Appendix 5A

CalSim II and DSM2 Modeling

This appendix provides information about the methods and assumptions used for the Remanded Biological Opinions on the Coordinated Long-Term Operation of the Central Valley Project (CVP) and State Water Project (SWP) Environmental Impact Statement (EIS) environmental consequences analysis using the CalSim II and DSM2 models. This appendix is organized in three main sections:

- CalSim II and DSM2 Modeling Methodology
- CalSim II and DSM2 Modeling Simulations and Assumptions
- CalSim II and DSM2 Modeling Results

An outline is provided at the beginning of each section.

Appendix 5A, Section A

CalSim II and DSM2 Modeling Methodology

This section summarizes the modeling methodology used to analyze the No Action Alternative, Second Basis of Comparison, and other alternatives in this Environmental Impact Statement (EIS). It describes the overall analytical framework and contains descriptions of the key analytical tools and approaches used in the environmental consequences evaluation for the alternatives.

Appendix 5A, Section A is organized as follows:

- Introduction
- Overview of the Modeling Approach
    - Analytical Tools
    - Key Components of the Analytical Framework
    - Climate Change and Sea-Level Rise
- Hydrology and System Operations
    - CalSim II
    - Artificial Neural Network for Flow-Salinity Relationship
    - Application of CalSim II to Evaluate EIS Alternatives
    - Output Parameters
    - Appropriate Use of CalSim II Results
    - Linkages to Other Models
- Delta Hydrodynamics and Water Quality
    - Overview of Hydrodynamics and Water Quality Modeling Approach
    - Delta Simulation Model (DSM2)
    - Application of DSM2 to Evaluate EIS Alternatives
    - Output Parameters
    - Modeling Limitations
    - Linkages to Other Models
- Climate Change and Sea-Level Rise
    - Climate Change
    - Sea-Level Rise
    - Incorporating Climate Change and Sea-Level Rise in EIS Simulations
    - Climate Change and Sea-Level Rise Modeling Limitations
- References

5A.A.1 Introduction

This EIS includes identifying effects of operations considered until Year 2030 and the hydrologic response of the system to those operations. For modeling purposes, the alternatives are simulated at Year 2030; and in the evaluation of all alternatives at Year 2030, climate change and sea-level rise of 15 centimeters (cm) were assumed to be inherent.

The analytical framework and the tools are used for the environmental consequences analysis are described in this section. Modeling assumptions for all the alternatives are provided in Section B of this appendix.

5A.A.2 Overview of the Modeling Approach

To support the impact analysis of the alternatives, numerical modeling of physical variables (or “physically based modeling”), such as river flows and water temperature, is required to evaluate changes to conditions affecting resources in the Central Valley including the Sacramento-San Joaquin Delta (Delta). A framework of integrated analyses including hydrologic, operations, hydrodynamics, water quality, and fisheries analyses is required to provide information for the comparative National Environmental Policy Act (NEPA) assessment of several resources, such as water supply, surface water, groundwater, and aquatic resources.

The alternatives include operational changes in the coordinated operation of the Central Valley Project (CVP) and State Water Project (SWP). Both these operational changes and other external forcings such as climate and sea-level changes influence the future conditions of reservoir storage, river flow, Delta flows, exports, water temperature, and water quality. Evaluation of these conditions is the primary focus of the physically based modeling analyses.

Figure 5A.A.1 shows the analytical tools applied in these assessments and the relationship between these tools. Each model included in Figure 5A.A.1 provides information to the subsequent model in order to provide various results to support the impact analyses.

Changes to the historical hydrology related to the future climate are applied in the CalSim II model and combined with the assumed operations for each alternative. The CalSim II model simulates the operation of the major CVP and SWP facilities in the Central Valley and generates estimates of river flows, exports, reservoir storage, deliveries, and other parameters.

Agricultural and municipal and industrial deliveries resulting from CalSim II are used for assessment of changes in groundwater resources and in agricultural, municipal, and regional economics. Changes in land use reported by the agricultural economics model are subsequently used to assess changes in air quality.

