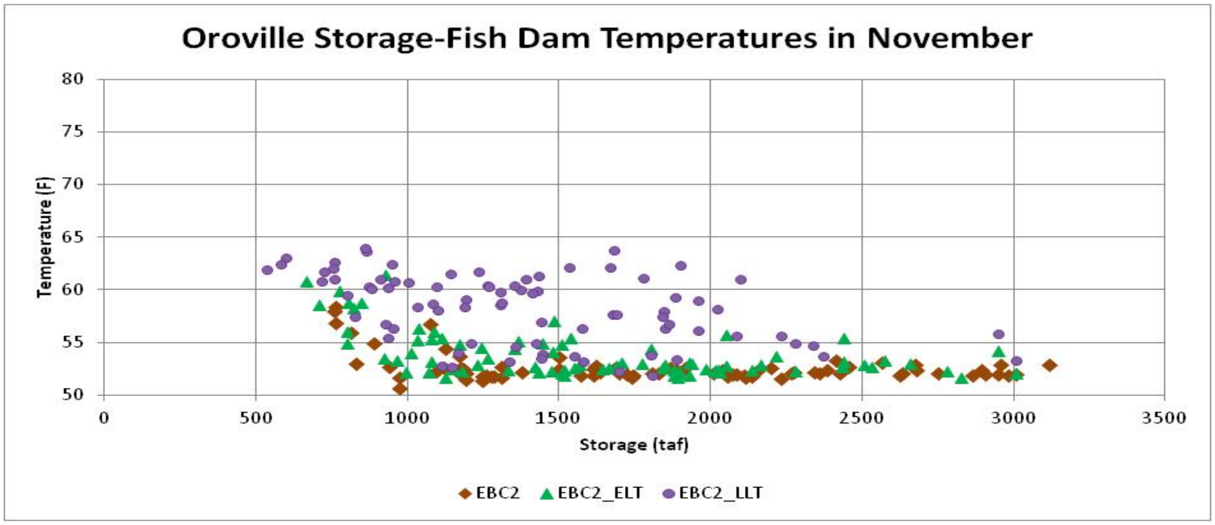
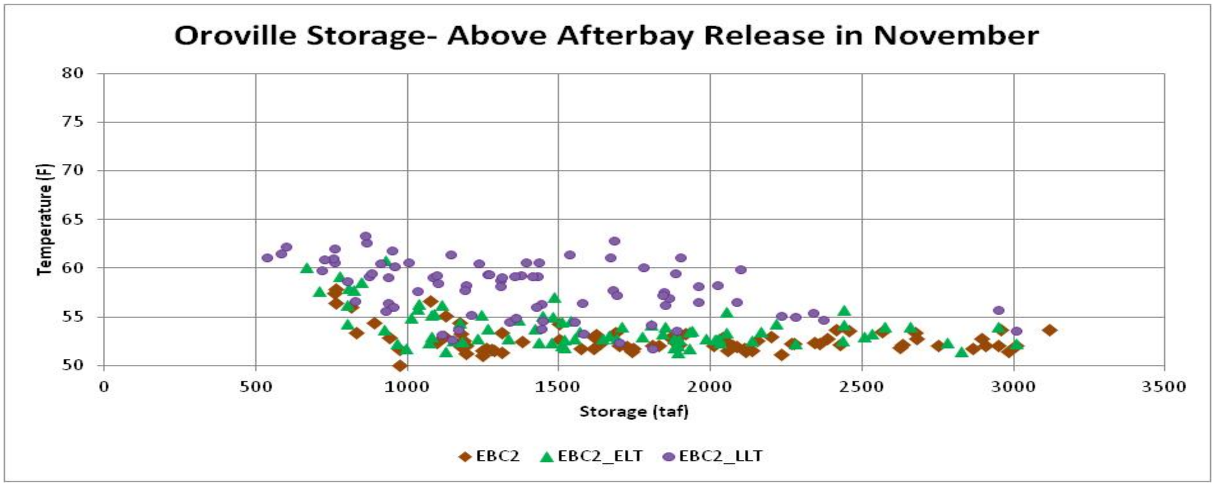


Figure 5.A.2.5-18. Oroville Reservoir Storage (TAF) and Feather River Temperatures (°F) at the Fish Dam, upstream of Thermalito Release (Robinson Riffle), and Gridley in October for the EBC2 Climate Change Cases for WY 1922–2003





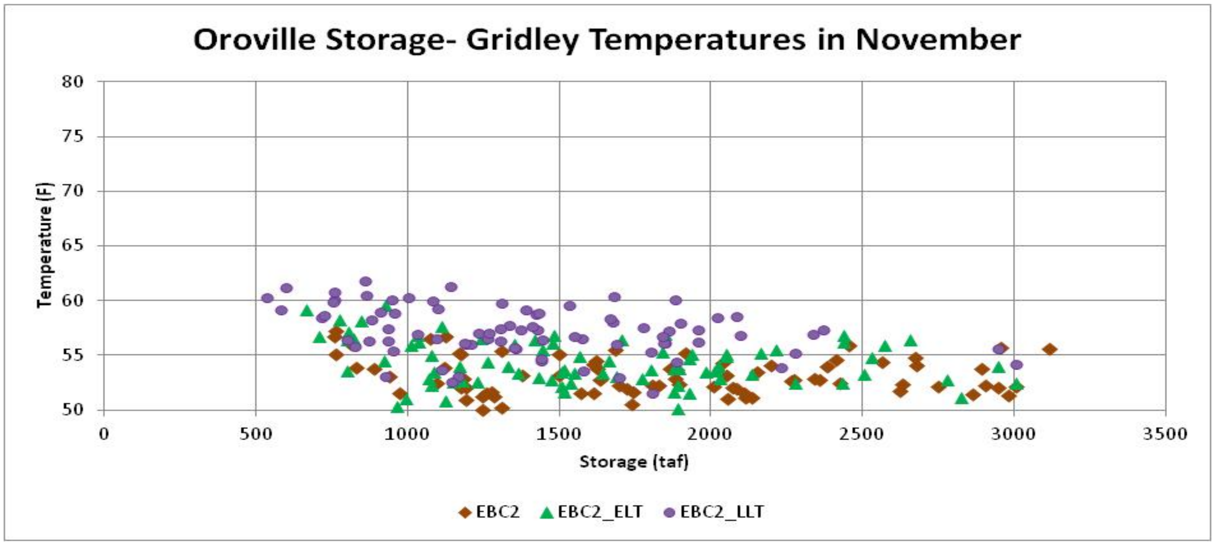


Figure 5.A.2.5-19. Oroville Reservoir Storage (TAF) and Feather River Temperatures (°F) at the Fish Dam, upstream of Thermalito Release (Robinson Riffle), and Gridley in November for the EBC2 Climate Change Cases for WY 1922–2003

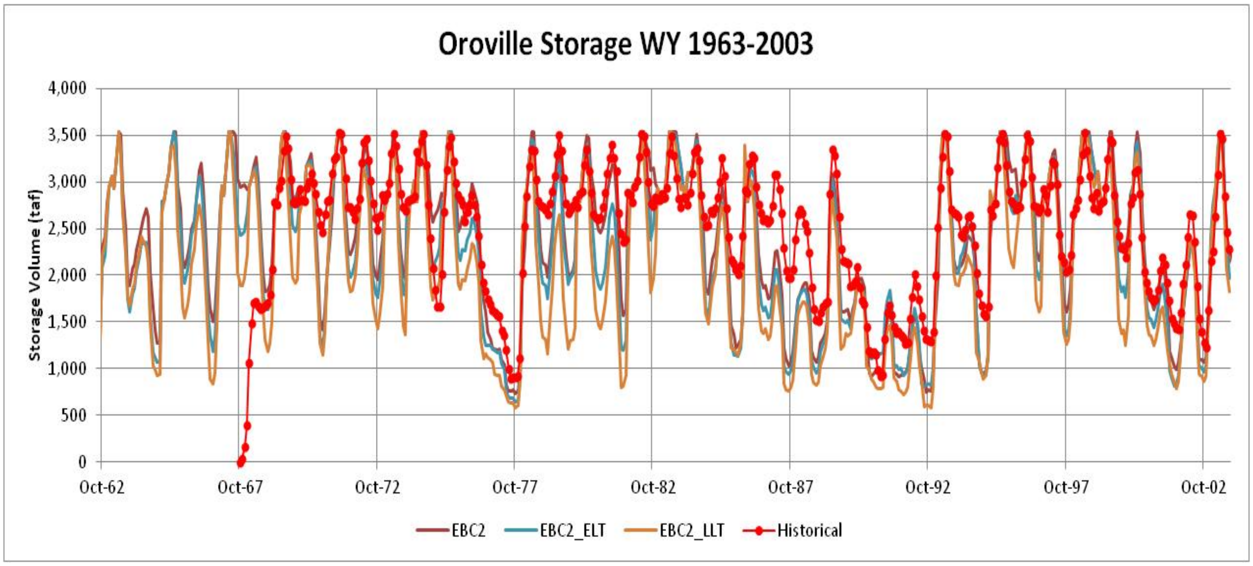


Figure 5.A.2.5-20. Historical and CALSIM-Simulated Oroville Reservoir Storage for the EBC2 Climate Change Cases for WY 1963–2003

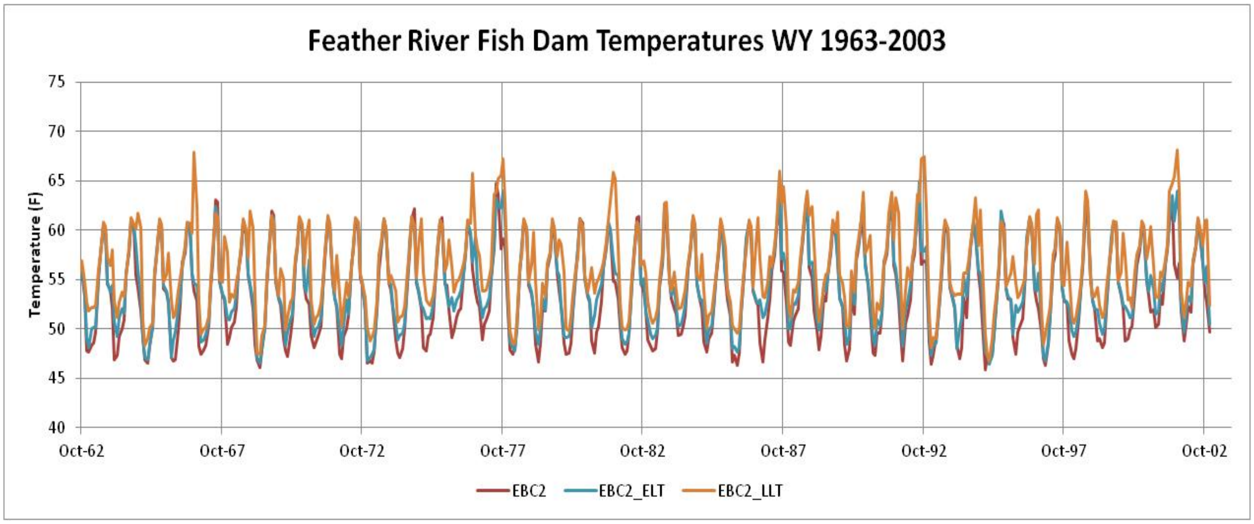


Figure 5.A.2.5-21. Reclamation Temperature Model Results for the Feather River at the Fish Dam for the EBC2 Climate Change Cases for WY 1963–2003

5.A.2.5.4 American River Water Temperatures

The monthly Reclamation water temperature model includes Folsom Reservoir, Lake Natoma, and the American River downstream of Nimbus Dam. Folsom Reservoir has outlet panels that can be raised to allow releases from lower in the water column as the reservoir is drawn down in the summer. This allows limited selective withdrawal for temperature control. These panels extend from the bottom of the trash rack at elevation 285 feet to 400 feet. The panels have been modified in recent years to allow easier and more flexible operation. The Reclamation temperature model uses target release temperatures to simulate the effects of the outlet panels on release temperatures (to preserve some cool water until August and September). The maximum storage is about 975 TAF at elevation of 470 feet msl. The penstock centerline elevation is 307 feet with a volume of about 50 TAF below the power plant outlet. Folsom reservoir is operated to meet water temperature objectives at the Watt Avenue Bridge, about 13 miles downstream from Nimbus Dam (68°F from June 1 to September 30). The Nimbus hatchery is located at Nimbus Dam and generally opens the fish ladder when temperatures cool to 60°F.

Figure 5.A.2.5-22 shows the simulated monthly range of American River water temperatures at Folsom Dam, Nimbus Dam (hatchery), and the Watt Avenue Bridge for existing conditions (EBC2) for WY 1922–2003. The American River temperatures are warmest in July, August, and September. Steelhead rearing temperatures are generally 65–70°F in these months. Spawning temperatures for fall-run Chinook salmon of less than 60°F are not likely until November. Although the effects of the temperature control panels are simulated using target release temperatures of 65°F in June, July, and August, the amount of cold water in Folsom Reservoir is limited by the summer drawdown of this relatively shallow reservoir (maximum depth of 250 feet, 150 feet above the penstock outlet). Warming of 2–5°F is simulated between Folsom Dam and Nimbus Dam in the summer months. Additional warming of 2–3°F is simulated downstream to the Watt Avenue Bridge in the spring and summer months. Figure 5.A.2.5-23 shows the simulated monthly range of American River water temperatures at Folsom Dam, Nimbus Dam, and the Watt Avenue Bridge for the LLT conditions (EBC2_LLT). These results indicate that Nimbus Dam release temperatures would be 5°F warmer for the EBC2_LLT conditions in September, October, and November.

Figure 5.A.2.5-24 shows the monthly Reclamation temperature model results for Folsom Dam, Nimbus Dam, and Watt Avenue in September, plotted against the September Folsom Reservoir storage volume for the EBC2 climate change cases. The existing Folsom Dam temperatures (brown symbols) were less than 65°F with a storage volume of 300 TAF and increased to about 70°F with a storage volume of 100 TAF. The existing Nimbus Dam release temperatures (brown symbols) increased from 65°F with a storage volume of 500 TAF to about 70°F with a storage volume of 200 TAF. The existing Watt Avenue temperatures were more variable because of downstream heating that varied with the Nimbus flow. The existing Watt Avenue temperatures were 65–70°F when the storage was greater than 500 TAF and were warmer than 70°F in years when the storage was less than 300 TAF (likely lower release flows in these years). The September temperatures at Folsom Dam for the ELT conditions (green symbols) were similar (65°F) for Folsom storage greater than 500 TAF, and similar (warming to 70°F) for storage of 200 TAF. The September Nimbus Dam temperatures for the LLT conditions (purple symbols) were similar (65°F) for storage of greater than 500 TAF but were much warmer (70–75°F) in many of the years with storage of less than 400 TAF. The temperatures at Nimbus Dam (hatchery) and at Watt Avenue reflect these same climate change effects on higher water temperatures. The only remedy for these simulated climate change effects on downstream water temperatures would appear to be higher carryover storage, which would reduce the water supply benefits of Folsom Reservoir.

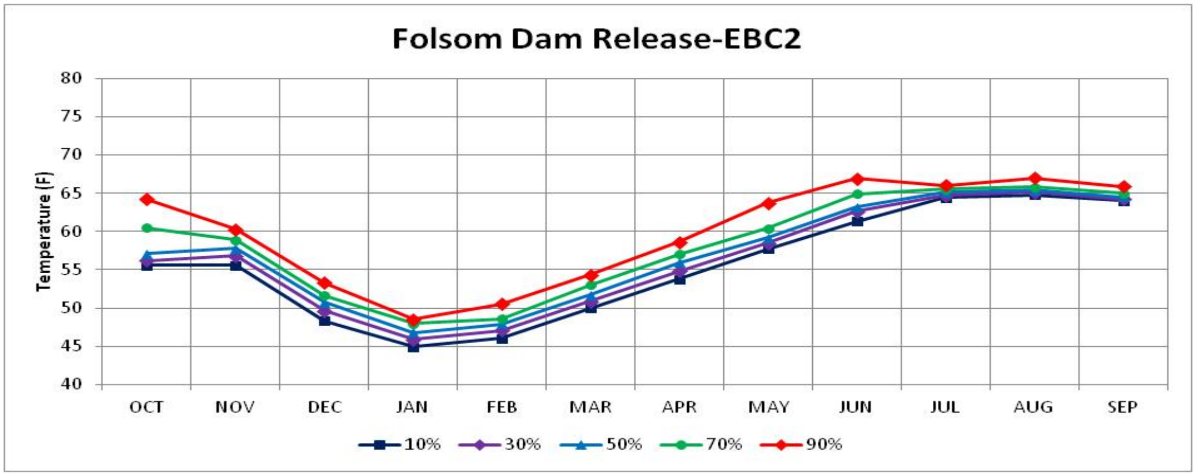
Figure 5.A.2.5-25 shows the monthly Reclamation temperature model results for Folsom Dam, Nimbus Dam, and Watt Avenue in October, plotted against the September Folsom Reservoir storage volume for the EBC2 climate change cases. The October Nimbus Dam temperatures for existing conditions (brown symbols) were less than 60°F with a storage volume greater than 500 TAF and increased to 65°F at a storage volume of 300 TAF. The October Nimbus Dam temperatures for the ELT conditions (green symbols) were 2–5°F warmer for storage of 300–600 TAF, similar (60°F) for storage greater than 600 TAF, and similar (65°F) for storage less than 300 TAF. The October Nimbus Dam temperatures for the LLT conditions (purple symbols) were 5–10°F warmer for all Folsom storage volumes. The maximum October release temperatures for the LLT (70°F) were about 5°F

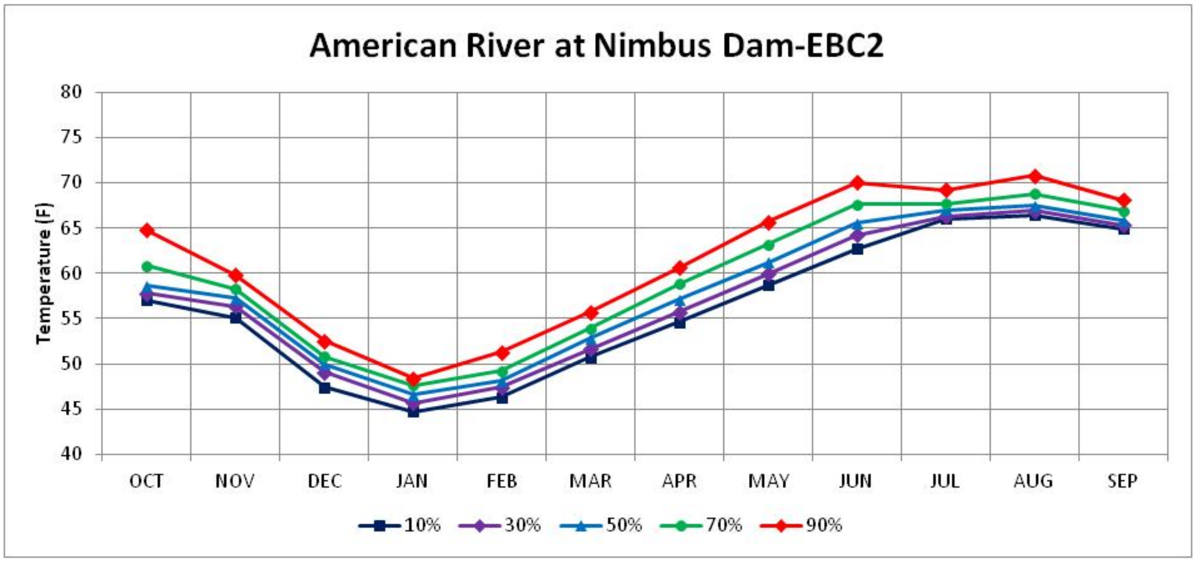
warmer than the maximum baseline temperatures of 65°F. The simulated effects of climate change (LLT) on Nimbus Dam release temperatures were therefore about 5°F in September and 10°F in October.

Figure 5.A.2.5-26 shows the warming in Lake Natoma and downstream in the American River at Watt Avenue in September for existing conditions (EBC2) and climate change conditions (EBC2_LLT). The temperatures at Folsom Dam, Nimbus Dam, and the Watt Avenue Bridge are shown, plotted against the Nimbus release flow (cfs). In September, most of the Folsom release temperatures for existing conditions were about 65°F. The warming was greatest at lower flows (1,000 cfs) when the travel time to Nimbus Dam was about 5 days. Warming from Nimbus Dam to Watt Avenue was relatively small because the equilibrium temperature was also about 70°F in September. There was not much warming because the Folsom release temperatures were similar to the equilibrium temperatures. In September, the Folsom release temperatures for the EBC2_LLT case ranged from 65 F to 75°F (10°F warmer than existing conditions). The warming was greatest for the coolest release temperatures. The EBC2_LLT release flows were generally 1,500 cfs or lower in September.

Figure 5.A.2.5-27 shows the warming in Lake Natoma and the American River in October for existing conditions (EBC2) and climate change conditions (EBC2_LLT). In October, the EBC2 Folsom release temperatures ranged from 55°F to 65°F. The majority of years were simulated with a release flow of 1,500 cfs. In October, the EBC2_LLT Folsom release temperatures ranged from 60°F to 70°F, about 5°F warmer than the existing temperatures. There was a slight cooling in most years because the release temperatures were higher than the October equilibrium temperatures. The Folsom temperatures were simulated to increase more than any other reservoir because of the very limited cold water storage and very low carryover storage in most years.

Figure 5.A.2.5-28 shows the historical Folsom Reservoir storage volumes for WY 1962–2010 along with the simulated Folsom Reservoir storage for the EBC2 climate change cases. The historical operations reduced the Folsom Reservoir storage volume to less than 200 TAF in 1977, in several of the years from 1988–1994, and in 2007–2008. Figure 5.A.2.5-29 shows the simulated Folsom Reservoir release temperatures for the EBC2 climate change cases for WY 1962–2003. The years with simulated storage of less than 300 TAF had Folsom Reservoir release temperatures greater than 70°F in September and October. Climate change effects on runoff and sea level rise will tend to reduce the Folsom Reservoir storage and thereby increase the Folsom Reservoir release temperatures in many years.