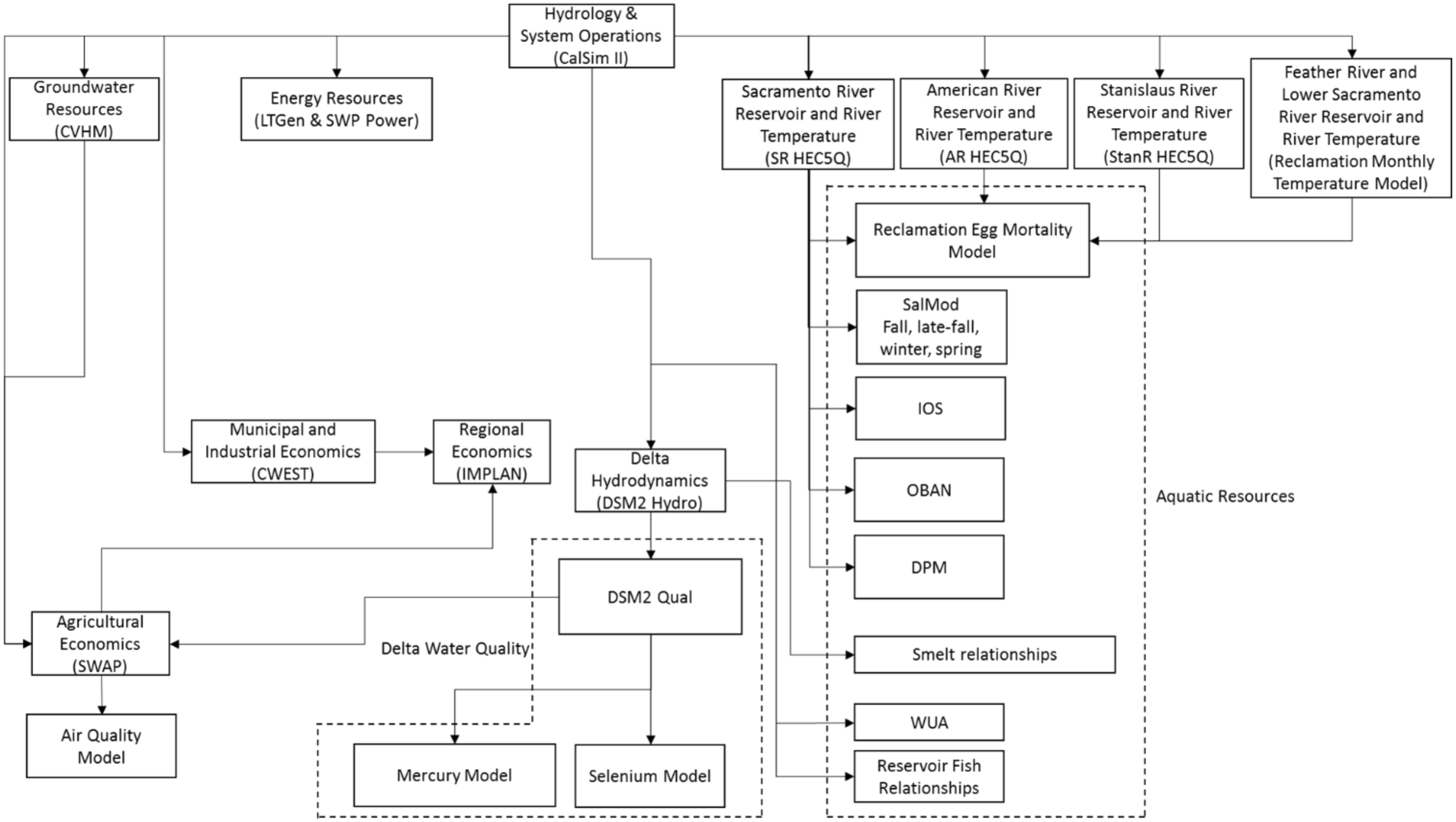


Figure 5A.A.1 Analytical Framework Used to Evaluate Impacts of the Alternatives

The Delta boundary flows and exports from CalSim II are used to drive the DSM2 Delta hydrodynamic and water quality models for estimating tidally based flows, stage, velocity, and salt transport within the estuary. DSM2 water quality and volumetric fingerprinting results are used to assess changes in concentrations of selenium and methylmercury in Delta waters.