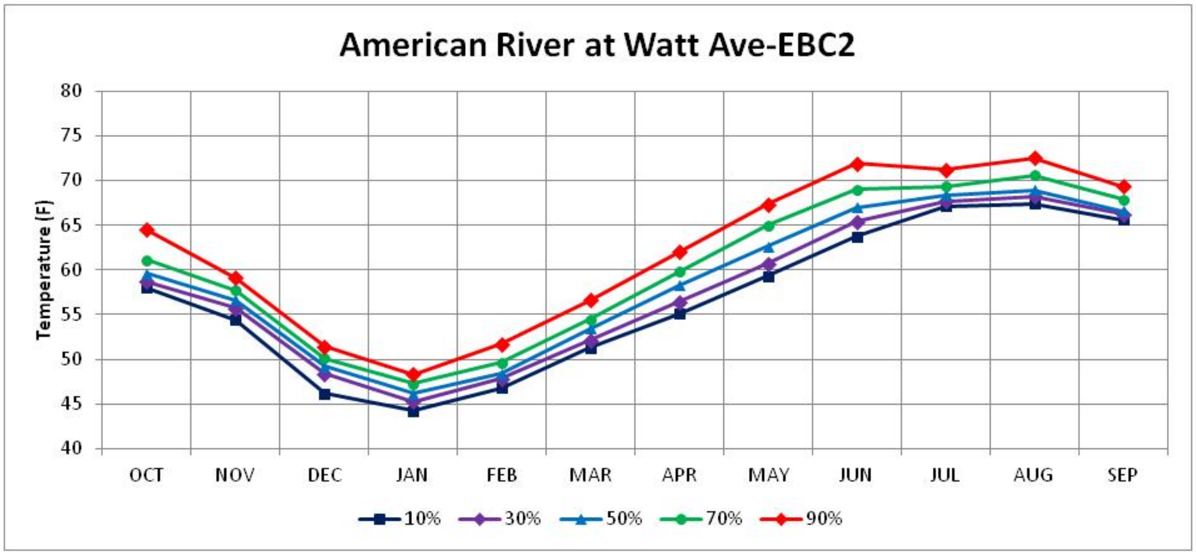
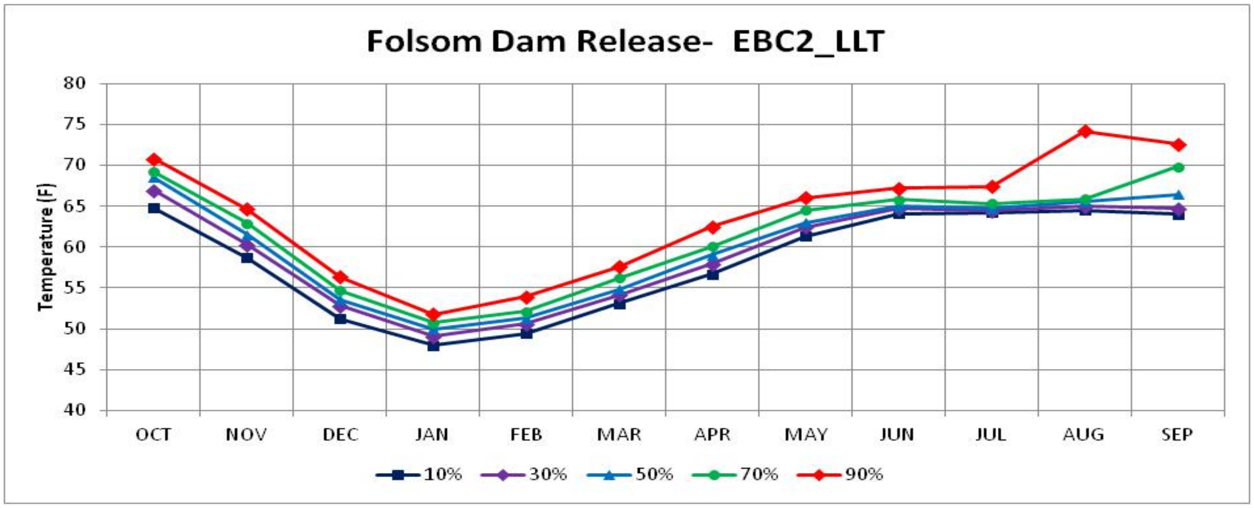
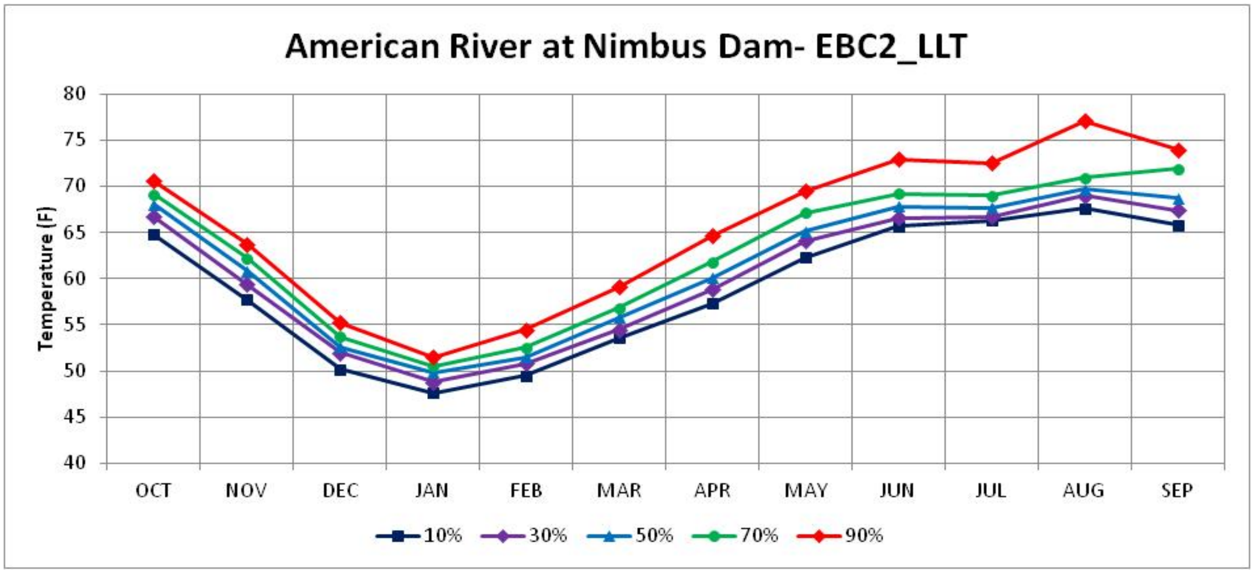


Figure 5.A.2.5-22. Reclamation Temperature Model Monthly Temperature Ranges for American River at Folsom Dam, Nimbus Dam, and Watt Avenue Bridge for WY 1922–2003 for EBC2





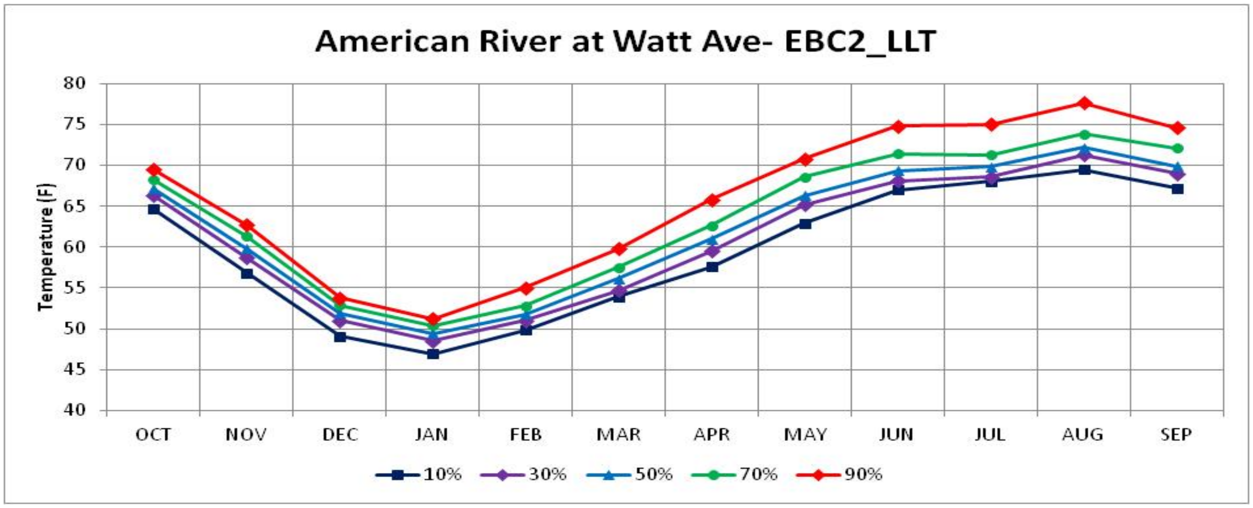
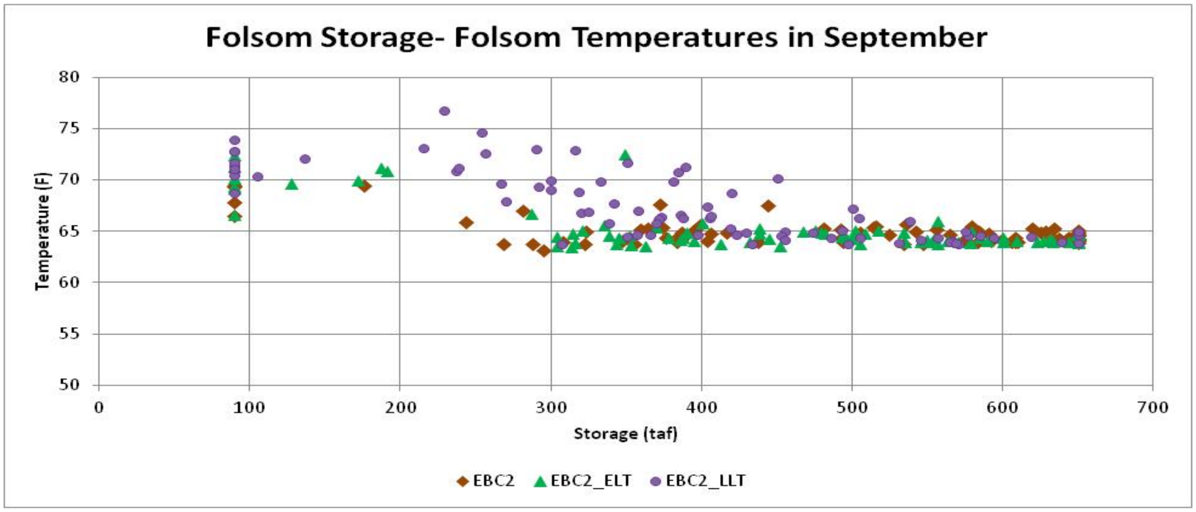
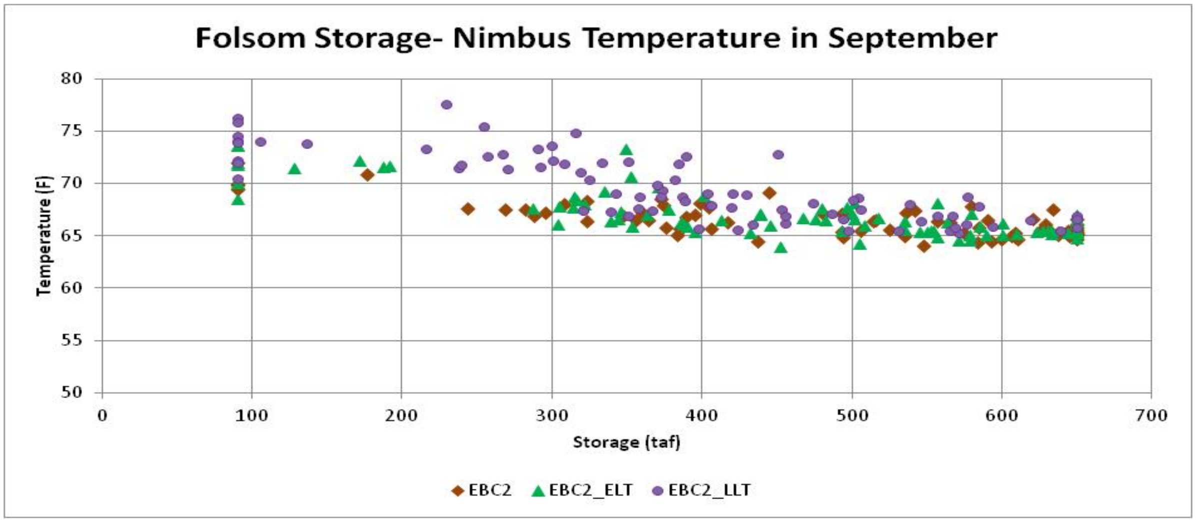


Figure 5.A.2.5-23. Reclamation Temperature Model Monthly Temperature Ranges for American River at Folsom Dam, Nimbus Dam, and Watt Avenue Bridge for WY 1922–2003 for EBC2_LLT





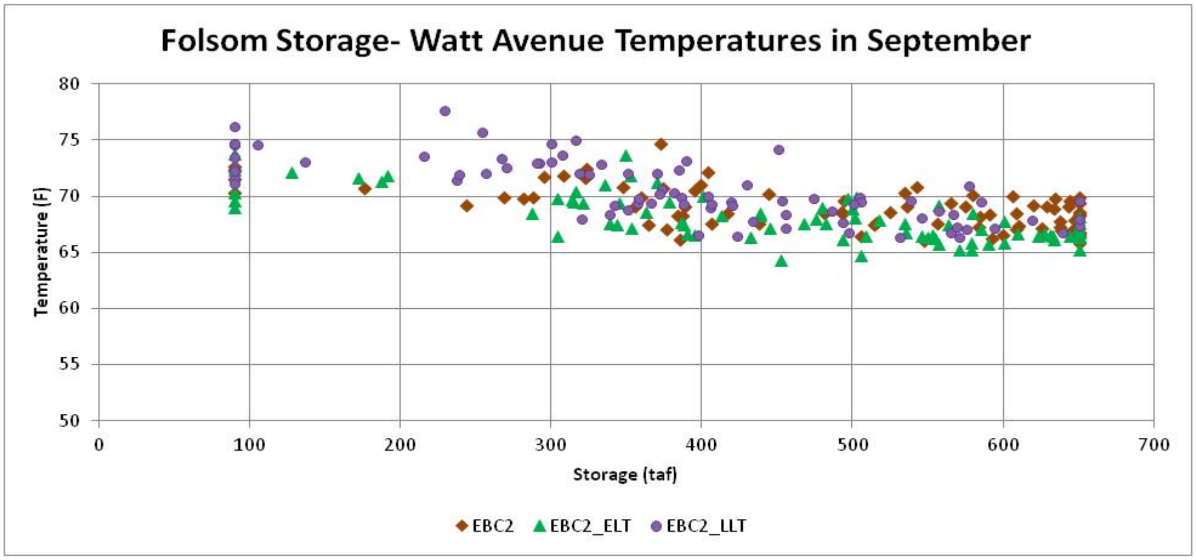
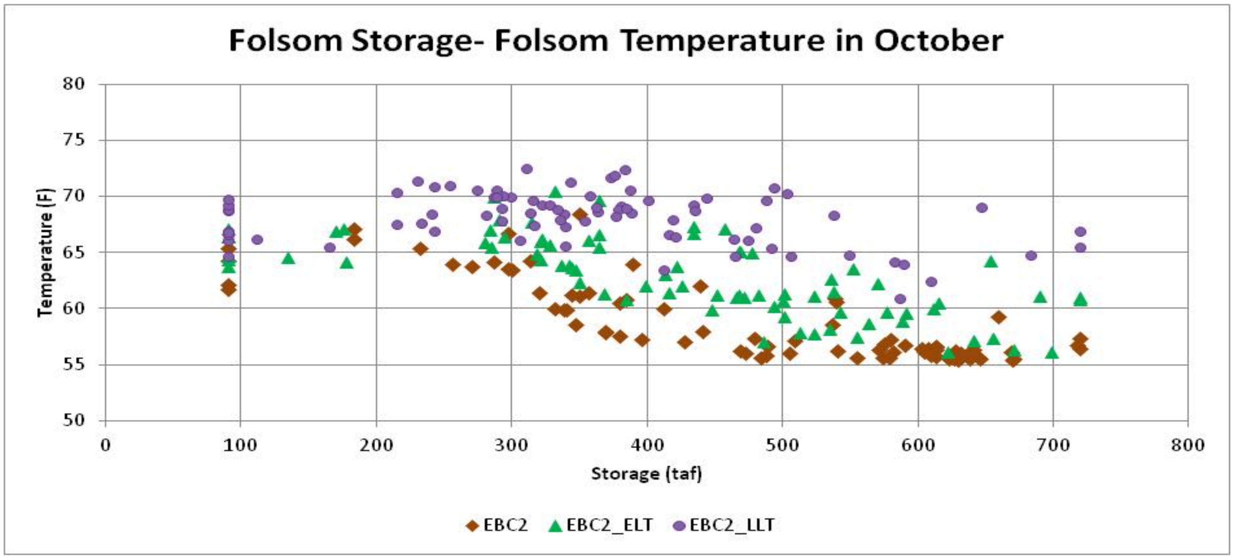
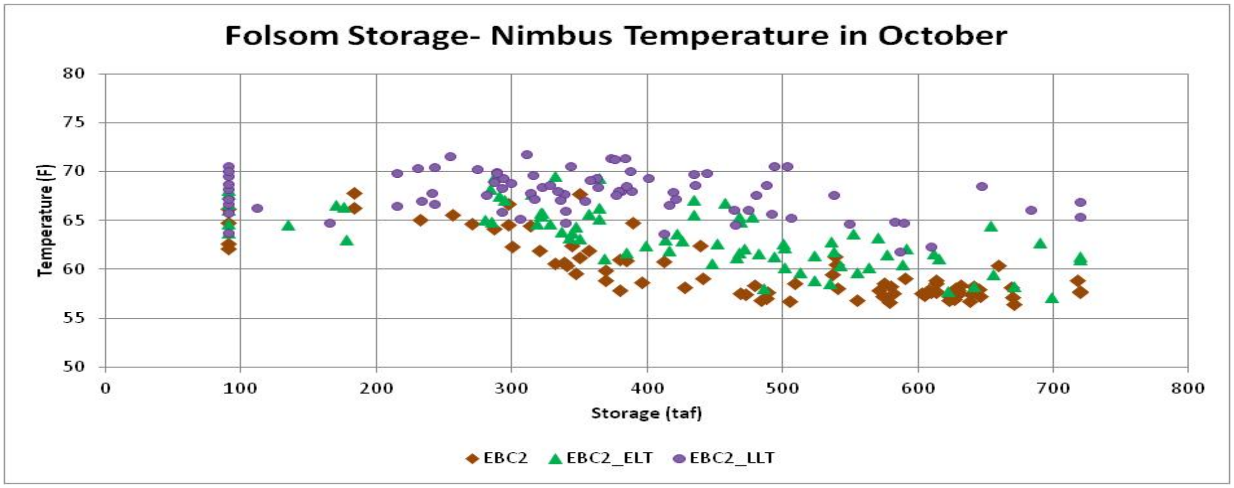


Figure 5.A.2.5-24. Folsom Reservoir Storage (TAF) and Temperatures (°F) in September at Folsom Dam, Nimbus Dam, and Watt Avenue for the EBC2 Climate Change Cases for WY 1922–2003





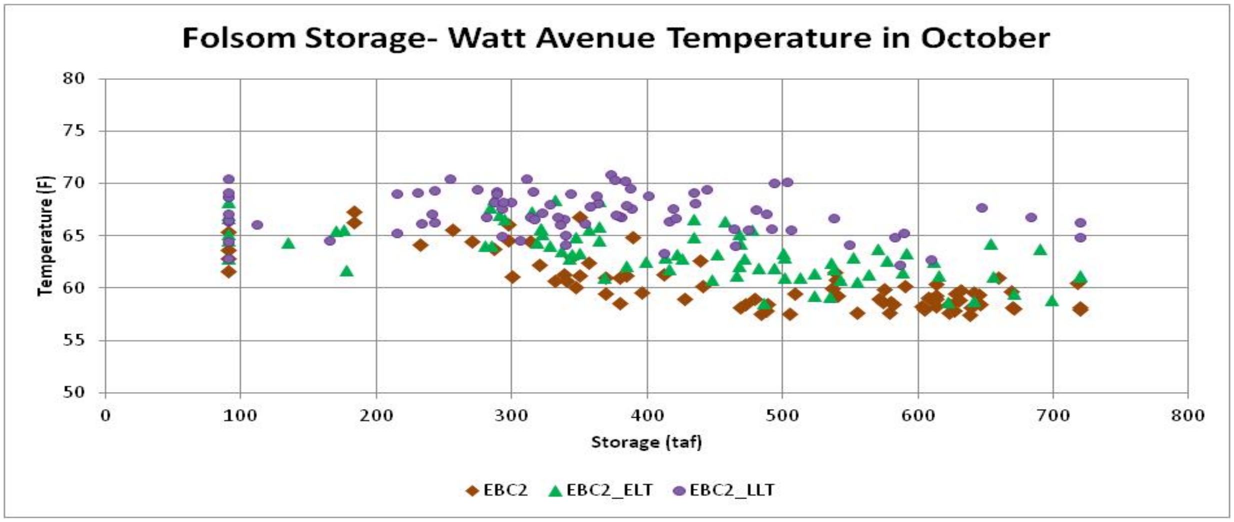
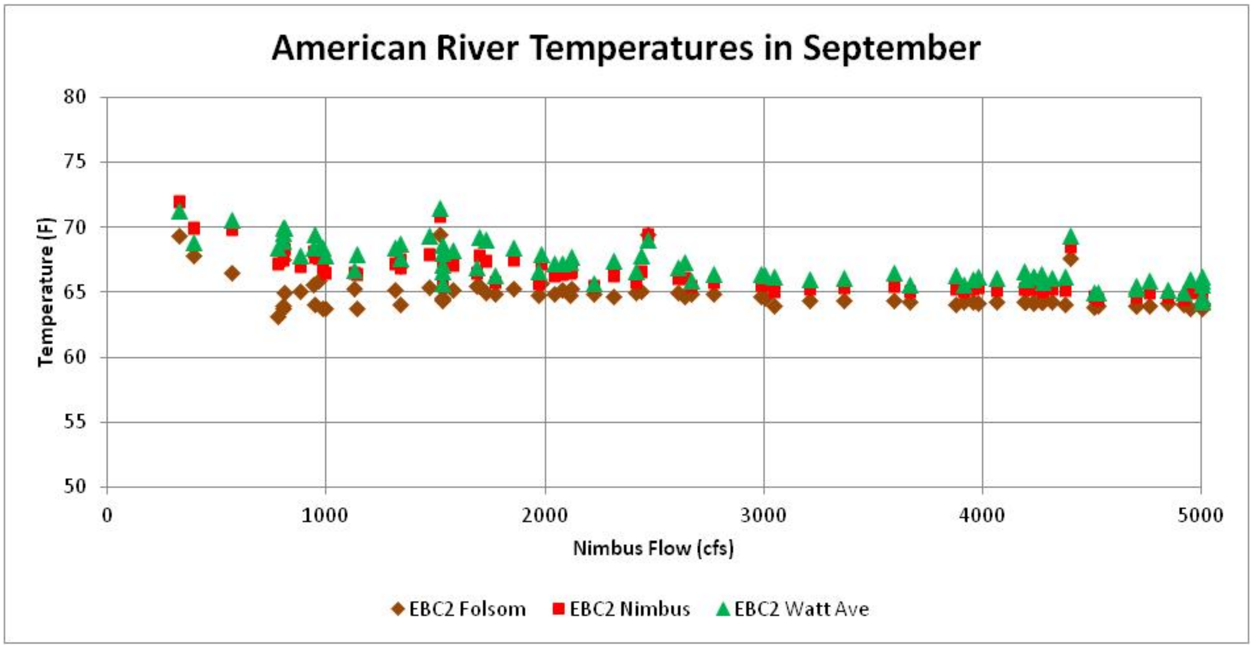