Power generation models use CalSim II reservoir levels and releases to estimate power use and generation capability of the projects.

River and temperature models for the primary river systems use the CalSim II reservoir storage, reservoir releases, river flows, and meteorological conditions to estimate reservoir and river temperatures under each scenario.

Results from these temperature models are further used as an input to fisheries models (e.g., SalMod, Reclamation Egg Mortality Model, and IOS) to assess changes in fisheries habitat due to flow and temperature. CalSim II and DSM2 results are also used for fisheries models (IOS, DPM) or aquatic species survival/habitat relationships developed based on peer-reviewed scientific publications.

The results from this suite of physically based models are used to describe the effects of each individual scenario considered in the EIS.

5A.A.2.1 Analytical Tools

A brief description of the hydrologic and hydrodynamic models discussed in Chapter 5, Surface Water Resources and Water Supplies, is provided below. All other subsequent models to CalSim II presented in the analytical framework are described in detail in appendices of the respective chapters where their results are used.

5A.A.2.1.1 CalSim II

The CalSim II planning model was used to simulate the coordinated operation of the CVP and SWP over a range of hydrologic conditions. CalSim II is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets or goals (Draper et al. 2004). CalSim II represents the best available planning model for the CVP and SWP system operations and has been used in previous system-wide evaluations of CVP and SWP operations (Reclamation 2008a).

Inputs to CalSim II include water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiencies, return flows, non-recoverable losses, and groundwater operations. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical sequence of monthly stream flows over an 82-year period (1922 to 2003) to represent a sequence of flows at a particular level of development.

Adjustments to historical water supplies are determined by imposing a defined level of land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the CVP and SWP at that defined level of development.

CalSim II produces outputs for river flows and diversions, reservoir storage, Delta flows and exports, Delta inflow and outflow, deliveries to project and non-project users, and controls on project operations. Reclamation's 2008 Operations Criteria and Plan Biological Assessment (2008 OCAP BA) Appendix D provides more information about CalSim II (Reclamation 2008a). CalSim II output provides the basis for multiple other hydrologic, hydrodynamic, and biological models and analyses. CalSim II results feed into other models as described above.

5A.A.2.1.2 Artificial Neural Network for Flow-Salinity Relationships

An artificial neural network (ANN) that mimics the flow-salinity relationships as modeled in DSM2 and transforms this information into a form usable by the CalSim II model has been developed (Sandhu et al. 1999; Seneviratne and Wu, 2007). The ANN is implemented in CalSim II to constrain the operations of the upstream reservoirs and the Delta export pumps in order to satisfy particular salinity requirements in the Delta. The current ANN predicts salinity at various locations in the Delta using the following parameters as input: Sacramento River inflow, San Joaquin River inflow, Delta Cross Channel gate position, and total exports and diversions. Sacramento River inflow includes Sacramento River flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (east side streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include SWP Banks Pumping Plant, CVP Tracy Pumping Plant, and Contra Costa Water District (CCWD) diversions including diversion to Los Vaqueros Reservoir. The ANN model approximates DSM2 model-generated salinity at the following key locations for the purpose of modeling Delta water quality standards: X2, Sacramento River at Emmaton, San Joaquin River at Jersey Point, Sacramento River at Collinsville, and Old River at Rock Slough. In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, CCWD Alternate Intake Project, and Los Vaqueros diversion locations. A more detailed description of the ANNs and their use in the CalSim II model is provided in Wilbur and Munévar (2001). In addition, the California Department of Water Resources (DWR) Modeling Support Branch website (http://baydeltaoffice.water.ca.gov/modeling/) provides ANN documentation.

5A.A.2.1.3 DSM2

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta. DSM2 represents the best available planning model for Delta tidal hydraulic and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations.