Figure 5.A.2.5-25. Folsom Reservoir Storage (TAF) and Temperatures (°F) in October at Folsom Dam, Nimbus Dam, and Watt Avenue for the EBC2 Climate Change Cases for WY 1922–2003



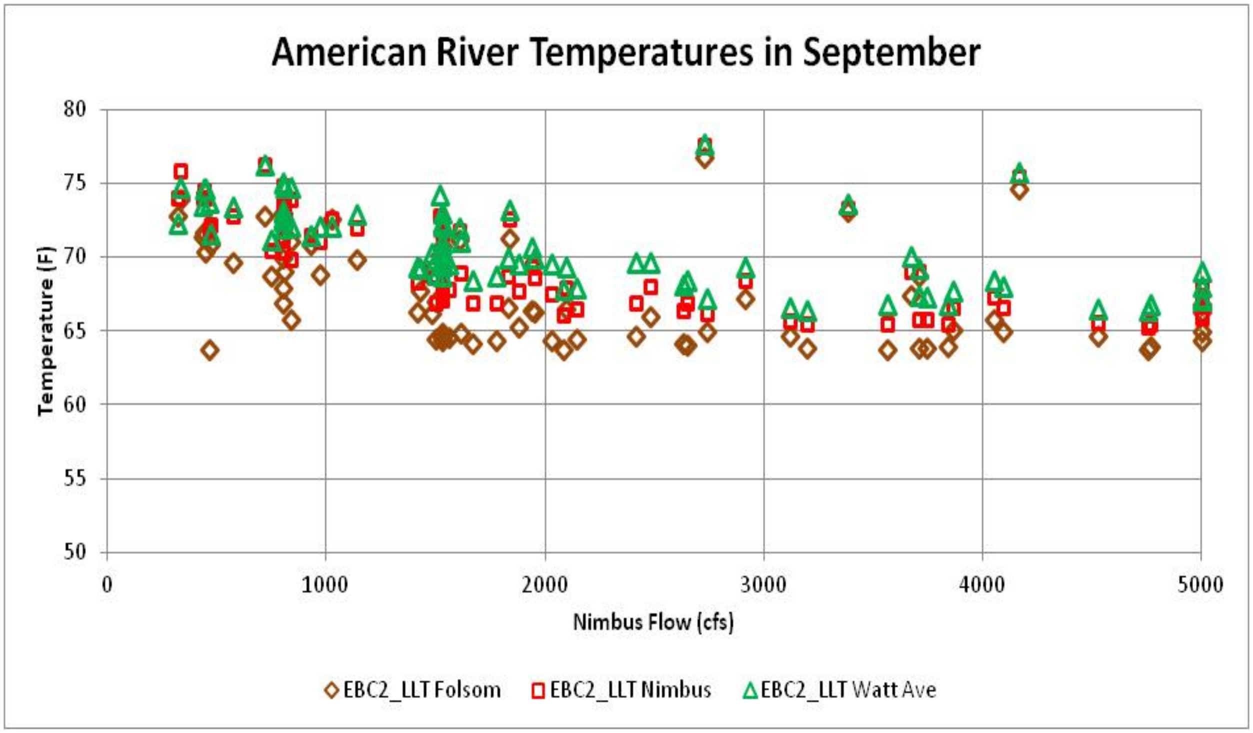
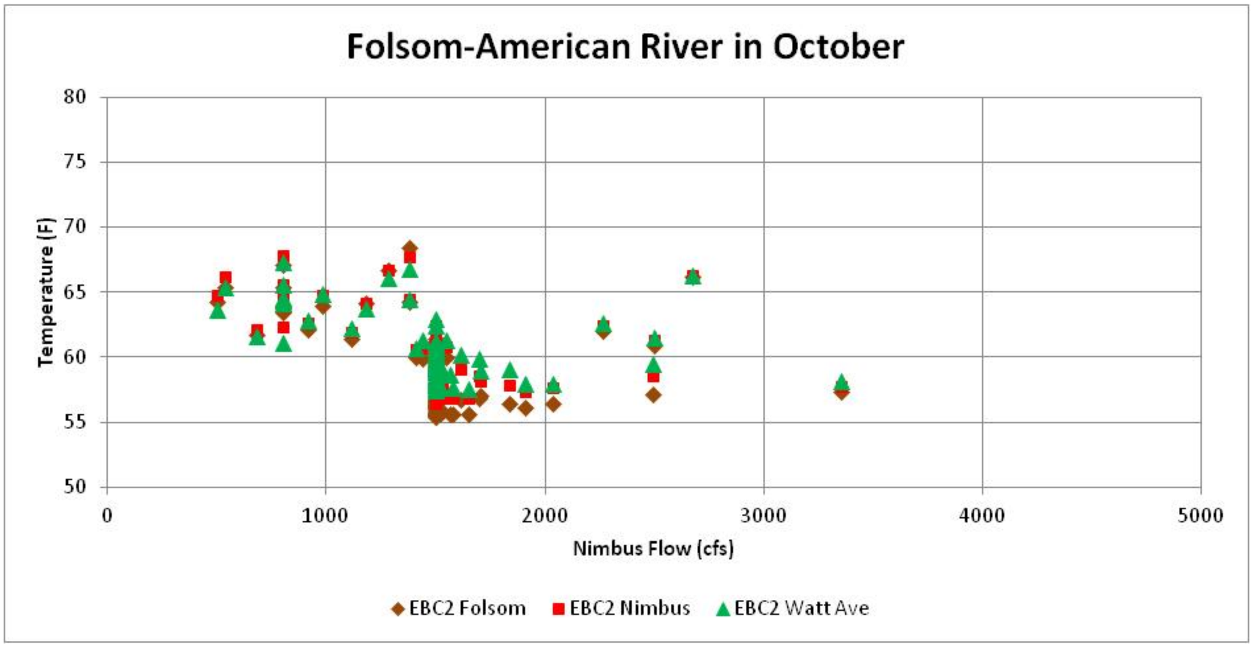


Figure 5.A.2.5-26. American River at Nimbus Flow (cfs) and American River Temperatures (°F) at Folsom Dam, Nimbus Dam, and Watt Avenue Bridge in September for EBC2 and EBC2_LLT Cases for WY 1922–2003



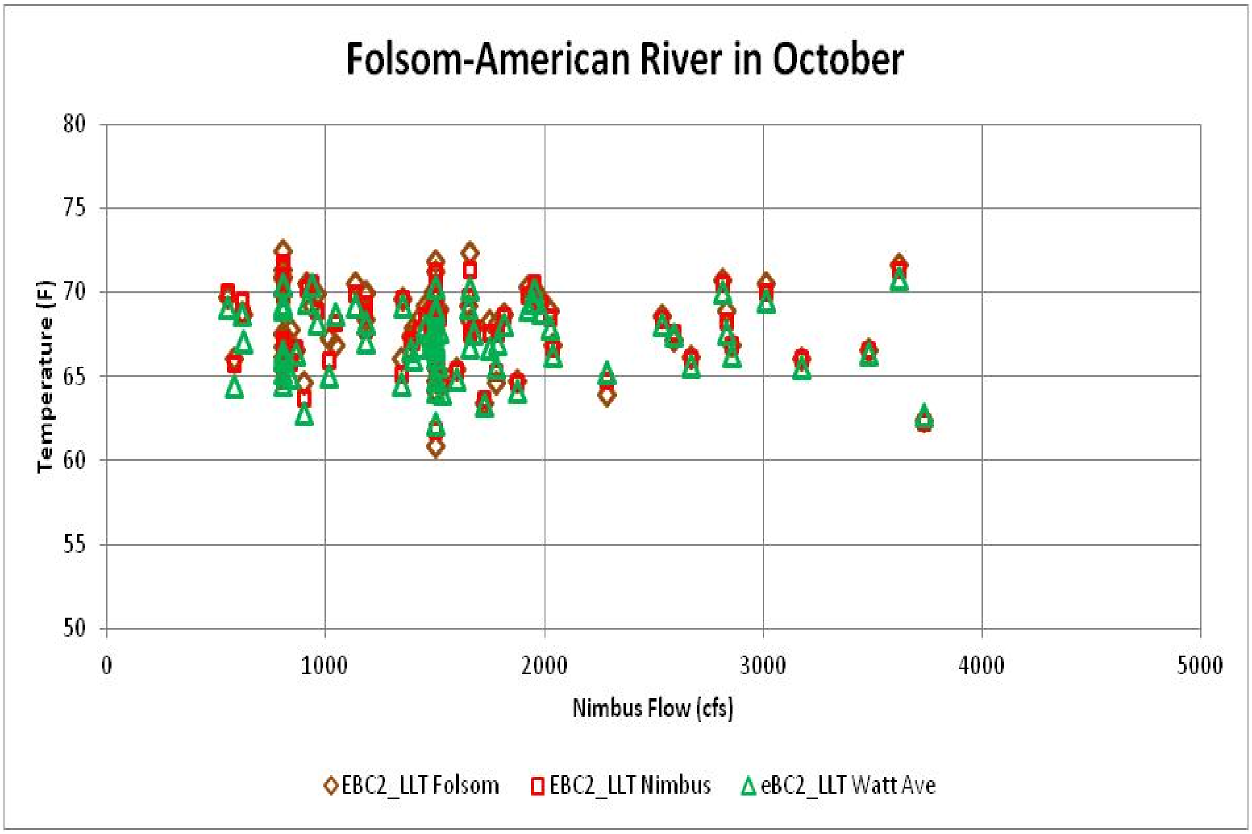


Figure 5.A.2.5-27. American River at Nimbus Flow (cfs) and American River Temperatures (°F) at Folsom Dam, Nimbus Dam, and Watt Avenue Bridge in October for the EBC2 and EBC2_LLT Cases for WY 1922–2003

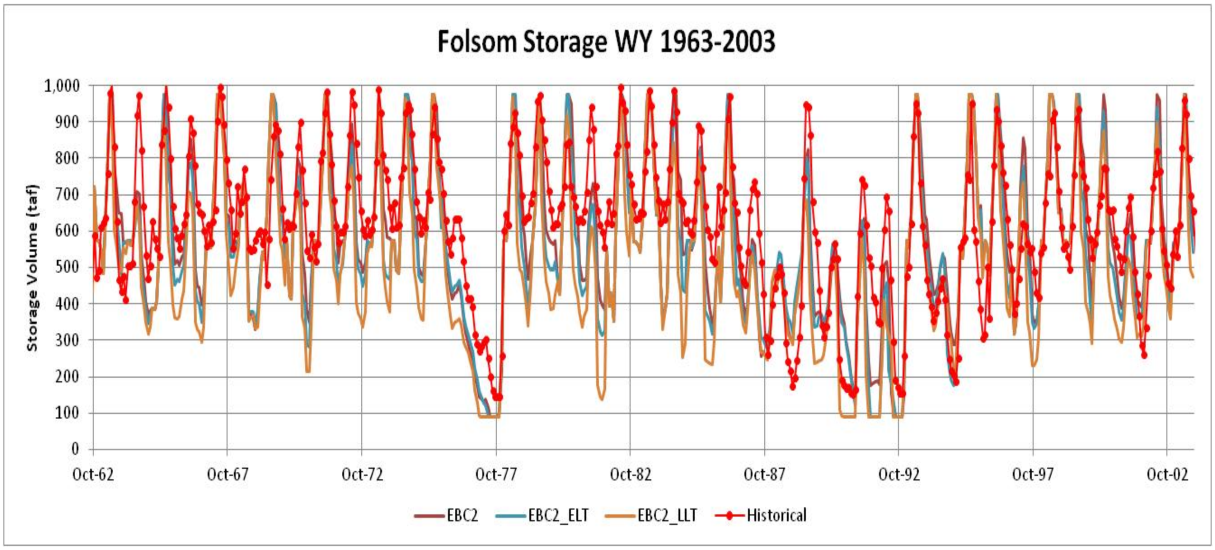


Figure 5.A.2.5-28. Historical and CALSIM-Simulated Folsom Reservoir Storage for the ECB2 Climate Change Cases for WY 1963–2003

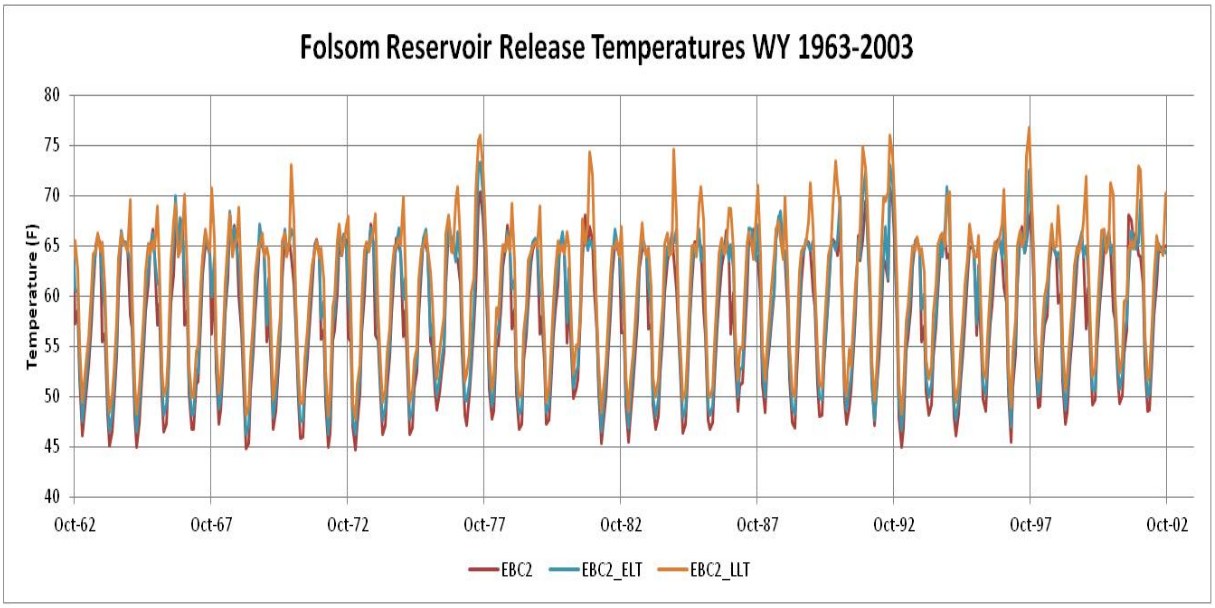


Figure 5.A.2.5-29. Reclamation Temperature Model Results for Folsom Reservoir Release Temperatures for the EBC2 Climate Change Cases for WY 1963–2003

5.A.2.5.5 Stanislaus River Water Temperatures

The Reclamation monthly water temperature model includes New Melones Reservoir and Tulloch Reservoir as vertical temperature models, and Goodwin Forebay and the Stanislaus River downstream of Goodwin Dam are simulated with longitudinal equilibrium temperature models. New Melones Reservoir has a maximum storage of about 2,450 TAF at an elevation of 1,090 feet. The power plant outlet is at elevation 760 feet with a minimum volume of 160 TAF (below the power plant outlet). A low-level outlet at elevation 540 feet was used in the 1987–1992 drought period. Tulloch Reservoir has a volume of 68 TAF and is stratified in the summer, allowing cool water to pass through Tulloch Reservoir and be released to the Goodwin Dam Forebay (for diversion canals). The Stanislaus River summer temperature objective is 65°F from June through November at Orange Blossom, about 12 miles downstream of Goodwin Dam.

Figure 5.A.2.5-30 shows the simulated monthly range of water temperatures at New Melones Dam, Goodwin Dam, and the Stanislaus River at Orange Blossom for existing conditions (EBC2) and the projected LLT conditions. The New Melones release temperatures are usually 50–55°F in August–November. The Goodwin release temperatures are 55–60°F in August, September, and October. The Orange Blossom temperatures are 60–65°F in July–October, providing good steelhead rearing temperatures during the summer. Spawning temperatures for fall-run Chinook salmon of less than 60°F are not likely until November. Warming of 5°F is simulated between New Melones Dam and Goodwin Dam in the summer and fall months. Additional warming of 5°F is simulated downstream to Orange Blossom in the spring and summer months. Figure 5.A.2.5-31 shows the simulated monthly range of water temperatures at New Melones Dam, Goodwin Dam, and the Stanislaus River at Orange Blossom for the EBC2_LLT climate change conditions. The New Melones release temperatures were generally 2–3°F warmer for the EBC2_LLT conditions.

Figure 5.A.2.5-32 shows the monthly Reclamation temperature model results for New Melones Dam and Goodwin Dam release temperatures and Stanislaus River temperatures at Orange Blossom in September, plotted against the September New Melones Reservoir storage volume for the EBC2 climate change cases. The New Melones Dam release temperatures for EBC2 were less than 55°F when the September storage was greater than 750 TAF and increased to 60°F with a storage volume of about 250 TAF. The New Melones Dam release temperatures for the ELT cases (green symbols) were 1–2°F warmer, and the release temperatures for the LLT cases (purple symbols) were 3–5°F warmer than the baseline September temperatures. The Goodwin Dam release temperatures were about 55–60°F for EBC2 when the September New Melones storage volume was greater than 750 TAF. The Goodwin Dam release temperatures for EBC2 increased from 60°F with a storage volume of 750 TAF to about 65°F with a storage volume of 250 TAF. The Goodwin Dam release temperatures for the ELT cases (green symbols) were 2–3°F warmer, and the Goodwin Dam release temperatures for the LLT cases (purple symbols) were 3–5°F warmer than the baseline September temperatures. The Orange Blossom temperatures for EBC2 were about 2–3°F warmer than the Goodwin temperatures but remained less than the 65°F temperature objective. The September temperatures at Orange Blossom for the ELT case were 1–2°F warmer than the baseline temperatures, and the September temperatures at Orange Blossom for the LLT cases were 2–3°F warmer than the baseline temperatures.

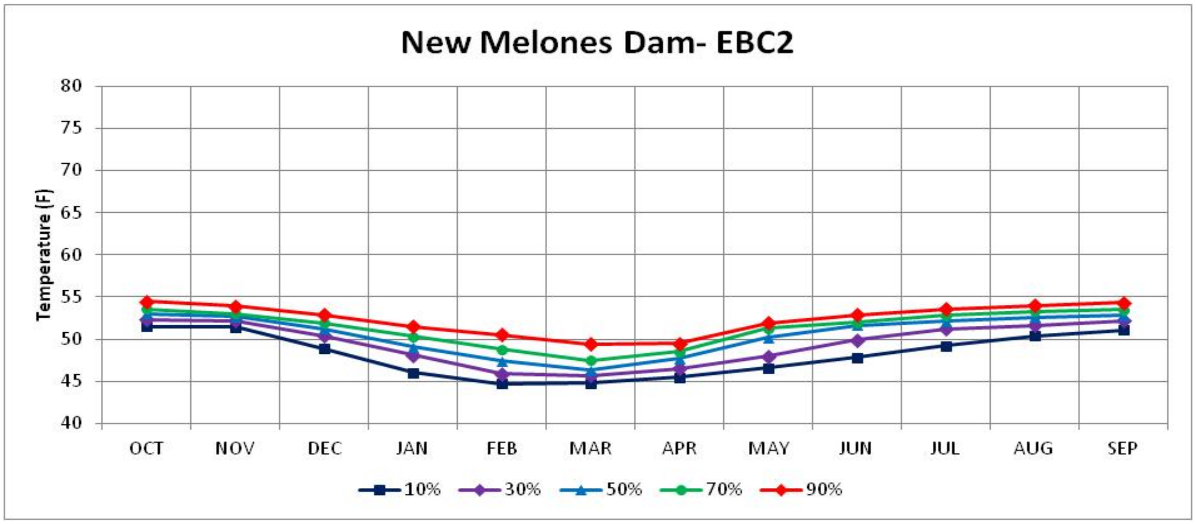
Figure 5.A.2.5-33 shows the monthly Reclamation temperature model results for New Melones Dam and Goodwin Dam release temperatures and Stanislaus River temperatures at Orange Blossom in October, plotted against the October New Melones Reservoir storage volume for the EBC2 climate change cases. The New Melones Dam release temperatures for EBC2 (brown symbols) were less than 55°F when the October storage was greater than 750 TAF and increased to 60°F with a storage volume of about 250 TAF. The New Melones Dam release temperatures for the ELT cases (green symbols) were 1–2°F warmer, and the release temperatures for the LLT cases (purple symbols) were 3–5°F warmer than the baseline October temperatures. The Goodwin Dam release temperatures were about 55–60°F for EBC2 when the October New Melones storage volume was greater than 750 TAF and increased to about 65°F with a storage volume of 250 TAF. The Orange Blossom temperatures for EBC2 were very similar to the Goodwin temperatures in October, suggesting that the equilibrium temperatures were about 55–60°F in October. The coolest temperatures (55°F) were associated with the highest storage (2,000 TAF), and temperatures of greater than 60°F were associated with the lowest storage (less than 1,000 TAF). The October

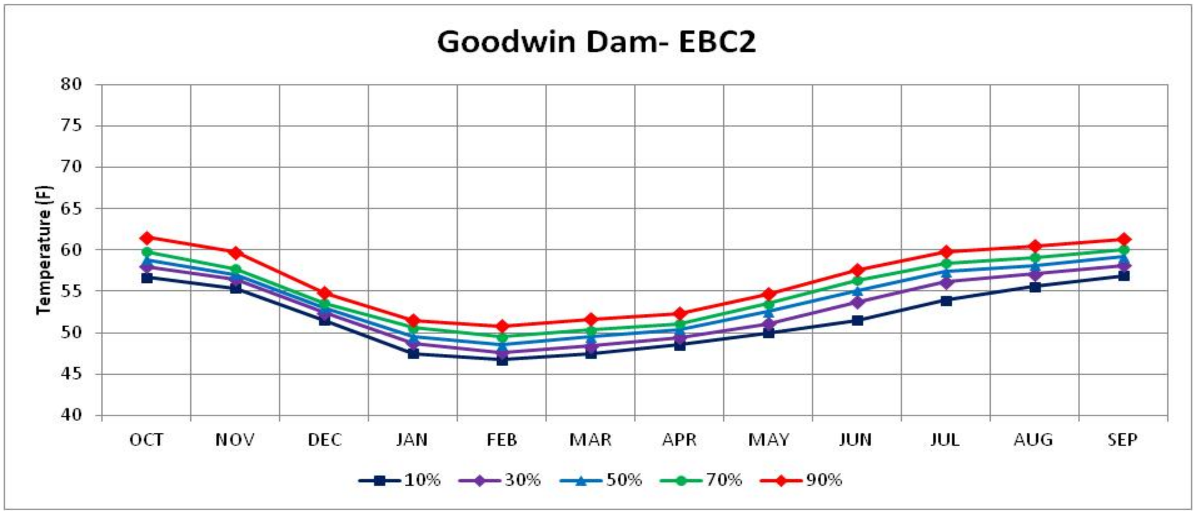
temperatures at Orange Blossom for the ELT case were 1–2°F warmer than the baseline temperatures, and the September temperatures at Orange Blossom for the LLT cases were 3–5°F warmer than the baseline temperatures. The October temperatures were very similar to the September temperatures.

Figure 5.A.2.5-34 shows the monthly Reclamation temperature model results for New Melones Dam and Goodwin Dam release temperatures and Stanislaus River temperatures at Orange Blossom in November, plotted against the November New Melones Reservoir storage volume for the EBC2 climate change cases. The New Melones Dam release temperatures for EBC2 (brown symbols) were less than 55°F when the October storage was greater than 500 TAF and increased to 60°F with a storage volume of about 250 TAF. The New Melones Dam release temperatures for the ELT cases (green symbols) were 1–2°F warmer, and the release temperatures for the LLT cases (purple symbols) were 3–5°F warmer than the baseline November temperatures. The Goodwin Dam release temperatures were about 55–60°F for EBC2 when the October New Melones storage volume was greater than 750 TAF. The November temperatures at Goodwin Dam were 2–3°F cooler than the October temperatures. The Goodwin Dam release temperatures for the ELT case were 1–2°F warmer, and the Goodwin Dam release temperatures for the LLT case were 2–3°F warmer than the baseline November temperatures. The Orange Blossom temperatures for EBC2 were about 55°F for New Melones storage volume of greater than 750 TAF and were less than 60°F in all years. The Orange Blossom temperatures were less than the Goodwin Dam temperatures because the equilibrium temperatures in November are less than the Goodwin Dam release temperatures. November temperatures at Orange Blossom for the ELT case were 1–2°F warmer than the baseline temperatures, and the LLT temperatures were 2–3°F warmer than the baseline temperatures. The November temperatures at Goodwin Dam were about 60–65°F, and the Orange Blossom temperatures were 55–60°F for the LLT cases, well below the temperature objective of 65°F.

The simulated effects of LLT climate change on Goodwin Dam release temperatures and Orange Blossom temperatures were therefore about 5°F in September and October. Because the LLT temperatures at Goodwin Dam in October were above 60°F, climate change likely will delay the period for successful fall-run Chinook salmon spawning into November of most years. The majority of Chinook spawning, which occurs in November, should be only moderately affected by these slightly warmer LLT temperatures between Goodwin Dam and Orange Blossom. Much warmer Goodwin Dam release temperatures were simulated in September and October when the New Melones Reservoir storage volume was less than 500 TAF. The Reclamation temperature model results for the Stanislaus River were caused solely by climate change warming of air, inflow, and equilibrium temperatures because the reservoir operations (storage levels and river flows) were simulated to be nearly identical for the EBC2 cases.

Figure 5.A.2.5-35 shows the historical New Melones Reservoir storage volumes for WY 1963–2003 along with the simulated New Melones Reservoir storage for the EBC2 cases. The historical operations of New Melones Reservoir (filled in 1982) showed decreasing storage volume from WY 1986 to 1992, with very low storage in 1991 and 1992 (less than 250 TAF in 1992). The CALSIM simulated storage patterns showed a very similar multi-year drawdown during these dry-year sequences. The years with simulated storage of less than 500 TAF had higher Goodwin Dam release temperatures in September and October. Figure 5.A.2.5-36 shows the Reclamation temperature model simulated Goodwin Dam release temperatures for WY 1963–2003. The highest temperatures (September and October) were simulated only in years with low storage of less than 500 TAF.





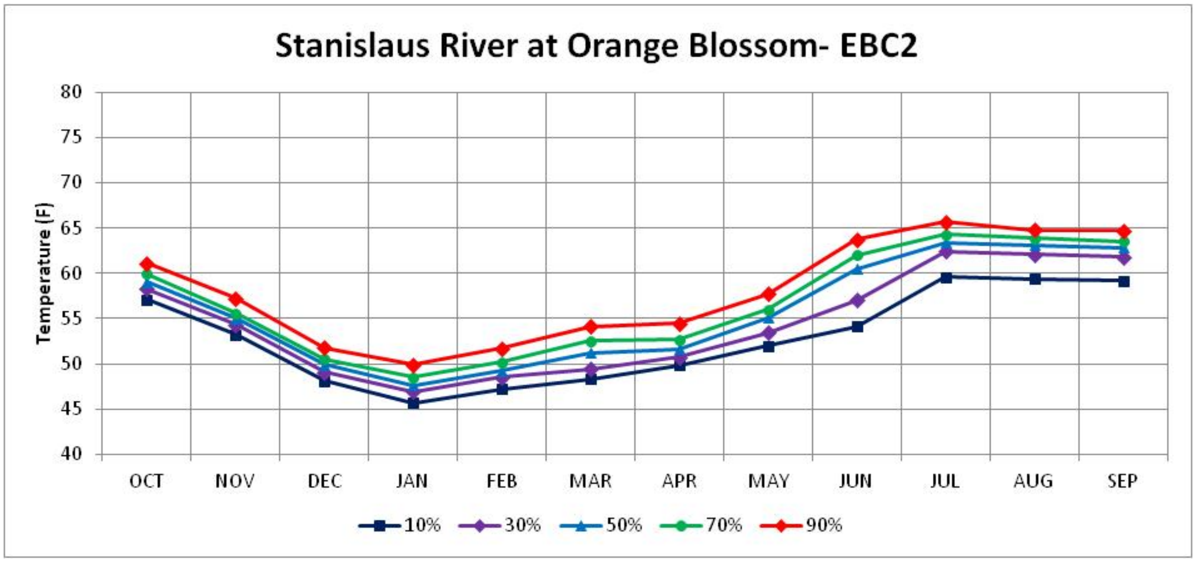
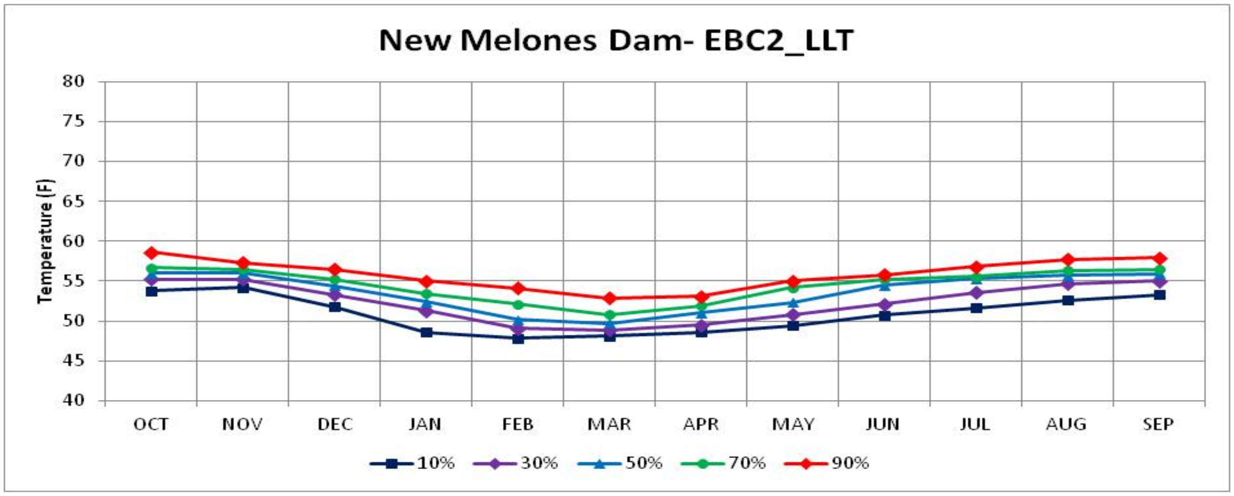
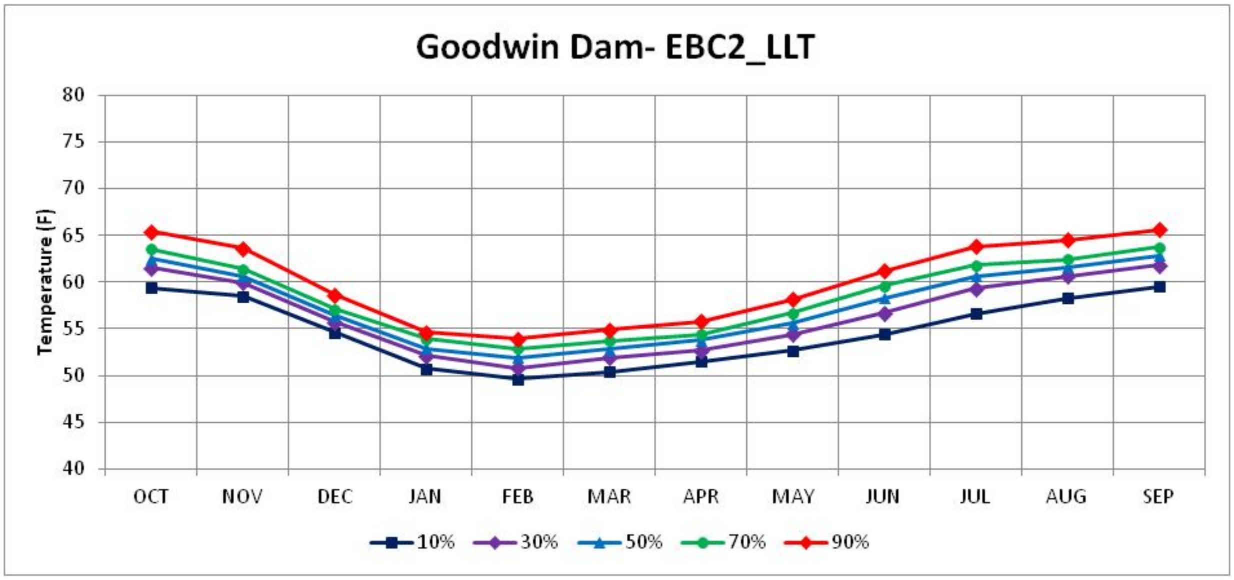


Figure 5.A.2.5-30. Reclamation Temperature Model Monthly Temperature Ranges for Stanislaus River at New Melones Dam, Goodwin Dam, and Orange Blossom for WY 1922–2003 for EBC2





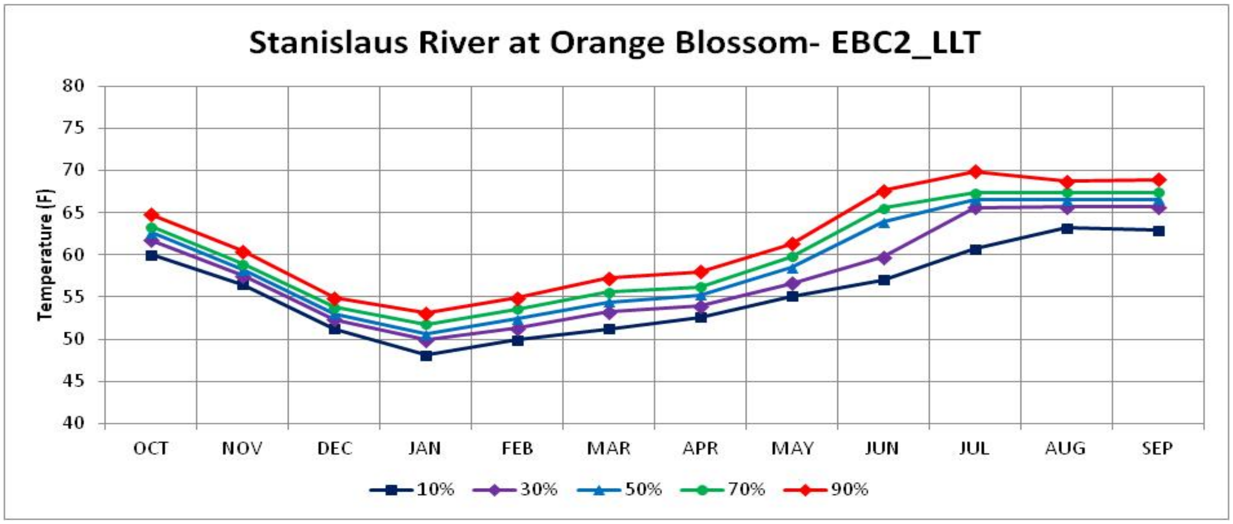
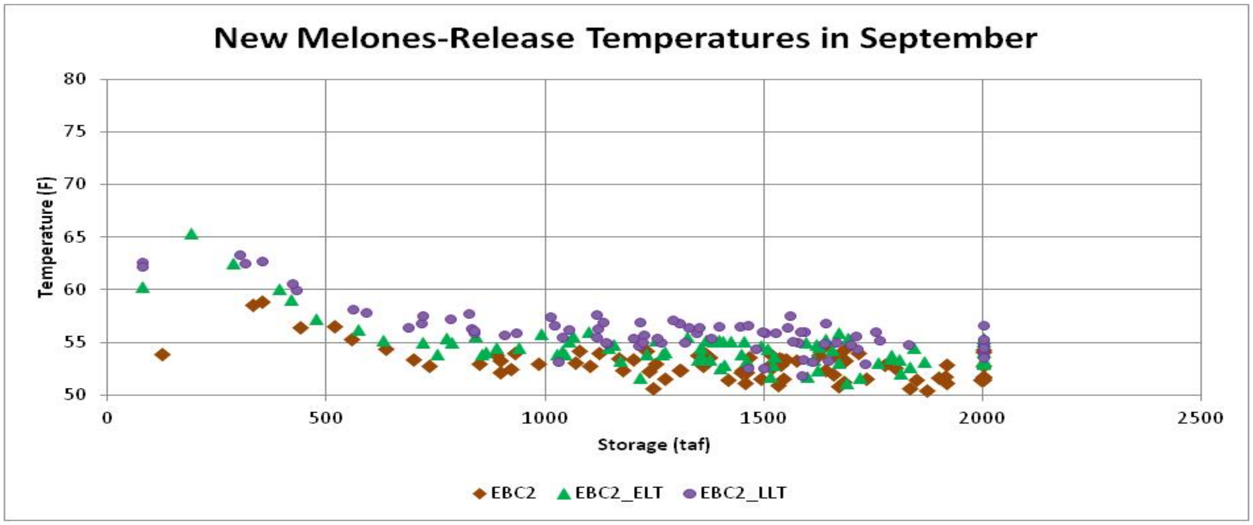
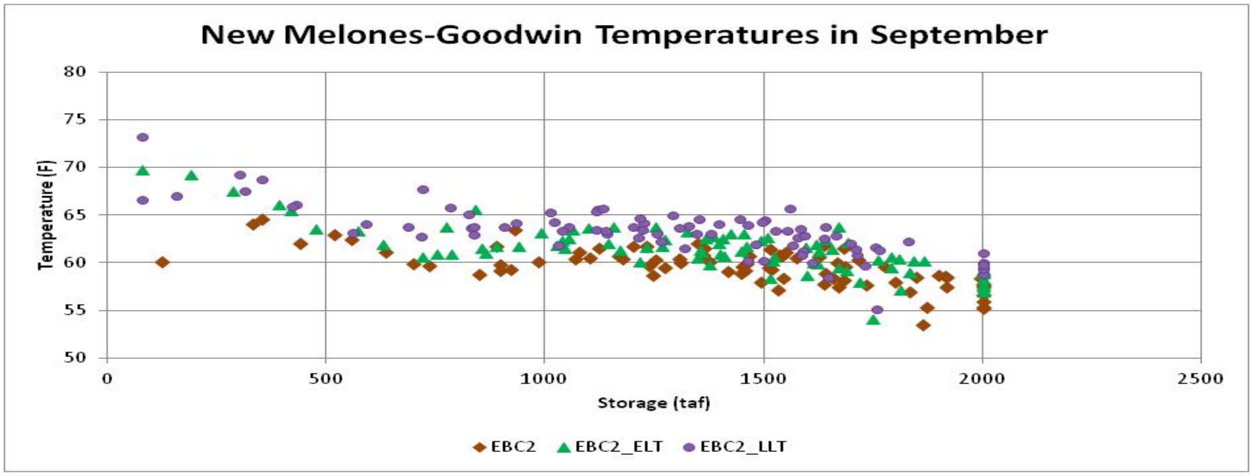


Figure 5.A.2.5-31. Reclamation Temperature Model Monthly Temperature Ranges for Stanislaus River at New Melones Dam, Goodwin Dam, and Orange Blossom for WY 1922–2003 for EBC2_LLT





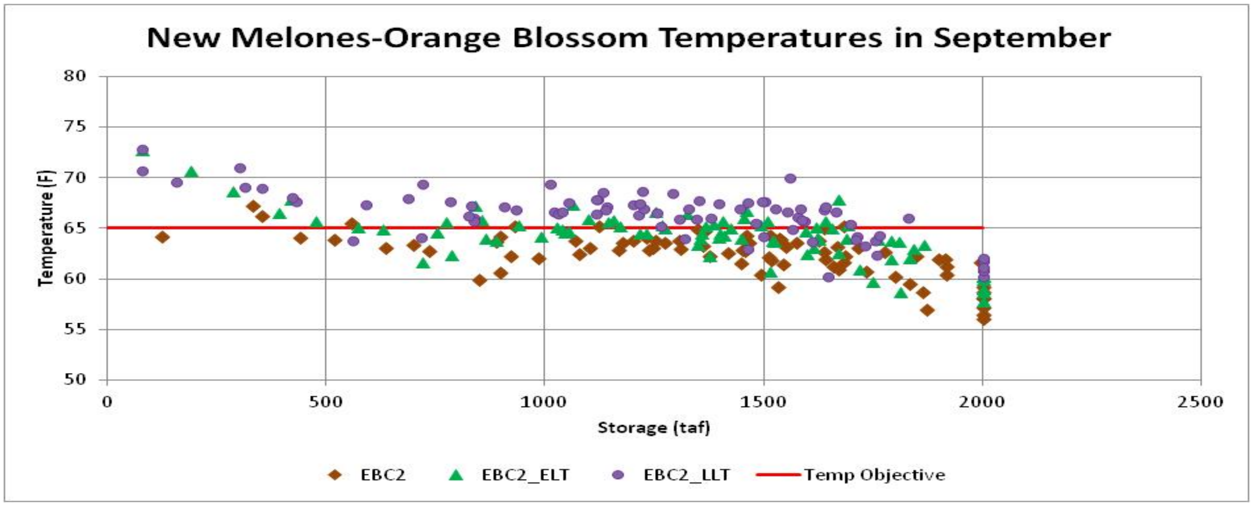
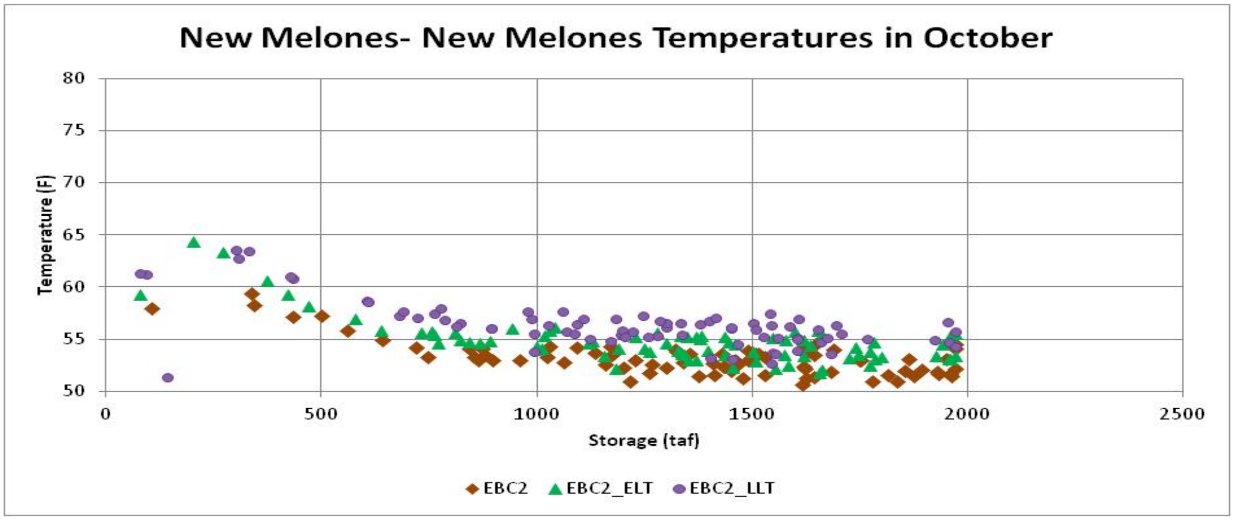
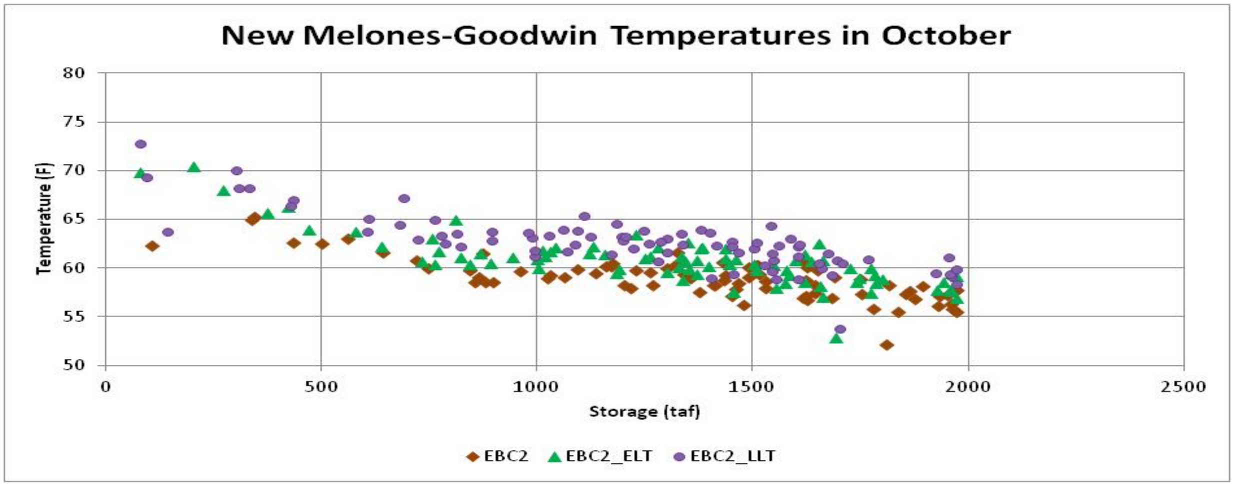