The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates velocities and water surface elevations and provides the flow input for QUAL and PTM. DSM2-HYDRO outputs are used to predict changes in flow rates and depths, and their effects on covered species, as a result of the EIS and climate change.

The QUAL module simulates fate and transport of conservative and non-conservative water quality constituents, including salts, given a flow field simulated by HYDRO. Outputs are used to estimate changes in salinity, and their effects on covered species, as a result of the EIS and climate change. The QUAL module is also used to simulate source water fingerprinting, which allows determining the relative contributions of water sources to the volume at any specified location. Reclamation's 2008 OCAP BA Appendix F provides more information about DSM2 (Reclamation 2008b).

DSM2-PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. It simulates the transport and fate of individual particles traveling throughout the Delta. The model uses velocity, flow, and stage output from the HYDRO module to monitor the location of each individual particle using assumed vertical and lateral velocity profiles and specified random movement to simulate mixing. Additional information on DSM2 can be found on the DWR Modeling Support Branch website at http://baydeltaoffice.water.ca.gov/modeling/.

5A.A.2.2 Key Components of the Analytical Framework

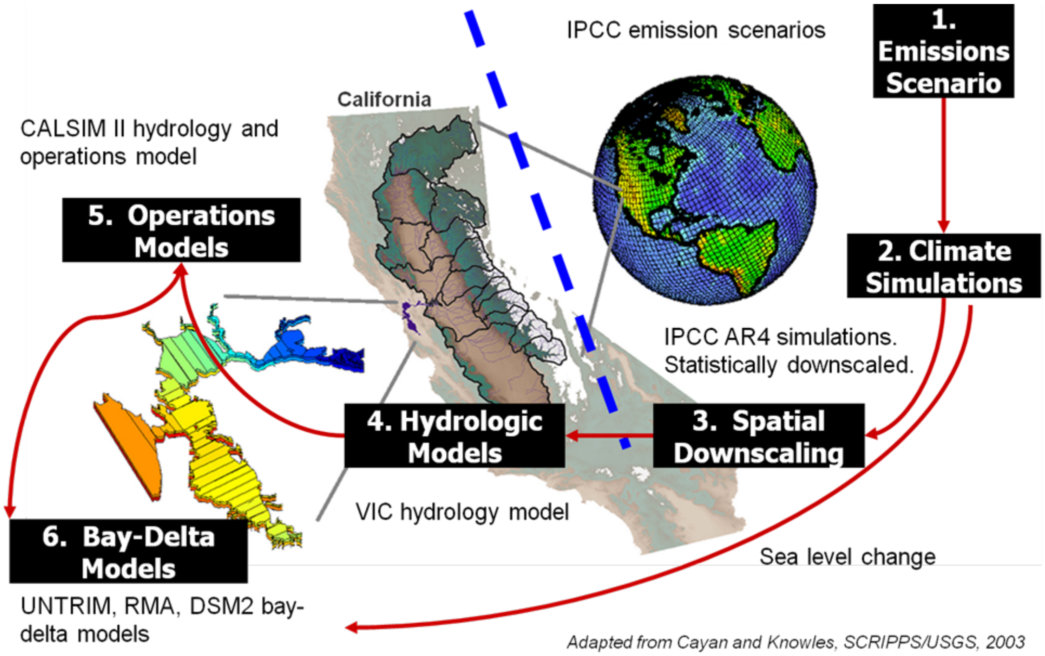
Components of the EIS modeling relevant to Chapter 5, Surface Water Resources and Water Supplies, are described in this appendix in separate sections, including hydrology and systems operations modeling and delta hydrodynamics and water quality. Each section describes in detail the key tools used for modeling, data interdependencies, and limitations. It also includes descriptions of how the tools are applied in a long-term planning analysis such as evaluating the alternatives and describes any improvements or modifications performed for application in EIS modeling.

Section 5A.A.3, Hydrology and Systems Operations Modeling, describes the application of the CalSim II model to evaluate the effects of hydrology and system operations on river flows, reservoir storage, Delta flows and exports, and water deliveries. Section 5A.A.4, Delta Hydrodynamics and Water Quality, describes the application of the DSM2 model to assess effects of the operations considered in the EIS and resulting effects to tidal stage, velocity, flows, and salinity.