Figure 5.A.2.5-32. New Melones Reservoir Storage (TAF) and Stanislaus River Temperature (°F) at New Melones Dam, Goodwin Dam, and Orange Blossom in September for the EBC2 Climate Change Cases for WY 1922–2003





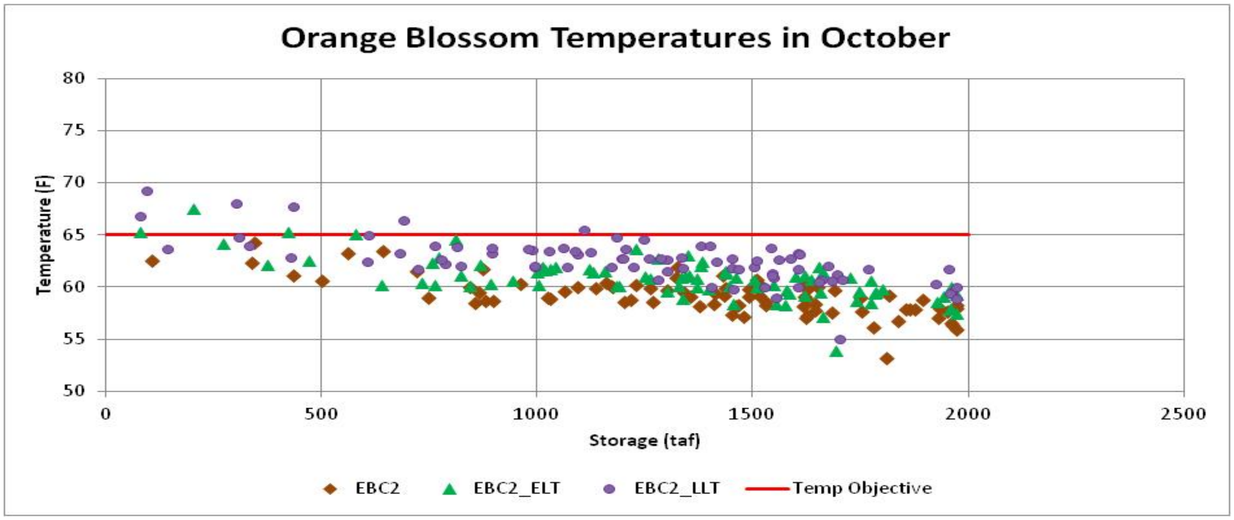
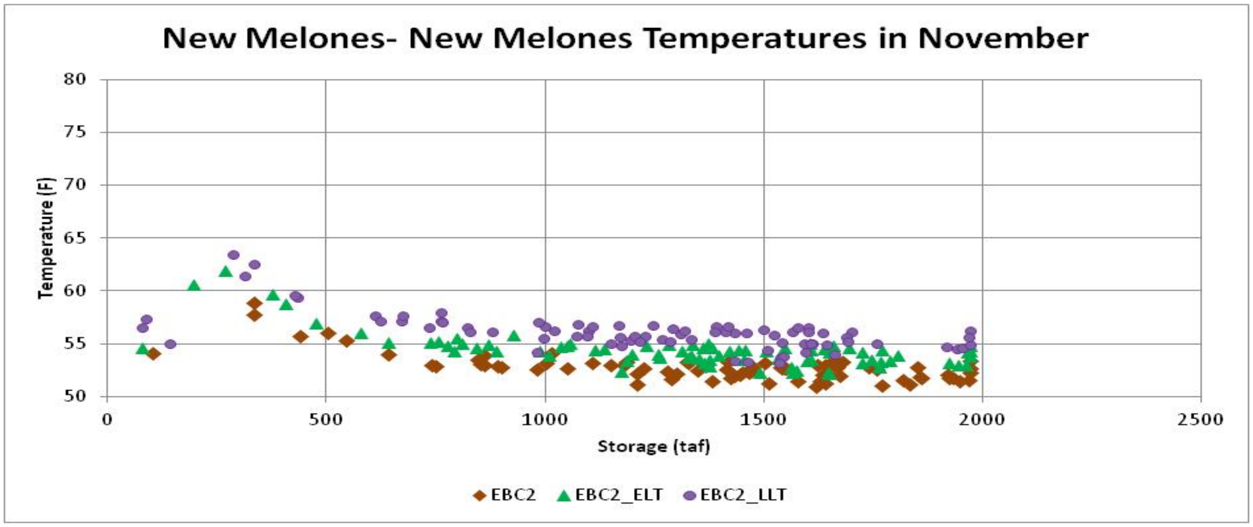
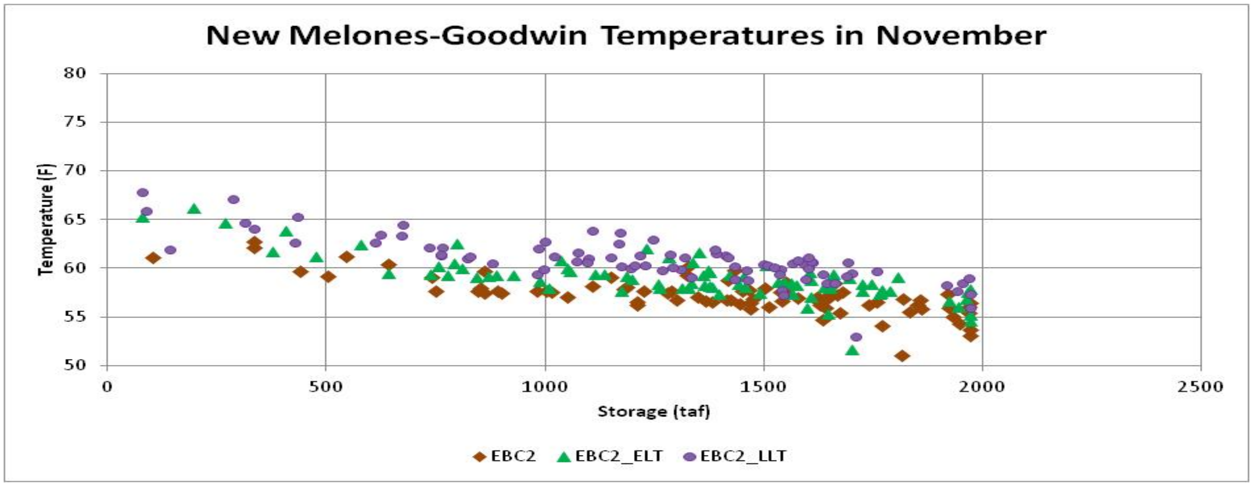


Figure 5.A.2.5-33. New Melones Reservoir Storage (TAF) and Stanislaus River Temperature (°F) at New Melones Dam, Goodwin Dam, and Orange Blossom in October for the EBC2 Climate Change Cases for WY 1922–2003





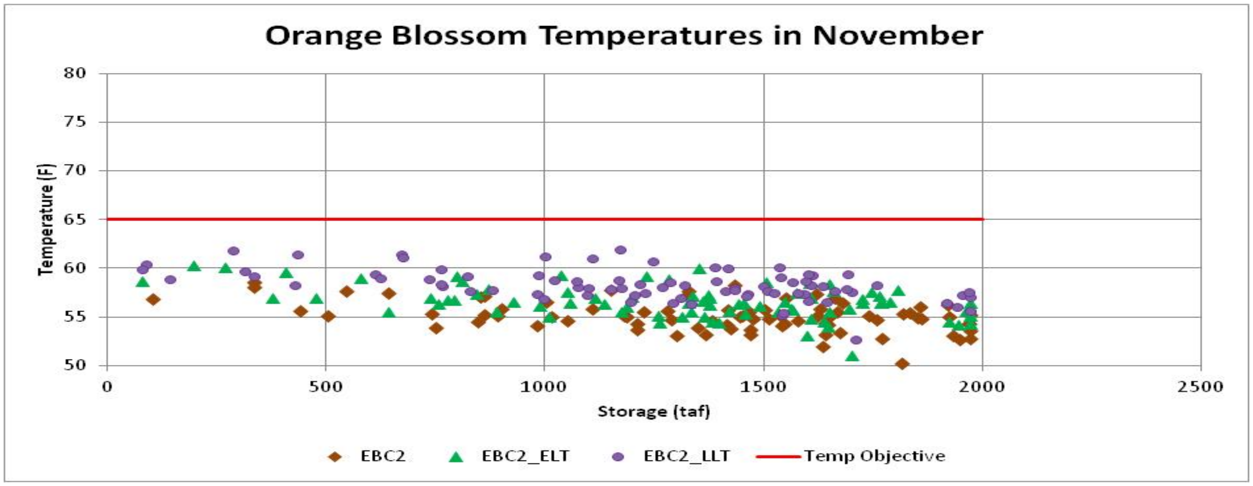


Figure 5.A.2.5-34. New Melones Reservoir Storage (TAF) and Stanislaus River Temperature (°F) at New Melones Dam, Goodwin Dam, and Orange Blossom in November for the EBC2 Climate Change Cases for WY 1922–2003

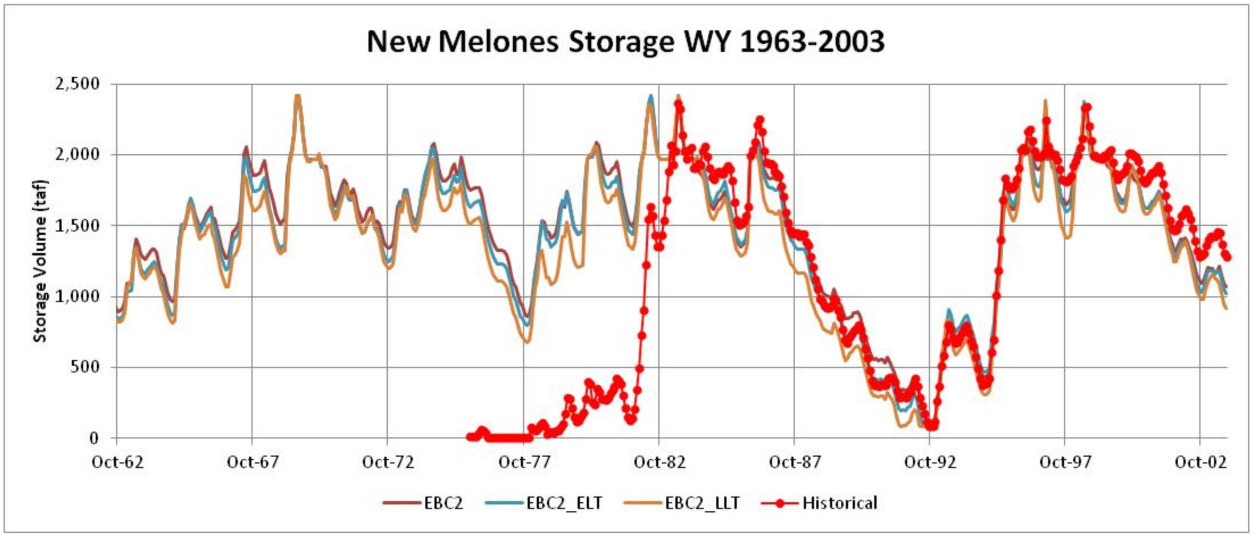


Figure 5.A.2.5-35. Historical and CALSIM-Simulated New Melones Reservoir Storage for the EBC2 Climate Change Cases for WY 1963–2003

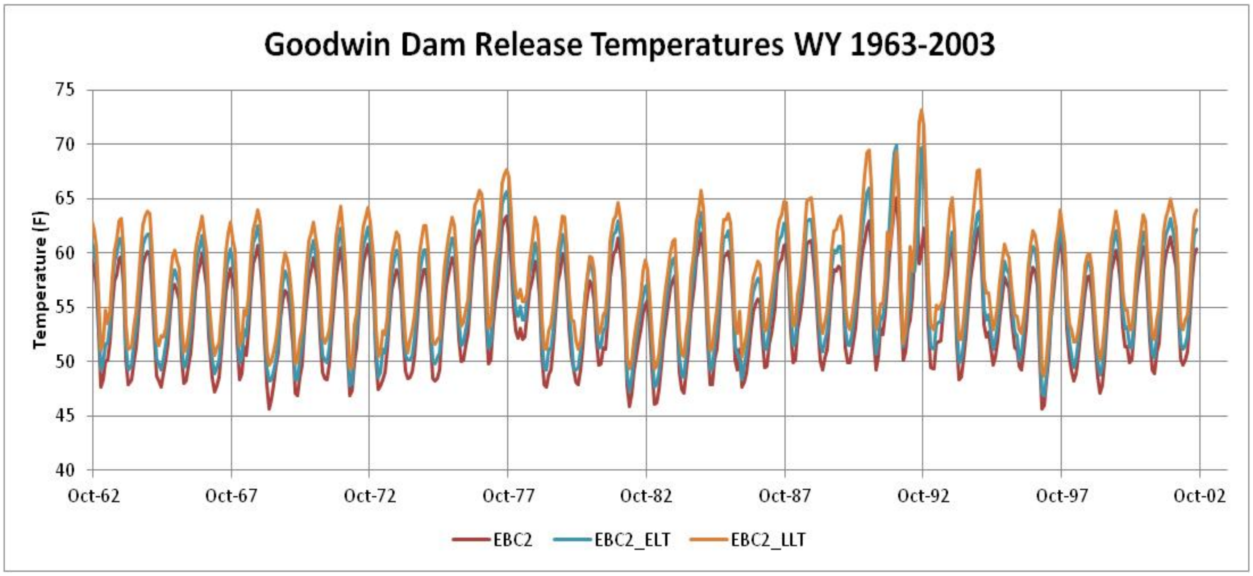


Figure 5.A.2.5-36. Reclamation Temperature Model Results for Goodwin Dam Release Temperatures for the EBC2 Climate Change Cases for WY 1963–2003

5.A.2.6 Delta Water Temperatures and Salinity Modeling Results

The effects of climate change on the Delta are the combination of upstream effects on runoff and increases in Delta water temperatures caused by the increase in equilibrium temperatures. There also will be effects from sea level rise on the tidal flows and salinity, resulting from the larger (intertidal) surface area and slightly deeper estuary.

5.A.2.6.1 Delta Water Temperatures

Because the Delta water temperatures are controlled by equilibrium temperatures (meteorological conditions) the effects of climate change warming of air temperatures is expected also to warm the Delta water temperatures. Therefore, projected climate change warming of future monthly air temperatures would raise Delta water temperatures by approximately the same amount. The DSM2 model was used to simulate increases in Delta water temperatures with projected climate change. Table 5.A.2.6-1 gives a summary of average monthly water temperature increases in the Delta subregions. For the ELT timeframe, the annual average water temperature increases ranged from 0.32°C (0.6°F) to 0.54°C (1°F). The simulated warming of water temperatures was generally uniform through the year but was somewhat different in the different regions. For the LLT timeframe, the average annual water temperature increases ranged from 0.91°C (1.6°F) to 1.57°C (2.8°F). The simulated warming of water temperatures was more variable through the year and was somewhat different in each region. The water temperature changes were generally similar to the monthly air temperature changes that were projected in the model inputs (meteorological data).

5.A.2.6.2 Tidal Flows and Salinity

The UnTRIM Bay-Delta model simulated effects of sea level rise on tidal elevations and tidal amplitude showed that there were no appreciable changes in the tidal amplitude between the Golden Gate and Martinez (DSM2 boundary). Therefore, a constant increase can be applied to the measured tidal elevation at Martinez. The increase in the average tidal elevation at Martinez was simulated to be about 44 cm for the 45-cm (18-inch) sea level rise projected at the ocean boundary for the LLT conditions (2060 climate). The tidal prism is defined as the volume change from the MHHW to the MLLW. The average tidal prism is proportional to the flood-tide flows (upstream) and ebb-tide flows (downstream) each day. The San Francisco estuary has a mixed tide with two uneven high tides and two uneven low tides each lunar day. The average flood-tide flow volume is about 75% of the tidal prism. The UnTRIM model simulated a 5% increase in the average tidal prism for the projected 45-cm (18-inch) sea level rise case (LLT) at Martinez. The slightly increased tidal flows throughout the estuary may cause increased tidal dispersion (mixing) along the salinity gradient and may cause the salinity at Martinez and upstream in the Delta to increase with sea level rise.

The salinity effects of sea level rise in the Bay and Delta channels were simulated with the 3-D UnTRIM model for six projected sea level rise increments from 15 cm to 150 cm (6 inches to 60 inches). The UnTRIM model results generally indicated that the effects of sea level rise on salinity at Martinez and upstream at Chipps Island and Collinsville would increase linearly with sea level rise. Therefore, the results for the LLT with a 45-cm (18-inch) sea level rise are summarized and discussed here. The salinity effects at Martinez are the combined effects of tidal dispersion (gradient mixing) and gravitational circulation (density effects) between the Golden Gate and the Martinez. Tidal dispersion causes mixing along the salinity gradient, and gravitational circulation allows salinity to move upstream near the bottom of the channel. High flow increases velocity shear and increases vertical mixing that reduces the gravitational effects. The depth profile and cross-section geometry influence these hydrodynamic mixing processes.

Table 5.A.2.6-1. DSM2-Simulated Increases in Average Monthly Water Temperatures (°C) from Projected Climate Changes in Air Temperatures

Month	Cache Slough	North Delta	East Delta	West Delta	South Delta	Suisun Marsh	Suisun Bay
A. Water Temperature Increase from Existing to ELT							
Jan	0.43	0.20	0.29	0.38	0.45	0.47	0.25
Feb	0.48	0.32	0.37	0.46	0.50	0.49	0.30
Mar	0.45	0.36	0.40	0.44	0.53	0.47	0.33
Apr	0.68	0.29	0.50	0.67	0.71	0.72	0.49
May	0.69	0.53	0.57	0.69	0.63	0.72	0.58
Jun	0.53	0.51	0.50	0.50	0.49	0.53	0.42
Jul	0.60	0.39	0.43	0.57	0.53	0.60	0.47
Aug	0.53	0.34	0.37	0.54	0.55	0.54	0.45
Sep	0.39	0.28	0.29	0.38	0.39	0.41	0.29
Oct	0.63	0.24	0.36	0.58	0.68	0.64	0.39
Nov	0.47	0.32	0.35	0.50	0.56	0.47	0.32
Dec	0.46	0.23	0.28	0.42	0.50	0.46	0.25
Annual	0.53	0.33	0.39	0.51	0.54	0.54	0.38
B. Water Temperature Increase from Existing to LLT							
Jan	1.37	1.53	1.32	1.30	1.05	1.25	0.77
Feb	1.50	2.09	1.75	1.49	0.74	1.21	0.85
Mar	1.63	2.26	1.99	1.61	0.66	1.26	0.98
Apr	1.48	1.67	1.60	1.45	0.96	1.26	1.00
May	1.01	0.91	0.98	1.01	0.80	1.02	0.93
Jun	1.16	1.46	1.29	1.09	0.89	1.11	1.11
Jul	1.39	2.54	2.08	1.32	0.92	1.08	1.25
Aug	1.45	2.02	1.80	1.46	1.28	1.31	1.42
Sep	1.44	1.60	1.51	1.40	1.29	1.36	1.14
Oct	1.53	1.23	1.39	1.47	1.47	1.46	0.92
Nov	1.16	0.67	0.85	1.11	1.36	1.10	0.26
Dec	1.19	0.84	0.95	1.05	1.26	1.06	0.26
Annual	1.36	1.57	1.46	1.31	1.06	1.21	0.91

Calendar year 2002 was used for the UnTRIM model study period. The model was previously calibrated and matched this new period (measured tidal elevations and salinity) without additional adjustments. The match of the tidal amplitude to the measured tidal elevations was excellent. Figure 5.A.2.6-1 shows the match of the tidal elevations at Martinez, and Figure 5.A.2.6-2 shows the match of the tidal elevations in the San Joaquin River at Jersey Point. Simulating the tidal elevations properly (amplitude and timing) generally indicates that the tidal flows are also being simulated accurately.

The UnTRIM-simulated salinity also matched the measured salinity (EC) data well throughout the Bay and Delta. The UnTRIM model simulates practical salinity units (psu), very similar to salinity as total dissolved solids (grams per liter [g/l]), so that ocean water has a salinity of about 32 g/l (parts per thousand [ppt]) and about 32 psu. The measured salinity data are EC values (normalized to 77°F). A slight nonlinearity is involved in the conversion of psu and EC. The EC data were converted to psu for these validation graphs. Figure 5.A.2.6-3 shows the comparison of the UnTRIM-simulated and the measured salinity (psu) at Martinez for 2002. The maximum Martinez salinity in the fall months when the outflow was about 4,000 cfs was about 20 psu (32,000 microSiemens per centimeter [µS/cm]). Figure 5.A.2.6-4 shows the comparison of the UnTRIM-simulated and the measured salinity (psu) at Mallard Slough (Chipps Island) for 2002. The maximum salinity at Chipps Island was about 7.5 psu. The maximum salinity at Collinsville was about 5 psu.

Figure 5.A.2.6-5 shows the simulated salinity at Martinez (RSAC054) for the historical conditions and six sea level rise cases for 2002. The ELT corresponds to the 15 cm (first, dark blue line) case; the LLT corresponds to the 45 cfs (third, red line) case; the other three cases are for greater sea level–rise increases. The simulated increase in daily-average salinity at Martinez was relatively constant throughout the year, with the exception of the high flow periods. Figure 5.A.2.6-6 shows the simulated salinity at Chipps Island for the historical conditions and six sea level–rise cases for 2002. The projected salinity increase for all sea level–rise cases approaches zero during December as salt was pushed out of Suisun Bay by high Delta outflows. The largest increases in daily-average salinity for all cases were in November and December, prior to the high flows in late December.

The results from the UnTRIM model at Martinez indicated that the effects of a 45-cm (18-inch) sea level rise would be a nearly constant increase in salinity of about 0.8 psu (equivalent to about 1,500 µS/cm). Anderson and Miller (2005) used a similar approach to estimate the effects of sea level rise on the Martinez EC simulated using the RMA 2D Bay-Delta model for a 30-cm (12-inch) sea level rise. They found a constant increase of about 840 µS/cm. This compares to a constant increase of about 0.6 psu (1,200 µS/cm) found with the UnTRIM model.

The UnTRIM model results for 2002 were processed to show the simulated upstream movement of X2 caused by sea level rise. X2 is the distance, expressed in kilometers from the Golden Gate Bridge, at which channel-bottom water salinity (isohaline) is 2 ppt. This has been estimated to correspond to a surface EC measurement of 2,640 µS/cm, based on the average salinity stratification near X2 and the conversion between 2 psu and EC units (i.e., 2 psu = 3,800 µS/cm). The X2 position is highly variable within each day because the tidal excursion is several kilometers in this portion of the estuary. Nevertheless, the daily average bottom salinity of 2 psu was calculated for the UnTRIM simulations of the historical 2002 conditions (i.e., outflow) with various sea level rise assumptions, and the changes (i.e., upstream movement) of X2 were evaluated. Figure 5.A.2.6-7 shows the simulated X2 location for the historical simulation and for the projected sea level rise of 15 cm (6 inches) (ELT) and the projected sea level rise of 45 cm (18 inches) (LLT). For the LLT conditions, the UnTRIM model simulated the X2 position to move upstream a constant distance of about 2 km for the entire year of 2002, with a range of Delta outflow from about 12,000 cfs in April and May to about 4,000 cfs from August to October. The increased daily X2 distance is shown in the bottom panel. For the existing salinity conditions, the X2 will move downstream about 1 km for each 10% increase in Delta outflow. Therefore, to move the X2 positions downstream 2 km would likely require about 20% more outflow. For existing conditions, an outflow of about 7,100 cfs is required to maintain X2 at Collinsville (km 81); the required Delta outflow for the projected LLT sea level rise of 45 cm likely would require about 8,520 cfs (1.2 x 7,100 cfs). An outflow of about 11,400 cfs is required to maintain X2 at Chipps Island (km 75); the required Delta outflow for the projected LLT sea level rise of 45 cm likely would require about 13,680 cfs (1.2 x 11,400 cfs). Figure 5.A.2.6-8 shows that the simulated changes in X2 generally increased linearly with projected sea level rise.

The increase in X2 was highest in January at higher outflows. However, the changes in X2 are most important for Delta operations when Delta outflow is relatively low (less than 5,000 cfs).

The simulated salinity effects for 2002 conditions were generally consistent with previous analyses conducted as part of the Delta Risk Management Strategy (DRMS) studies (Gross et al. 2007a, 2007b). As the Delta outflow conditions were higher for the sea level–rise analysis conducted for DRMS (Gross et al. 2007a), gravitational circulation was estimated to be more substantial for those higher-flow conditions. However, the spatial variability of dispersion components and variability with sea level rise projected in the DRMS studies (Gross et al. 2007a) were generally similar to those projected in this appendix. The salinity effects simulated for the 2002 conditions apply to moderate to low-flow conditions typical of summer and fall when salt intrusion is most pronounced.

The sea level–rise simulations of salinity with the UnTRIM model did not change Delta outflow to compensate for the increased salinity intrusion caused by sea level rise. The simulated salinity effects from the UnTRIM Bay-Delta model subsequently were used to incorporate the increases in salinity at Martinez and the increased tidal dispersion in Suisun Bay to adjust the DSM2 parameters (Martinez boundary EC and mixing coefficients) and to adjust the CALSIM II model required outflow calculation (ANN method) to allow the proper simulation of operational responses to projected sea level–rise conditions. The adjustments in the required Delta outflow to maintain X2 objectives or meet salinity objectives because of increased salinity intrusion with sea level rise are described in more detail in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*, Attachment 5C.A, *CALSIM and DSM2 Modeling*.

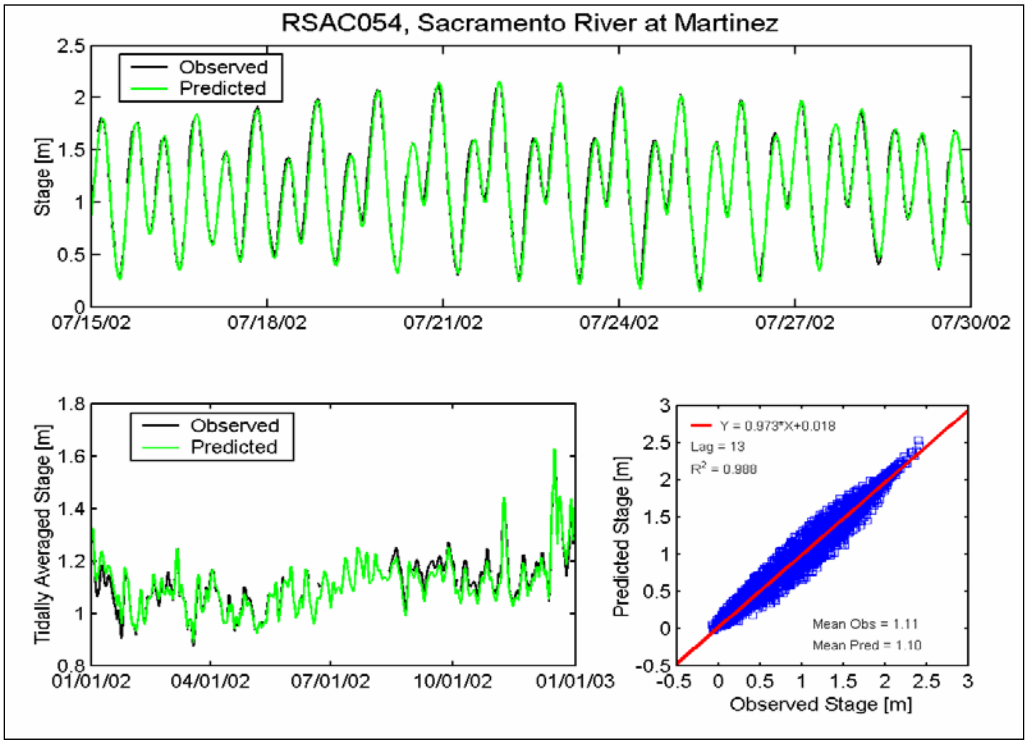


Figure 5.A.2.6-1. Comparison of UnTRIM Modeled and Measured Tidal Elevations at Martinez for 2002

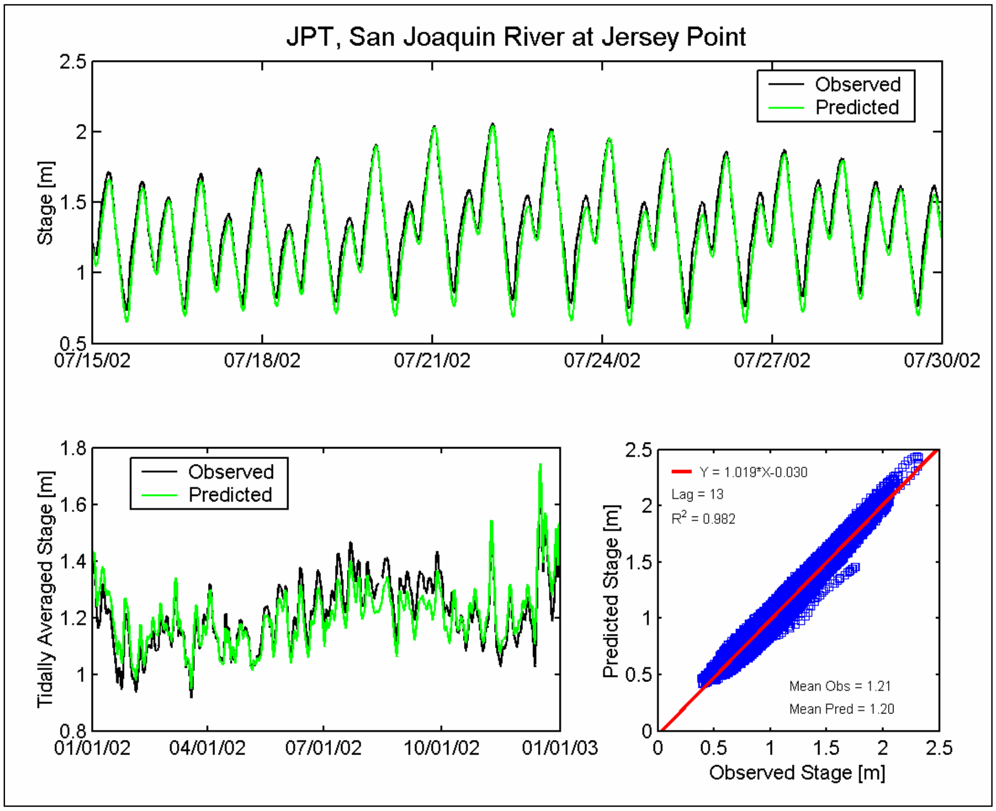


Figure 5.A.2.6-2. Comparison of UnTRIM Modeled and Measured Tidal Elevations at Jersey Point for 2002

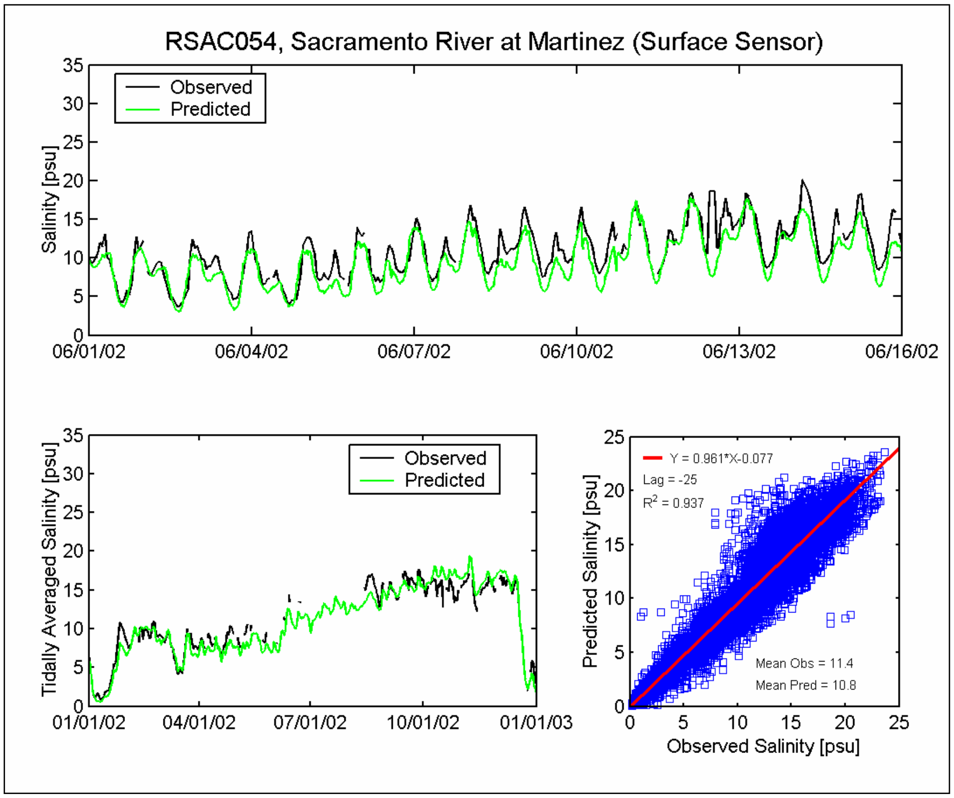


Figure 5.A.2.6-3. Comparison of UnTRIM Simulated and Measured Salinity at Martinez for 2002

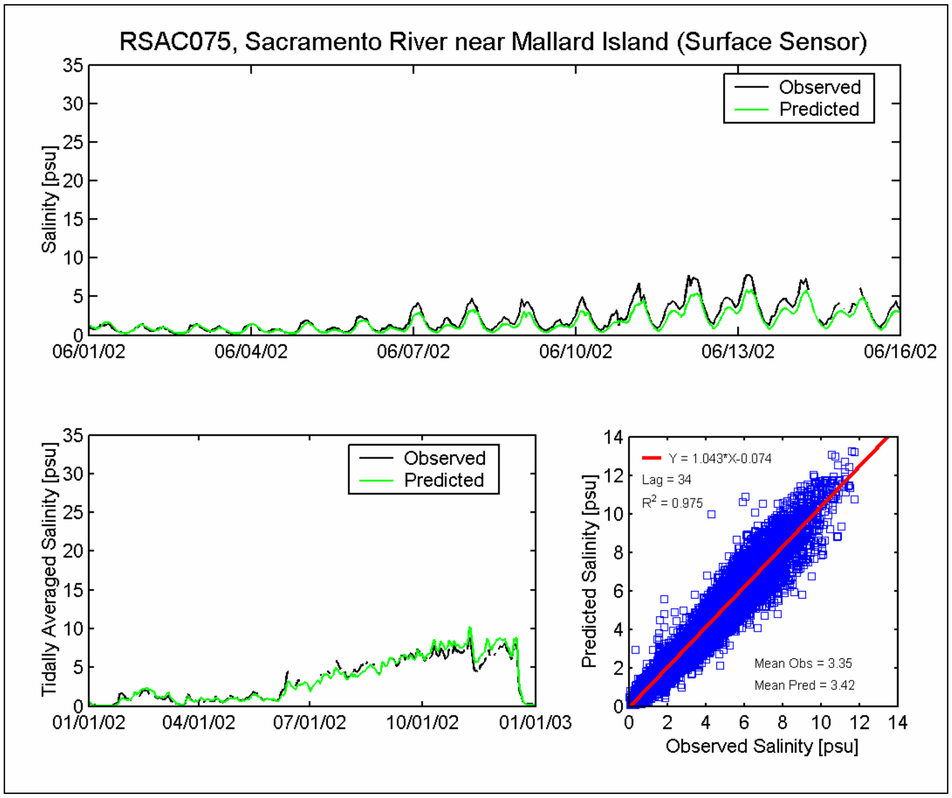


Figure 5.A.2.6-4. Comparison of UnTRIM Simulated and Measured Salinity at Mallard Slough

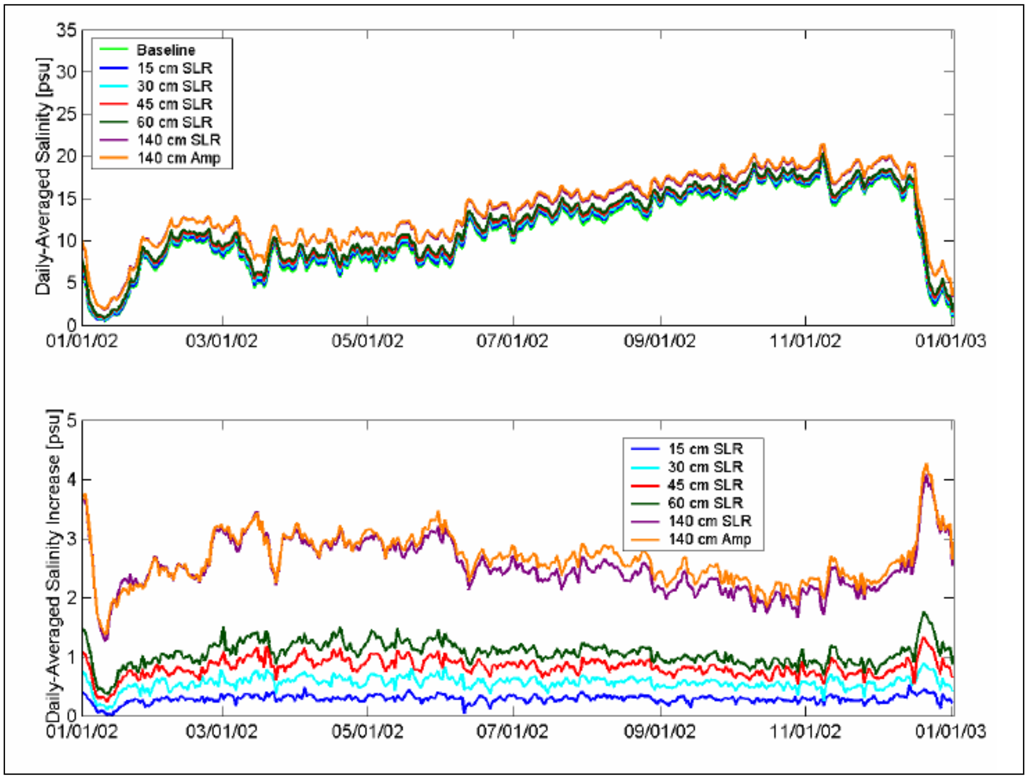


Figure 5.A.2.6-5. UnTRIM Simulated Salinity at Martinez for a Range of Projected Sea Level Rise (15 cm to 140 cm) for 2002

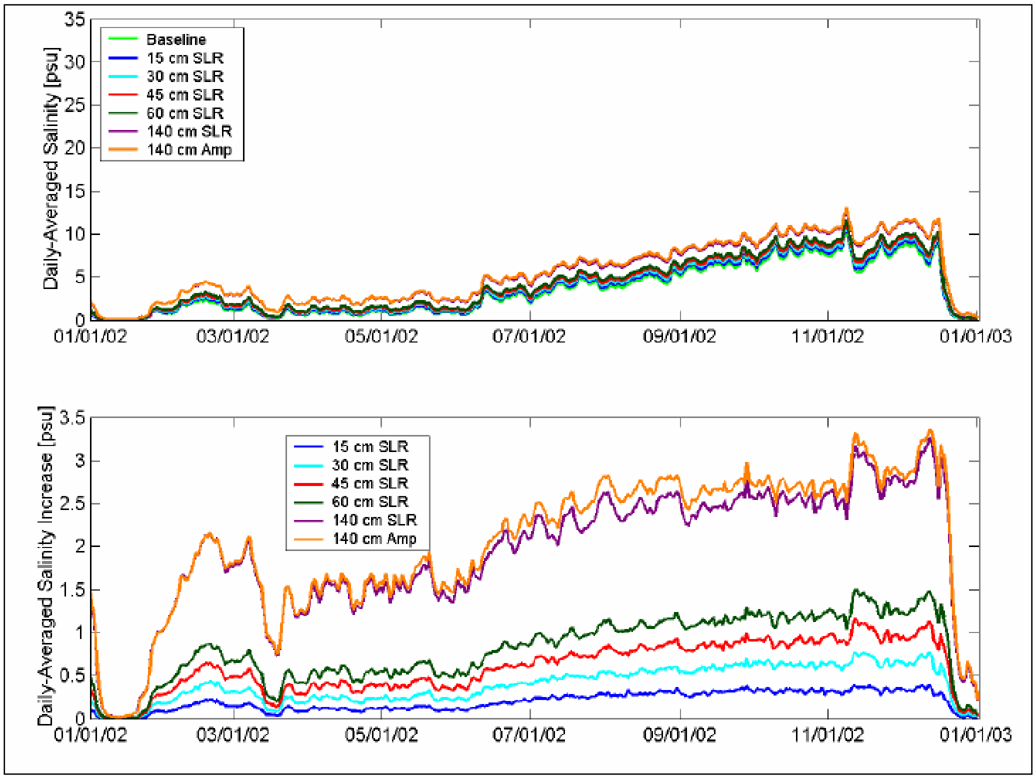
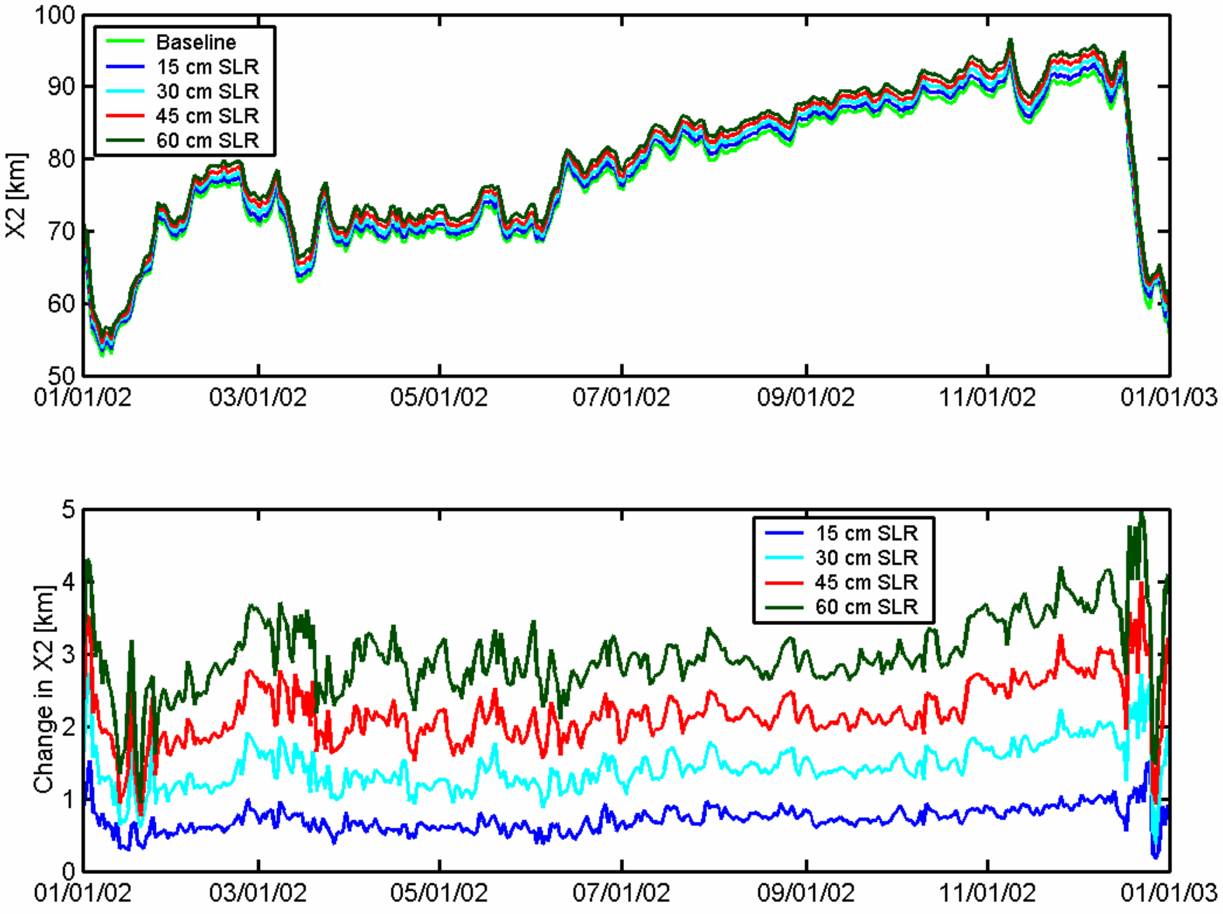


Figure 5.A.2.6-6. UnTRIM Simulated Salinity at Mallard Slough for a Range of Projected Sea Level Rise (15 cm to 140 cm) for 2002



The increased X2 distance is shown in the bottom panel.