5A.A.2.3 Climate Change and Sea-Level Rise

The modeling approach applied for the EIS integrates a suite of analytical tools in a unique manner to characterize changes to the system from "atmosphere to ocean." Figure 5A.A.2 illustrates the general flow of information for incorporating climate and sea-level change in the modeling analyses. Climate and sea level can be considered the most upstream and most downstream boundary forcings on the system analyzed in the modeling for the EIS. However, these forcings are outside the influence of the EIS and are considered external forcings.

The effects of these forcings are incorporated into the key models used in the analytical framework.



Adapted from Cayan and Knowles, SCRIPPS/USGS, 2003

Figure 5A.A.2 Characterizing Climate Impacts from Atmosphere to Oceans

For the selected future climate scenario, regional hydrologic modeling was performed with the Variable Infiltration Capacity (VIC) hydrology model using temperature and precipitation projections of future climate. In addition to a range of hydrologic process information, the VIC model generates natural stream flows under each assumed climate condition (DWR et al. 2013). Section 5A.A.5 provides more detailed information on climate change and sea-level rise modeling approach followed for the EIS.

5A.A.3 Hydrology and System Operations

The hydrology of the Central Valley and coordinated operation of the CVP and SWP systems is a critical element in any assessment of changed conditions in the Central Valley and the Delta. Changes to conveyance, flow patterns, demands, regulations, or Delta configuration will influence the operations of the CVP and SWP reservoirs and export facilities. The operations of these facilities, in turn, influence Delta flows, water quality, river flows, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive and detailed analysis of this interaction often results in new understanding of system responses. Modeling tools are required to approximate these complex interactions under future conditions.

This section describes in detail the use of CalSim II and the methodology used to simulate hydrology and system operations for evaluating the effects of the EIS.

5A.A.3.1 CalSim II

The CalSim II planning model was used to simulate the operation of the CVP and SWP over a range of regulatory conditions. CalSim II is a generalized reservoir-river basin simulation model that allows for the achievement of user-specified allocation targets, or goals (Draper et al. 2004). The current application to the Central Valley system is called CalSim II and represents the best available planning model for the CVP and SWP system operations. CalSim II includes major reservoirs in the Central Valley of the California including Trinity, Lewiston, Whiskeytown, Shasta, Keswick, Folsom, Oroville, San Luis, New Melones, and Millerton located along the Sacramento and San Joaquin rivers and their tributaries. CalSim II also includes all the major CVP and SWP facilities including Clear Creek Tunnel, Tehama Colusa Canal, Corning Canal, Jones Pumping Plant, Delta Mendota Canal, Mendota Pool, Banks Pumping Plant, California Aqueduct, South Bay Aqueduct, North Bay Aqueduct, Coastal Aqueduct and East Branch Extension. It also includes some locally managed facilities such as the Glenn Colusa Canal, Contra Costa Canal, and Los Vaqueros Reservoir.

The CalSim II simulation model uses single time-step optimization techniques to route water through a network of storage nodes and flow arcs based on a series of user-specified relative priorities for water allocation and storage. Physical capacities and specific regulatory and contractual requirements are input as linear constraints to the system operation using the water resources simulation language (WRESL). The process of routing water through the channels and storing water in reservoirs is performed by a mixed-integer linear-programming solver. For each time step, the solver maximizes the objective function to determine a solution that delivers or stores water according to the specified priorities and satisfies all system constraints. The sequence of solved linear-programming problems represents the simulation of the system over the period of analysis.

CalSim II includes an 82-year modified historical hydrology (water years 1922-2003) developed jointly by Reclamation and DWR. Water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiencies, return flows, nonrecoverable losses, and groundwater operations are components that make up the hydrology used in CalSim II. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical observed sequence of monthly stream flows to represent a sequence of flows at a future level of development. Adjustments to historic water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the system at a future level of development. Figure 5A.A.3 shows the valley floor depletion regions, which represent the spatial resolution at which the hydrologic analysis is performed in the model.