Figure 5.A.2.6-7. UnTRIM Simulated X2 Position (km from Golden Gate Bridge) for the Historical and Projected Sea Level Rise Cases (15 cm to 60 cm) for 2002 Historical Flows

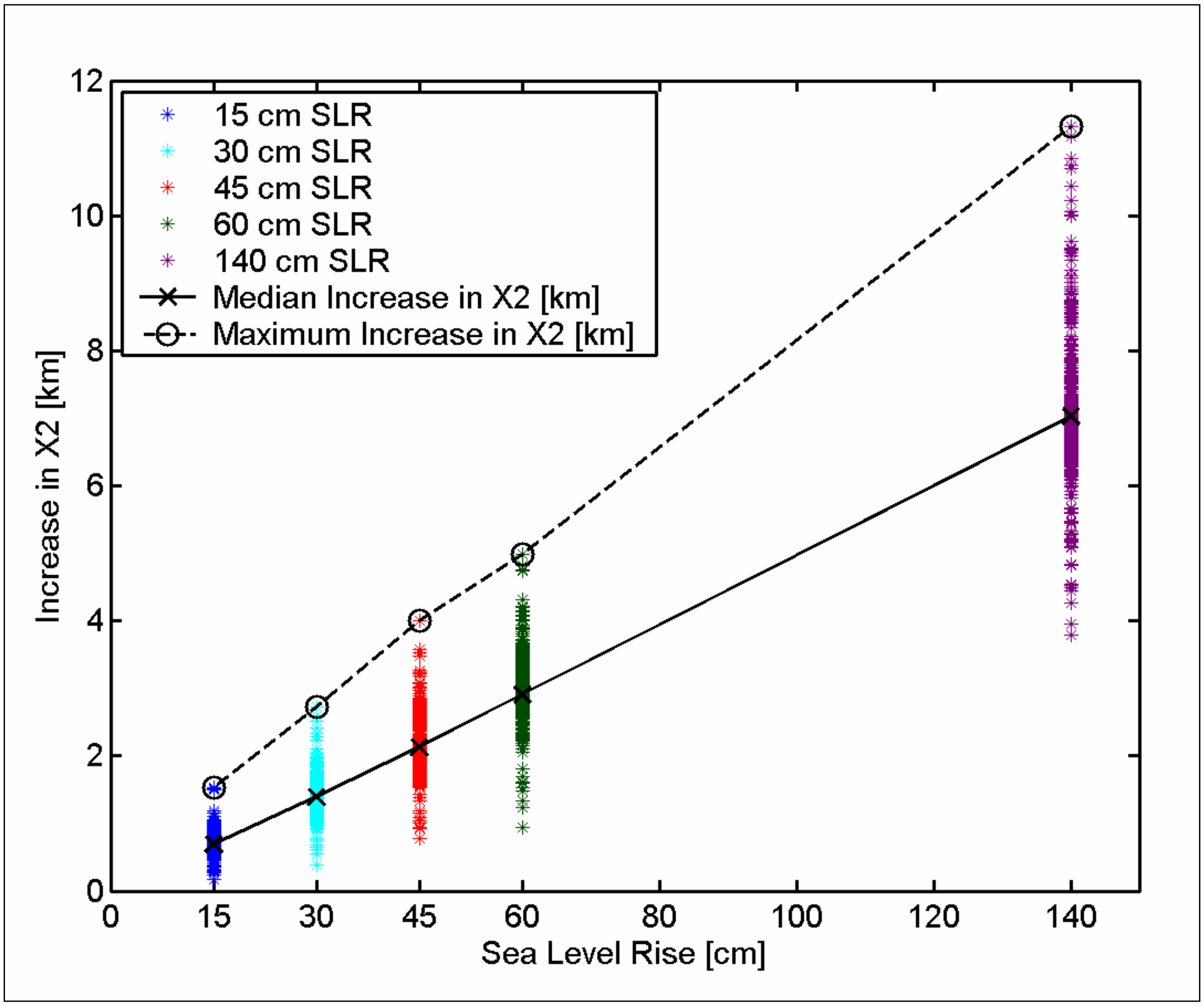


Figure 5.A.2.6-8. Scatter Plot of the Simulated Daily Increases in X2 during 2002 for the Sea Level–Rise Cases

5.A.2.6.3 Use of Modeling Results to Evaluate Effects on Aquatic Species

The modeling results presented in Section 5.A.2.3, *Aquatic Methods and Models*, were used in Appendices 5.B to 5.I to evaluate the potential effects on individual covered fish species under future conditions with climate change. Table 5.A.2.6-2 summarizes the location of climate change results in each appendix for each covered fish species.

Table 5.A.2.6-2. Location of Climate Change Discussion by Appendix

Expected Physical Parameter Change	Species	Section	Life Stage or Location
Appendix 5.B, *Entrainment*			
Change in exports as a result of climate change; entrainment results of fish species as a result of the movement of X2 and change in outflow	Steelhead	5.B.6.1.1	Juvenile
	Winter-run Chinook salmon	5.B.6.1.2	Juvenile
	Spring-run Chinook salmon	5.B.6.1.3.	Juvenile
	Fall-/late fall–run Chinook salmon	5.B.6.1.4	Juvenile
	Delta smelt	5.B.6.1.5	Larval, Adult, Total Population
	Longfin smelt	5.B.6.1.6	Larval, Juvenile, Adult
	Sacramento splittail	5.B.6.1.7	Juvenile, Adult
	White surgeon	5.B.6.1.8	Juvenile
	Green sturgeon	5.B.6.1.9	Juvenile
	Pacific and river lamprey	5.B.6.1.10	Macropthalmia and Adult
Appendix 5.C, *Flow, Salinity, and Passage*			
Change in upstream habitat for spawning, egg incubation, and/or rearing (water temperatures and flow) as a result of climate change	Steelhead	5.C.5.2.1.1	Mainstem Sacramento River
		5.C.5.2.2.1	Trinity River
		5.C.5.2.3.1	Clear Creek
		5.C.5.2.4.1	Feather River
		5.C.5.2.5.1	American River
		5.C.5.2.6.1	Mainstem San Joaquin River
		5.C.5.2.7.1	Stanislaus River
	Winter-run Chinook salmon	5.C.5.2.1.2	Mainstem Sacramento River
	Spring-run Chinook salmon	5.C.5.2.1.3	Mainstem Sacramento River
		5.C.5.2.2.2	Trinity River
		5.C.5.2.3.2	Clear Creek
		5.C.5.2.4.2	Feather River
		5.C.5.2.6.2	Mainstem San Joaquin River
	Fall-/Late fall–run Chinook salmon	5.C.5.2.1.4	Mainstem Sacramento River
		5.C.5.2.2.3	Trinity River
		5.C.5.2.4.3	Feather River
		5.C.5.2.5.2	American River
		5.C.5.2.6.3	Mainstem San Joaquin River
		5.C.5.2.7.2	Stanislaus River
	Splittail	5.C.5.2.1.5	Mainstem Sacramento River
		5.C.5.2.4.4	Feather River
		5.C.5.2.5.3	American River
		5.C.5.2.6.4	Mainstem San Joaquin River
	White sturgeon	5.C.5.2.1.6	Mainstem Sacramento River
		5.C.5.2.4.5	Feather River
		5.C.5.2.6.5	Mainstem San Joaquin River
		5.C.5.2.7.3	Stanislaus River
	Green sturgeon	5.C.5.2.1.7	Mainstem Sacramento River
		5.C.5.2.4.6	Feather River

Expected Physical Parameter Change	**Species**	**Section**	**Life Stage or Location**
	Lamprey	5.C.5.2.1.8	Mainstem Sacramento River
		5.C.5.2.2.4	Trinity River
		5.C.5.2.4.7	Feather River
		5.C.5.2.5.4	American River
		5.C.5.2.7.4	Stanislaus River
Change in upstream migration as a result of flows and temperature changes caused by climate change	Steelhead, winter-run Chinook salmon, spring-run Chinook salmon, fall-run Chinook salmon, late fall–run Chinook salmon, white sturgeon, green sturgeon, pacific lamprey, river lamprey	5.C.5.3.1.9	Delta Region, Sacramento River Subregion, Trinity River Subregion, Clear Creek Subregion, Feather River Subregion, American River Subregion, Stanislaus River Subregion, San Joaquin River Subregion
Change in passage related to Delta inflow and outflow associated with climate change	Smelt larval transport flows	5.C.5.3.1.2	N/A
	Juvenile winter-run, spring-run, and fall-run Chinook salmon	5.C.5.3.1.3	N/A
Change in Delta water temperatures as a result of climate change	Steelhead	5.C.5.4.3.1	Juvenile
		5.C.5.4.3.2	Smoltification
		5.C.5.4.3.3	Adult
	Winter-run Chinook salmon	5.C.5.4.3.4	Juvenile
		5.C.5.4.3.5	Smoltification
		5.C.5.4.3.6	Adult
	Spring-run Chinook salmon	5.C.5.4.3.7	Juvenile
		5.C.5.4.3.8	Smoltification
		5.C.5.4.3.9	Adult
	Fall-run Chinook salmon	5.C.5.4.3.10	Juvenile
		5.C.5.4.3.11	Smoltification
		5.C.5.4.3.12	Adult
	Late fall–run Chinook salmon	5.C.5.4.3.13	Juvenile
		5.C.5.4.3.14	Smoltification
		5.C.5.4.3.15	Adult
	Delta smelt	5.C.5.4.3.16	Adult and Juvenile
	Longfin smelt	5.C.5.4.3.17	Juvenile
		5.C.5.4.3.18	Adult
	White sturgeon	5.C.5.4.3.19	Juvenile
		5.C.5.4.3.20	Adult
	Green sturgeon	5.C.5.4.3.21	Juvenile
		5.C.5.4.3.22	Adult
	Pacific lamprey	5.C.5.4.3.23	Macropthalmia
		5.C.5.4.3.24	Adult
	River lamprey	5.C.5.4.3.25	Macropthalmia
		5.C.5.4.3.26	Adult

Expected Physical Parameter Change	**Species**	**Section**	**Life Stage or Location**
Change in salinity and movement of X2 as a result of climate change	Delta smelt	5.C.5.4.7	Juveniles and adults
Appendix 5.G, *Fish Life Cycle Models*			
Through-Delta survival and adult escapement associated with upstream and Delta climate changes	Winter-run Chinook salmon	5.G.7.1.1, 5.G.7.2.1, 5.G.8.1	Entire life cycle
	Spring-run Chinook salmon	5.G.7.1.2, 5.G.8.2	Entire life cycle
	Delta smelt	5.G.7.3, 5.G.8.3	Entire life cycle
Appendix 5.E, *Habitat Restoration*			
Change in sea level rise and salinity and movement of X2 resulting in changes in habitat suitability	Delta smelt	5.E.6.2.3.1	Cache Slough
		5.E.6.2.4.1	Suisun Marsh
		5.E.6.2.5.1	West Delta
		5.E.6.2.6.1	Cosumnes-Mokelumne
		5.E.6.2.7.1	South Delta
	Longfin smelt	5.E.6.2.3.2	Cache Slough
		5.E.6.2.4.2	Suisun Marsh
		5.E.6.2.5.2	West Delta
		5.E.6.2.6.2	Cosumnes-Mokelumne
		5.E.6.2.7.2	South Delta
	Splittail	5.E.6.2.3.3	Cache Slough
		5.E.6.2.4.3	Suisun Marsh
		5.E.6.2.5.3	West Delta
		5.E.6.2.6.3	Cosumnes-Mokelumne
		5.E.6.2.7.3	South Delta
	Salmonids	5.E.6.2.3.4	Cache Slough
		5.E.6.2.4.4	Suisun Marsh
		5.E.6.2.5.4	West Delta
		5.E.6.2.6.4	Cosumnes-Mokelumne
		5.E.6.2.7.4	South Delta
	Sturgeon	5.E.6.2.3.5	Cache Slough
		5.E.6.2.4.5	Suisun Marsh
		5.E.6.2.5.5	West Delta
		5.E.6.2.6.5	Cosumnes-Mokelumne
		5.E.6.2.7.5	South Delta

The upstream and Delta effects presented below are discussed generally with respect to all covered fish species. Specific effects on those species at greatest risk, including delta smelt or winter-run Chinook salmon, are also presented.

5.A.2.7 Upstream Effects

The modeling results presented above in Section 5.A.2.4, *Upstream Inflow Modeling Results,* show that annual upstream precipitation and runoff are likely to result in either no change or very little change to the inflow at Trinity, Shasta, Oroville, and Folsom Reservoirs. Flows on the Sacramento River and its tributaries are expected either to show no change or only small changes. Inflows to New Melones, New Don Pedro, and New Exchequer Reservoirs on the San Joaquin River are expected to decline under future climate change conditions. The future Millerton Reservoir inflow from the San Joaquin River with climate change would be influenced by the combination of shifted runoff and seasonal storage changes for hydropower in the upstream reservoirs. Therefore, reduced San Joaquin River flows would result from assumed climate change effects, such as reduced inflow from above Friant Dam and tributaries.

Modeling results suggest an increase in air temperatures and water temperatures due to climate change. Thus warmer reservoir inflow temperatures and an increase in the rate of downstream warming of Central Valley rivers are expected. In addition, the expected changes in reservoir inflows would interact with reservoir operations (flood control releases and water supply storage) to also change the release temperatures from the major CVP and SWP reservoirs. Thus the largest changes to reservoir operations result from changes in runoff and inflow caused by climate change unrelated to the BDCP. This suggests that the management of storage for the coldwater pool would be increasingly difficult in the future. Greater carryover storage levels likely would be needed to maintain the coldwater pool for downstream temperature control; this would reduce the available water supply storage capacity in several of the CVP and SWP reservoirs. Water temperatures in rivers below the CVP and SWP reservoirs are expected to increase in the future as air temperatures increase. Modeling indicates that Trinity River temperatures would not exceed the water temperature criteria, but that all other rivers would, especially during years of low storage. For results, including the BDCP, see Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*.

High temperature events are expected to become more common under climate change and could result in stress for species with narrow temperature tolerance levels during one or more life stages. Water temperature changes are perhaps the clearest example of interactions between BDCP biological effects and future climate change effects. Compared with EBC, most of the differences and associated effects on spawning and egg incubation habitat observed among the modeled scenarios for upstream rivers are attributable to near-term and long-term climate change effects (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*).

Of the four runs of Chinook salmon that spawn in the Sacramento and San Joaquin Rivers and tributaries, spring-run adults in Butte Creek and winter-run (all life stages) are vulnerable because of life history stages that occur during the heat of the summertime. Other runs of Chinook salmon are less vulnerable because their life history stages occur during cooler months. Spring-run adults in Butte Creek are limited at the present time by summer holding temperatures, which will increase more with climate change (Thompson et al. 2012). Winter-run is at high risk because its spawning is timed such that eggs develop in summer, when temperatures reach above critical levels. Table 5.A.2.7-1 summarizes the upstream temperature results for winter-run Chinook salmon (for eggs, juveniles, and adults) under future climate change conditions. Modeling results shows that the increased egg mortality for winter-run Chinook salmon is primarily a result of natural seasonal and interannual variation in river flows, coldwater storage, and temperature (Appendices 5.C*, Flow, Passage, Salinity, and Turbidity* and 5.G, *Fish Life Cycle Models*). The frequency of months with water temperatures greater than 56°F increased with distance downstream of Keswick Dam and in response to future climate change (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*). Future climate change likely will reduce suitable incubation temperature conditions, and the increase in upper Sacramento River water temperatures under future climate change would be expected to contribute to increased egg mortality for winter-run Chinook salmon and reduced incubation temperature conditions (Appendix 5.C). Results of egg mortality estimates for winter-run Chinook salmon in the mainstem Sacramento River show a trend toward increasing egg mortality in the future as a result of increased air and water temperatures and changes in expected future hydrologic conditions; the effects of climate change on winter-run Chinook salmon egg mortality are expected to become greater over time for EBC2 (e.g., moving from EBC2_ELT to EBC2_LLT).

Upstream juvenile winter-run salmon rearing occurs during August through December before migration downstream to the ocean. Climate change is expected to contribute greater increase in temperatures than the BDCP in rearing areas, thus reducing the length of river with suitable water temperature for rearing. There was a general increase in the frequency of higher temperatures through time as a result of future climate change and with distance downstream from Keswick Dam.

Adult winter-run Chinook salmon migrate upstream in the mainstem Sacramento River during winter (December through February) and hold in the upper river reaches through the spring and early summer (e.g., December through July) prior to spawning in May through September. There were no months during the early long-term (EBC2_ELT) when water temperatures exceeded the 65°F criterion. During the late long-term (EBC2_LLT), there was a small increase in the frequency of average monthly temperatures in the upper Sacramento River exceeding 65°F due to future climate change. There were no years at any location or in any model scenario when the frequency of exceedance was greater than 1 month within a year under ELT or LLT conditions.

Table 5.A.2.7-2 identifies the percentage of years with good conditions (based on results of Reclamation temperature model) for winter-run Chinook salmon habitat. These results and the results presented above and in Table 5.A.2.7-1 suggest that habitat conditions for spawning would decline in the future in response to climate change. They also suggest that the quality and quantity of suitable habitat for juvenile winter-run Chinook salmon rearing are expected to decline over time in response to changes in climate (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*). The biological significance of a reduction in available spawning habitat varies at the population level in response to a number of factors, including adult escapement. For those years when adult escapement is less than the carrying capacity of the spawning habitat, a reduction in area is expected to have little or no population level effect. In years when escapement is high and exceeds carrying capacity of the reduced habitat, competition among spawners for space (e.g., increased redd superimposition) may increase, resulting in reduced reproductive success. The reduction in the frequency of years when spawning habitat conditions are considered to be good has the potential to result in reduced reproductive success and abundance of winter-run Chinook salmon. Median escapement is generally lower under EBC2_ELT than under EBC2 and generally lower under EBC2_LLT than under EBC2_ELT (Appendix 5.G, *Fish life Cycle Models*). This indicates that climate change is projected to adversely affect winter-run escapement (Appendix 5.G).

Table 5.A.2.7-1. Temperature Results for Winter-Run Chinook Salmon Based on Reclamation Temperature Model

			Number of Years				
Fish Species	**Location**	**Criteria**	**EBC2**	**EBC2_ELT**	**EBC2_LLT**	**EBC2 vs. EBC2_ELT**	**EBC2 vs. EBC2_LLT**
Results of Monthly Analysis of Water Temperatures (>56°F) in the Upper Sacramento River during the May through September Winter-Run Chinook Salmon Egg Incubation Period							
Chinook salmon egg incubation period (May–September)	Sacramento River at Keswick Dam	≥ 1 exceedance	16	27	49	11	33
		2 exceedances	4	4	7	0	3
		3 exceedances	2	6	9	4	7
		4 exceedances	0	0	1	0	1
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	13	21	39	8	26
	Sacramento River at Ball's Ferry	≥ 1 exceedance	42	61	79	19	37
		2 exceedances	9	26	29	17	20
		3 exceedances	3	9	26	6	23
		4 exceedances	4	6	11	2	7
		5 exceedances	1	2	6	1	5
		Consecutive years ≥ 1 exceedance	34	57	79	23	45
	Sacramento River at Jelly's Ferry	≥ 1 exceedance	70	81	81	11	11
		2 exceedances	19	22	10	3	9
		3 exceedances	11	23	18	12	7
		4 exceedances	8	17	24	9	16
		5 exceedances	3	11	29	8	26
		Consecutive years ≥1 exceedance	67	81	81	14	14
	Sacramento River at Bend Bridge	≥ 1 exceedance	78	82	82	4	4
		2 exceedances	30	14	2	16	28
		3 exceedances	16	16	8	0	8
		4 exceedances	11	25	28	14	17
		5 exceedances	9	23	44	14	35
		Consecutive years ≥ 1 exceedance	77	82	82	5	5
Results of the Analysis of Water Temperatures (>65°F) in the Upper Sacramento River during the August through December Winter-Run Juvenile Rearing Period							
Chinook salmon juvenile rearing period (August–December)	Sacramento River at Keswick Dam	≥ 1 exceedance	1	7	9	6	8
		2 exceedances	0	4	7	4	7
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	6	7	6	7

Fish Species	**Location**	**Criteria**	**Number of Years**				
			EBC2	**EBC2_ELT**	**EBC2_LLT**	**EBC2 vs. EBC2_ELT**	**EBC2 vs. EBC2_LLT**
	Sacramento River at Ball's Ferry	≥ 1 exceedance	1	7	10	6	9
		2 exceedances	0	5	8	5	8
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	6	7	6	7
	Sacramento River at Jelly's Ferry	≥ 1 exceedance	1	7	11	6	10
		2 exceedances	1	6	8	5	7
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	6	7	6	7
	Sacramento River at Bend Bridge	≥ 1 exceedance	2	7	13	5	11
		2 exceedances	1	6	8	5	7
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	6	9	6	9
Results of Monthly Analysis of Water Temperatures (>65°F) in the Upper Sacramento River during the November through April Winter-Run Juvenile Chinook Salmon Migration Period							
Chinook salmon juvenile migration period (November–April)	Sacramento River at Keswick Dam	≥ 1 exceedance	0	0	0	0	0
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	0	0	0
	Sacramento River at Ball's Ferry	≥ 1 exceedance	0	0	0	0	0
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	0	0	0
	Sacramento River at Jelly's Ferry	≥ 1 exceedance	0	0	0	0	0
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0

Fish Species	Location	Criteria	Number of Years EBC2	EBC2_ELT	EBC2_LLT	EBC2 vs. EBC2_ELT	EBC2 vs. EBC2_LLT
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	0	0	0
	Sacramento River at Bend Bridge	≥ 1 exceedance	0	0	0	0	0
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	0	0	0
Results of Monthly Analysis of Water Temperatures (>65⁰F) in the Upper Sacramento River during the December through July Winter-Run Adult Chinook Salmon Migration Period							
Chinook salmon adult migration period (December–July)	Sacramento River at Keswick Dam	≥ 1 exceedance	0	0	0	0	0
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	0	0	0
	Sacramento River at Ball's Ferry	≥ 1 exceedance	0	0	2	0	2
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	0	0	0
	Sacramento River at Jelly's Ferry	≥ 1 exceedance	0	0	5	0	5
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	2	0	2
	Sacramento River at Bend Bridge	≥ 1 exceedance	0	0	5	0	5
		2 exceedances	0	0	0	0	0
		3 exceedances	0	0	0	0	0
		4 exceedances	0	0	0	0	0
		5 exceedances	0	0	0	0	0
		Consecutive years ≥ 1 exceedance	0	0	2	0	2

Table 5.A.2.7-2. Percentage of Years with "Good" Conditions for Winter-Run Chinook Salmon Habitat Metrics in the Upper Sacramento River (from SacEFT)[1]

Metric	EBC2	EBC2_ELT	EBC2_LLT	EBC2 vs. EBC2_ELT	EBC2 vs. EBC2_LLT
Spawning WUA[2]	58	46	32	12	26
Redd Scour Risk	98	98	98	0	0
Egg Incubation	97	88	74	9	23
Redd Dewatering Risk	40	37	25	3	15
Juvenile Rearing WUA	32	32	31	0	1
Juvenile Stranding Risk	0	0	0	0	0

[1] Please refer to Appendix 5.C, *Flow, Passage, Salinity, and Turbidity* Attachment C.B, *SacEFT Documentation*, for definition of "good" for each performance measure.

[2] WUA=Weighted Usable Area.

Note: The SacEFT model classifies spawning habitat conditions based on WUA, which was derived from the River 2D simulation model, fitted to data obtained and parameterized by Mark Gard (U.S. Fish and Wildlife Service 2005a).

Although SacEFT operates on a daily time step, results are presented in terms of the percent of years that are classified as good, which is defined differently for each parameter analyzed (see SacEFT documentation for further details). SacEFT classifies spawning habitat conditions as good in 58% of the years under EBC2 (Appendix 5.C, Table 5.C.5.2-10).

5.A.2.8 Delta Effects

Expected climate change outcomes for the Delta include increased extinction risk of covered fish species, especially those whose ranges are located primarily in the Plan Area, and continuing emergence of nonnative species as dominant components of biological communities. Fishes endemic to the Delta, such as delta smelt, are adapted to cool, turbid, low-salinity habitats. It is expected that sustaining these fish species will be increasingly difficult as Delta waters warm and become more saline (Cloern et al. 2011).

Delta smelt spends the majority of its life in the Delta, and is therefore more vulnerable to changes in the temperature and salinity of Delta waters. Other covered species are found in the Delta only during cooler months and are not subjected to high summertime temperatures. Longfin smelt and striped bass have higher salinity tolerances than delta smelt, and can move into the cooler Central Bay or even into the Pacific. Splittail have a comparatively high temperature tolerance so are unlikely to be affected by projected water temperature increases. Salmonids moving through the Delta during the migration period would experience increases in temperatures, but no lethal temperatures are projected (Appendices 5.C, *Flow, Passage, Salinity, and Turbidity* and 5.G, *Fish Life Cycle Models*) and they are less susceptible to water temperature changes because of spending a shorter duration in the Delta.

Table 5.A.2.8-1 identifies the temperature results under climate change for delta smelt. The temperature results for delta smelt suggest that the median spawning day shifted earlier in the year under climate change. The number of stressful days (daily average temperatures of 68–77°F) for juvenile delta smelt in each of the subregions increased into the future accounting for climate change. There were no lethal days (daily average temperatures greater than 77°F) in any of the

subregions for the EBC2 scenarios, and there were no lethal days under any scenario in the Suisun Bay and West Delta subregions.

The expected net result of the changes to sea level and salinity as a result of climate change will result in a Delta with a higher mean sea level, increased duration and frequency of inundation of the existing wetlands, and somewhat higher salinities in Suisun Bay. The primary effect of increased salinity in Suisun Bay caused by sea level rise will be an expected shift upstream of X2 for a given effective Delta outflow. Thus, more outflow would be required to maintain the existing X2 standard at Chipps Island or Collinsville. As X2 moves upstream with sea level rise, more delta smelt larvae/juveniles likely would be found upstream and in the southern Delta (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*).

The temperature, sea level, and salinity results expected under climate change were used to develop a Habitat Suitability Index (HSI) for aquatic species, and the results are presented by Restoration Opportunity Area (ROA) in Appendix 5.E, *Habitat Restoration*. Generally, HSI values decline over the BDCP permit term for all covered fish species because of modeled changes to salinity, temperature, and sea level rise as a result of climate change. The results indicate that the decline in water quality and HSI values for delta smelt over the permit term is primarily the result of increased temperature due to expected climate change. The delta smelt HSI declines in the Suisun Marsh ROA are also due to increases in salinity. For species that migrate through the Delta, such as juvenile salmon, the HSI results indicate that they are not as severely affected by the decline of habitat quality as a result of climate change, possibly because of spending less time in the Plan Area compared to other covered fish species, such as delta smelt.

Table 5.A.2.8-1. DSM2 Temperature Results for Delta Smelt in Plan Area

Subregion	Criteria	EBC2	EBC2_ELT	EBC2_LLT	EBC2 vs. EBC2_ELT	EBC2 vs. EBC2_LLT
Cache Slough	Median Spawning Day (Adult)	130	126	116	4	14
	Number of Stressful Days (Juvenile)	74	90	111	16	37
	Number of Lethal Days	0	0	1	0	1
East Delta	Median Spawning Day (Adult)	132	128	115	4	17
	Number of Stressful Days (Juvenile)	84	96	118	12	34
	Number of Lethal Days	0	0	2	0	2
North Delta	Median Spawning Day (Adult)	132	129	116	3	16
	Number of Stressful Days (Juvenile)	82	95	114	13	32
	Average Lethal Days	0	0	6	0	6
San Joaquin Portion of the South Delta	Median Spawning Day (Adult)	125	121	123	4	2
	Number of Stressful Days (Juvenile)	90	101	101	11	11
	Number of Lethal Days	0	0	0	0	0
South Delta	Median Spawning Day (Adult)	124	119	117	5	7
	Number of Stressful Days (Juvenile)	85	97	113	12	28
	Number of Lethal Days	0	0	1	0	1
Suisun Bay	Median Spawning Day (Adult)	134	129	121	5	13
	Number of Stressful Days (Juvenile)	73	87	111	14	38
	Number of Lethal Days	0	0	0	0	0
Suisun Marsh	Median Spawning Day (Adult)	131	125	117	6	14
	Number of Stressful Days (Juvenile)	73	88	109	15	36
	Average Lethal Days	0	0	0	0	0
West Delta	Median Spawning Day (Adult)	136	129	119	7	17
	Number of Stressful Days (Juvenile)	77	90	113	13	36
	Number of Lethal Days	0	0	0	0	0

5.A.2.9 References Cited

Anderson, J., and A. Miller, 2005. *Estimation of Electrical Conductivity at Martinez for Sea Level Rise Conditions, Methodology for Flow and Salinity Estimates in the Sacramento–San Joaquin Delta and Suisun Marsh.* 26th Annual Progress Report, Chapter 5.

Brekke, L. D., M. D. Dettinger, E. P. Maurer, and M. Anderson. 2008. Significance of Model Credibility in Estimating Climate Projection Distributions for Regional Hydroclimatological Risk Assessments. *Climate Change* 89:371–394.

Bureau of Reclamation. 1997. *Fish Habitat Methodology/Modeling Technical Appendix*. September. Volume 9 in Central Valley Project Improvement Act Draft Program Environmental Impact Statement. Sacramento, CA.

Bureau of Reclamation, U.S. Fish and Wildlife Service, National Marine Fisheries Service, California Department of Water Resources, California Department of Fish and Game, and Suisun Resource Conservation Department. 2011. *Suisun Marsh Habitat Management, Preservation, and Restoration Plan Final Environmental Impact Statement/Environmental Impact Report*. November. SCH#: 2003112039. Sacramento, CA. Prepared with assistance from: ICF International, Sacramento, CA.

Bureau of Reclamation. 2008. Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment. May 2008. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region. Sacramento, CA. Available: <http://www.usbr.gov/mp/cvo/OCAP/docs/OCAP_BA_2008.pdf>.

Bureau of Reclamation. 2008. *Biological Assessment on the Continued Long-term Operations of the Central Valley Project and the State Water Project.* Appendix R: *Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise*.

Bureau of Reclamation. 2012. *San Joaquin River Restoration Program*. Final Program Environmental impact Statement/Report. July Available: <http://www.restoresjr.net/>.

Bureau of Reclamation. 2010. *Climate Change and Hydrology Scenarios for Oklahoma Yield Studies.* Technical Memorandum 86-68210-2010-01. April.

Bureau of Reclamation. 2011. SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water 2011. April. U.S. Department of the Interior, Policy and Administration, Bureau of Reclamation, Denver, CO. Prepared for: United States Congress. Available: <http://www.usbr.gov/climate/SECURE/>.

CALFED Independent Science Board. 2007. Sea Level Rise and Delta Planning. September 6, 2007—Letter from Jeffrey Mount, Chair, CALFED Independent Science Board, to Michael Healey, Lead Scientist, CALFED Bay-Delta Program. Available: <http://science.calwater.ca.gov/pdf/isb/meeting_082807/ISB_response_to_ls_sea_level_090707.pdf>.

California Climate Action Registry. 2009. General Reporting Protocol. Reporting Entity-Wide Greenhouse Gas Emissions. Version 3.1. January. Available: <http://www.climateregistry.org/resources/docs/protocols/grp/GRP_3.1_January2009.pdf>.

California Department of Fish and Game. 2008. Yolo Bypass Wildlife Area Land Management Plan. June. Davis, CA. Prepared in association with: EDAW, Yolo Basin Foundation, and Phillip Williams & Associates, Sacramento, CA. Available: <http://www.yolobasin.org/management.cfm>.

California Department of Water Resources. 2007. Monterey Amendment to the State Water Contracts (Including Kern Water Bank Transfer) and Associated Actions as Part of a Settlement Agreement (Monterey Plus). Environmental Impact Report. Draft. October. (SCH#: 2003011118.) Prepared by PBS&J. Sacramento, CA. Available: <http://www.water.ca.gov/environmentalservices/monterey_plus.cfm>.

California Environmental Protection Agency. 2006. Climate Action Team Report (2006 CAT Report) to Governor Schwarzenegger and the Legislature. March. Submitted April 3, 2006. Available: <http://www.climatechange.ca.gov/climate_action_team/reports/>.

California Environmental Protection Agency. 2010a. Climate Action Team Biennial Report (2009 CAT Report) to Governor Schwarzenegger and the Legislature. April. Posted May 6, 2010. Sacramento, CA. Available: <http://www.climatechange.ca.gov/climate_action_team/reports/>.

California Environmental Protection Agency. 2010b. Climate Action Team Biennial Report (2010 CAT Report) to Governor Schwarzenegger and the Legislature. December. Posted December 31, 2010. Sacramento, CA. Available: <http://www.climatechange.ca.gov/climate_action_team/reports/>.

California Department of Water Resources. 2009. *California Water Plan Update 2009*. Integrated Water Management. Bulletin 160-09. Sacramento, CA. Available: <http://www.waterplan.water.ca.gov/cwpu2009/index.cfm>.

California Department of Water Resources. In process. *California Water Plan Update 2013*. Integrated Water Management. Sacramento, CA. Information and drafts available: <http://www.waterplan.water.ca.gov/cwpu2013/index.cfm>.

California Resources Agency. 2007. Salton Sea Ecosystem Restoration Final Programmatic Environmental Impact Report. June. Available: <http://www.water.ca.gov/saltonsea/peir/>. Sacramento, CA. Prepared by California Department of Water Resources and California Department of Fish and Game, Sacramento, CA. With assistance from: CH2MHill, Sacramento, CA.

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick. 2009. *Climate Change Scenarios and Sea Level Rise Estimates for the California 2008 Climate Change Scenarios Assessment*.

CH2M Hill. 2008. *Climate Change Study, Report on Evaluation Methods and Climate Scenarios. Lower Colorado River Authority—San Antonio Water System*.

Christensen, N. S., and D. P. Lettenmaier. 2006: A Multimodel Ensemble Approach to Assessment of Climate Change Impacts on the Hydrology and Water Resources of the Colorado River Basin. *Hydrol. Earth Sci*. 11:1417–1434.

Chung, F., J. Anderson, S. Arora, M. Ejeta, J. Galef, T. Kadir, K. Kao, A. Olson, C. Quan, E. Reyes, M. Roos, S. Seneviratne, J. Wang, and H. Yin. 2009. *Using Future Climate Projections to Support Water Resources Decision Making in Californi*a. California Energy Commission. CEC-500-2009-052-F.

Cloern, J. E., N. Knowles, L. R. Brown, D. Cayan, M.D. Dettinger, T. L. Morgan, D. H. Schoelhamer, M. T. Stacey, M. van der Wegen, R.W. Wagner, and A.D. Jassby. 2011. Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change. PLoS One 6:e24465. Available: <http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0024465>.

Flick, R. E., J. F. Murray, and L. C. Ewing. 2003. Trends in United States Tidal Datum Statistics and Tide Range. *Journal of Waterway, Port, Coastal and Ocean Engineering* 129 (4). July/August.

Gleckler, P. J., K. E. Taylor, and C. Doutriaux. 2008. Performance Metrics for Climate Models. *Journal of Geophysical Research* 10.

Gross, E. S., N. Nidzieko, and M. L. MacWilliams. 2007a. *Parameterization of Mixing Using a Three-Dimensional Hydrodynamic Model*. Delta Risk Management Strategy. Prepared for the California Department of Water Resources. March.

Gross, E. S., M. L. MacWilliams, and N. Nidzieko. 2007b. *Three-Dimensional Salinity Simulations of Sea Level Rise Scenarios*. Delta Risk Management Strategy. Prepared for the California Department of Water Resources. March.

Hamlet, A. F, E. P. Salathe, and P. Carrasco. 2009. *Statistical Downscaling Techniques for Global Climate Model Simulations of Temperature and Precipitation with Application to Water Resources Planning Studies*.

Intergovernmental Panel on Climate Change. 2000. *Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change.* Nebojsa Nakicenovic and Rob Swart (eds.). Cambridge, UK, and New York, NY: Cambridge University Press. 570 pp.

Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. D. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.). Cambridge, UK, and New York, NY: Cambridge University Press. 996 pp.

Jay, D. A. 2009. Evolution of Tidal Amplitudes in the Eastern Pacific Ocean. *Geophysical Research Letters* 36:L04603.

Liang, X., D. P. Lettenmaier, and E. F. Wood. 1996. *Surface Soil Moisture Parameterization of the VIC-2L Model: Evaluation and Modification*

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges. 1994. A Simple Hydrologically Based Model of Land Surface Water and Energy Fluxes for General Circulation Models. *Journal of Geophysical Research* 99:14415–14428.

MacWilliams, M. L. and E. S. Gross. 2010. *UNTRIM San Francisco Bay–Delta Model Sea Level Rise Scenario Modeling Report*. Prepared for Science Applications International Corporation and California Department of Water Resources. Draft Report, July 16.

Maurer, E. P. 2007. Uncertainty in Hydrologic Impacts of Climate Change in the Sierra Nevada, California under Two Emissions Scenarios. *Climatic Change* 82 (10):1007/s10584-006-9180-9.

Maurer, E. P., A. W. Wood, J. D. Adam, D. P. Lettenmaier, and B. Nijssen. 2002. A Long-Term Hydrologically Based Data Set of Land Surface Fluxes and States for the Conterminous United States. *J Climate* 15(22):3237–3251.

National Marine Fisheries Service. 2009. *Biological and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project*. June 4. Long Beach, CA. Available: <http://www.swr.noaa.gov/ocap/NMFS_Biological_and_Conference_Opinion_on_the_Long-Term_Operations_of_the _CVP_and_SWP.pdf>.

National Research Council. 2010. *Advancing the Science of Climate Change. America's Climate Choices: Panel on Advancing the Science of Climate Change*. Board on Atmospheric Sciences and Climate, Division of Earth and Life Sciences. National Academies Press, Washington, DC. 504 pp.

Nijssen, B., D. P. Lettenmaier, X. Liang, S. W. Wetzel, and E. F. Wood. 1997. Streamflow Simulation for Continental-Scale River Basins. *Water Resour. Res*. 33:711–724.

Pfeffer, W. T., J. T. Harper, and S. O'Neel. 2008. Kinematic Constraints on Glacier Contributions to 21st Century Sea Level Rise. *Science* 321:1340–1343.

Pierce, D. W., T. P. Barnett, B. D. Santer, and P. J. Gleckler. 2009. *Selecting Global Climate Models for Regional Climate Change Studies.* Proceedings of the National Academy of Sciences.

Rahmstorf, S. 2007. A Semi-empirical Approach to Projecting Future Sea Level. *Science* 315. January.

Salathe, E., P. Mote, and M. Wiley. 2007. Review of Scenario Selection and downscaling Methods for the Assessment of Climate Change Impacts on Hydrology in the United States Pacific Northwest. *International Journal of Climatology.* 27:1611–1621.

Semitropic Water Storage District. 2011. Delta Wetlands Project Place of Use Final Environmental Impact Report. August. Prepared by: ESA. Sacramento, CA. Available: <http://www.deltawetlandsproject.com/>.

Thompson, L., M. Escobar, C. Mosser, D. Purkey, D. Yates, and P. Moyle. 2012. Water Management Adaptations to Prevent Loss of Spring-Run Chinook Salmon in California under Climate Change. *Journal of Water Resources Planning and Management* 138 (5):465–478.

U.S. Army Corps of Engineers. 2009. *Water Resources Policies and Authorities Incorporating Sea Level Change Considerations in Civil Works Programs*. Circular No. 1165-2-211. July.

U.S. Fish and Wildlife Service. 2005a. *Flow-habitat relationships for fall-run Chinook salmon spawning in the Sacramento River between Battle Creek and Deer Creek*. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service, Sacramento, CA. 104p.

U.S. Fish and Wildlife Service. 2008. *Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP).* Biological opinion. December. Sacramento, CA. Available: *<http://www.fws.gov/sacramento/delta_update.htm>.*

U.S. Fish and Wildlife Service. 2010. Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California. Draft. January. U.S. Fish and Wildlife Service Region 8. Sacramento, CA. Available: <http://www.fws.gov/ecos/ajax/docs/recovery_plan/TMRP_Intro_1.pdf>.

University of Washington. 2010. Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model. Land Cover and Soil. Available: <http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml>.

Vermeer M., and S. Rahmstorf. 2009. Global Sea Level Linked to Global Temperature. *Proceedings of the National Academy of Sciences of the United States of America* 106:21527–21532.

Wood, A. W., E. P. Maurer, A. Kumar, and D. P. Lettenmaier. 2002. Long-range Experimental Hydrologic Forecasting for the Eastern United States. *J. Geophysical Research—Atmospheres* 107(D20):4429.

Wood, A. W., L. R. Leung, V. Sridhar, and D. P. Lettenmaier. 2004. Hydrologic Implications of Dynamical and Statistical Approaches to Downscaling Climate Model Outputs. *Climatic Change* 15(62):189–216.