Figure 5A.A.3 CalSim II Depletion Analysis Regions

CalSim II uses rule-based algorithms for determining deliveries to north-of-Delta and south-of-Delta CVP and SWP contractors. This delivery logic uses runoff forecast information, which incorporates uncertainty and standardized rule curves. The rule curves relate storage levels and forecasted water supplies to project delivery capability for the upcoming year. The delivery capability is then translated into CVP and SWP contractor allocations that are satisfied through coordinated reservoir-export operations.

The CalSim II model utilizes a monthly time step to route flows throughout the river-reservoir system of the Central Valley. Although monthly time steps are reasonable for long-term planning analyses of water operations, a component of the EIS conveyance and conservation strategy includes operations that are sensitive to flow variability at scales less than monthly (i.e., the operation of the

Fremont Weir). Initial comparisons of monthly versus daily operations at these facilities indicated that weir spills were likely underestimated and diversion potential was likely overstated using a monthly time step. For these reasons, a monthly to daily flow disaggregation technique was included in the CalSim II model for the Fremont Weir and the Sacramento Weir. The technique applies historical daily patterns, based on the hydrology of the year, to transform the monthly volumes into daily flows. Reclamation's 2008 OCAP BA Appendix D provides more information about CalSim II (Reclamation 2008a).

5A.A.3.2 Artificial Neural Network for Flow-Salinity Relationship

Determination of flow-salinity relationships in the Sacramento-San Joaquin Delta is critical to both project and ecosystem management. Operation of the CVP and SWP facilities and management of Delta flows is often dependent on Delta flow needs for salinity standards. Salinity in the Delta cannot be simulated accurately by the simple mass-balance routing and coarse time step used in CalSim II. Likewise, the upstream reservoirs and operational constraints cannot be modeled in the DSM2 model. An ANN has been developed (Sandhu et al. 1999) that attempts to mimic the flow-salinity relationships as simulated in DSM2, but provide a rapid transformation of this information into a form usable by the CalSim II operations model. The ANN is implemented in CalSim II to constrain the operations of the upstream reservoirs and the Delta export pumps in order to satisfy particular salinity requirements. A more detailed description of the use of ANNs in the CalSim II model is provided in Wilbur and Munévar (2001).

The ANN developed by DWR (Sandhu et al. 1999, Seneviratne and Wu 2007) attempts to statistically correlate the salinity results from a particular DSM2 model run to the various peripheral flows (Delta inflows, exports, and diversions), gate operations, and an indicator of tidal energy. The ANN is calibrated or trained on DSM2 results that may represent historical or future conditions using a full-circle analysis (Seneviratne and Wu 2007). For example, a future reconfiguration of the Delta channels to improve conveyance may significantly affect the hydrodynamics of the system. The ANN would be able to represent this new configuration by being retrained on DSM2 model results that included the new configuration.

The current ANN predicts salinity at various locations in the Delta using the following parameters as input: Northern flows, San Joaquin River inflow, Delta Cross Channel gate position, total exports and diversions, Net Delta Consumptive Use (an indicator of the tidal energy), and San Joaquin River at Vernalis salinity. Northern flows include Sacramento River flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (East Side Streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include SWP Banks Pumping Plant, CVP Jones Pumping Plant, and CCWD diversions, including diversions to Los Vaqueros Reservoir. A total of 148 days of values for each of these parameters is included in the correlation, representing an estimate of the length of memory of antecedent conditions in the Delta. The ANN model approximates DSM2 model-generated salinity at the following key locations for the purpose of modeling Delta water quality standards: X2, Sacramento River at Emmaton, San Joaquin River at Jersey Point, Sacramento River at Collinsville, and Old River at Rock Slough. In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, and the CCWD Alternate Intake Project and Los Vaqueros diversion locations.

The ANN may not fully capture the dynamics of the Delta under conditions other than those for which it was trained. It is possible that the ANN will exhibit errors in flow regimes beyond those for which it was trained. Therefore, a new ANN is needed for any new Delta configuration or under sea-level rise conditions that may result in changed flow-salinity relationships in the Delta.

5A.A.3.3 Application of CalSim II to Evaluate EIS Alternatives

Typical long-term planning analyses of the Central Valley system and operations of the CVP and SWP have applied the CalSim II model to analyze system responses. CalSim II simulates future CVP and SWP project operations based on an 82-year monthly hydrology derived from the observed 1922-2003 period. Future land use and demands are projected for the appropriate future period. The system configuration of facilities, operations, and regulations forms the input to the model and defines the limits or preferences for operation. The configuration of the Delta, while not simulated directly in CalSim II, informs the flow-salinity relationships and several flow-related regressions for interior Delta conditions (e.g., X2 and OMR) included in the model. The CalSim II model is simulated for each set of hydrologic, facility, operations, regulations, and Delta configuration conditions. Some refinement of the CVP and SWP operations related to delivery allocations and San Luis target storage levels is generally necessary to have the model reflect suitable north-south reservoir balancing under future conditions. These refinements are generally made by experienced modelers with project operators.

The CalSim II model produces outputs of river flows, exports, water deliveries, reservoir storage, water quality, and several derived variables such as X2, Delta salinity, OMR, and QWEST. The CalSim II model is most appropriately applied for comparing one alternative to another and drawing comparisons among the results. This is the method applied for the EIS.

The No Action Alternative simulation assumes continuation of operations under the current regulatory environment with existing facilities for future climate and sea-level conditions (projected to the Year 2030).

The Second Basis of Comparison is developed due to the identified need during scoping comments for a basis of comparison to operations that would occur “without” the reasonable and prudent alternatives (RPAs). The Second Basis of Comparison assumptions do not include most of the RPAs. The Second Basis of Comparison does, however, include actions that are constructed (e.g., Red Bluff Pumping Plant), implemented (e.g., the Suisun Marsh Habitat Management, Preservation, and Restoration Plan), legislatively mandated (e.g., the San Joaquin River Restoration Plan), and have made substantial progress (e.g., Yolo Bypass Salmonid Habitat Restoration and Fish Passage).

Each alternative is compared to the No Action Alternative and the Second Basis of Comparison to evaluate areas in which the project changes conditions and the seasonality and magnitude of such changes. The change in hydrologic response or system conditions is important information that informs the impact analysis related to water-dependent resources in Sacramento-San Joaquin watersheds.

5A.A.3.3.1 ANN Retraining

ANNs are used for simulating flow-salinity relationships in CalSim II. They are trained on DSM2 outputs and therefore emulate DSM2 results. ANN requires retraining whenever the flow-salinity relationship in the Delta changes. As mentioned earlier, EIS analysis assumes a 15-cm sea-level rise. An ANN developed to simulate salinity conditions with 15-cm sea-level rise was developed by and obtained from DWR. The ANN retraining process is described in Section 5A.A.4.3.1.

5A.A.3.3.2 Incorporation of Climate Change

Climate and sea level change are incorporated into the CalSim II model in two ways: changes to the input hydrology and changes to the flow-salinity relationship in the Delta due to sea-level rise. In this approach, changes in runoff and stream flow are simulated through VIC modeling under representative climate scenarios. These simulated changes in runoff are applied to the CalSim II inflows as a fractional change from the observed inflow patterns (simulated future runoff divided by historical runoff). These fraction changes are first applied for every month of the 82-year period consistent with the VIC simulated patterns. A second order correction is then applied to ensure that the annual shifts in runoff at each location are consistent with that generated from the VIC modeling. A spreadsheet tool has been prepared to process this information and generate adjusted inflow time series records for CalSim II. Once the changes in flows have been resolved, water year types and other hydrologic indices that govern water operations or compliance are adjusted to be consistent with the new hydrologic regime. This spreadsheet tool has been updated for the EIS analysis to accommodate the needs of the CalSim II version used in this study.

The effect of sea-level rise on the flow-salinity response is incorporated in the respective ANN.

The following input parameters are adjusted in CalSim II to incorporate the effects of climate change:

- Inflow time series records for all major streams in the Central Valley
- Sacramento and San Joaquin valley water year types
- Runoff forecasts used for reservoir operations and allocation decisions
- Delta water temperature as used in triggering Biological Opinion Smelt criteria
- A modified ANN to reflect the flow-salinity response under 15-cm sea-level change

Section 5A.A.5 provides more detailed information on climate change and sea-level rise modeling approaches followed for the EIS.

The CalSim II simulations do not consider future climate change adaptations that may manage the CVP and SWP system in a different manner than today to reduce climate impacts. For example, future changes in reservoir flood control reservation to better accommodate a seasonally changing hydrograph may be considered under future programs, but are not considered under the EIS. Thus, the CalSim II EIS results represent the risks to operations, water users, and the environment in the absence of dynamic adaptation for climate change.

5A.A.3.4 Output Parameters

The hydrology and system operations models produce the following key parameters on a monthly time step:

- River flows and diversions
- Reservoir storage
- Delta flows and exports
- Delta inflow and outflow
- Deliveries to project and non-project users
- Controls on project operations

Some operations have been informed by the daily variability included in the CalSim II model for the EIS and, where appropriate, these results are presented. However, it should be noted that CalSim II remains a monthly model. The daily variability inputs to the CalSim II model help to better represent certain operational aspects, but the monthly results are utilized for water balance.

5A.A.3.5 Appropriate Use of CalSim II Results

CalSim II is a monthly model developed for planning level analyses. The model is run for an 82-year historical hydrologic period, at a projected level of hydrology and demands, and under an assumed framework of regulations. Therefore, the 82-year simulation does not provide information about historical conditions, but it does provide information about variability of conditions that would occur at the assumed level of hydrology and demand with the assumed operations, under the same historical hydrologic sequence. Because it is not a physically based model, CalSim II is not calibrated and cannot be used in a predictive manner. CalSim II is intended to be used in a comparative manner, which is appropriate for a NEPA analysis.

In CalSim II, operational decisions are made on a monthly basis, based on a set of predefined rules that represent the assumed regulations. The model has no capability to adjust these rules based on a sequence of hydrologic events such as a prolonged drought, or based on statistical performance criteria such as meeting a storage target in an assumed percentage of years.

Although there are certain components in the model that are downscaled to daily time step (simulated or approximated hydrology) such as an air-temperature-based trigger for a fisheries action, the results of those daily conditions are always averaged to a monthly time step (for example, a certain number of days with and without the action is calculated and the monthly result is calculated using a day-weighted average based on the total number of days in that month), and operational decisions based on those components are made on a monthly basis. Therefore, reporting sub-monthly results from CalSim II or from any other subsequent model that uses monthly CalSim results as an input is not considered an appropriate use of model results.

Appropriate use of model results is important. Despite detailed model inputs and assumptions, the CalSim II results may differ from real-time operations under stressed water supply conditions. Such model results occur due to the inability of the model to make real-time policy decisions under extreme circumstances, as the actual (human) operators must do. Therefore, these results should only be considered an indicator of stressed water supply conditions under that alternative, and should not be considered to reflect what would occur in the future. For example, reductions to senior water rights holders due to dead-pool conditions in the model can be observed in model results under certain circumstances. These reductions, in real-time operations, would be avoided by making policy decisions on other requirements in prior months. In actual future operations, as has always been the case in the past, the project operators would work in real time to satisfy legal and contractual obligations given the current conditions and hydrologic constraints. Chapter 5, Surface Water Resources and Water Supplies, provides appropriate interpretation and analysis of such model results.

Reclamation's 2008 OCAP BA Appendix W (Reclamation 2008c) included a comprehensive sensitivity and uncertainty analysis of CalSim II results relative to the uncertainty in the inputs. This appendix provides a good summary of the key inputs that are critical to the largest changes in several operational outputs. Understanding the findings from this appendix may help in better understanding the alternatives.

5A.A.3.6 Linkages to Other Models

The hydrology and system operations models generally require input assumptions relating to hydrology, demands, regulations, and flow-salinity responses. Reclamation and DWR have prepared hydrologic inputs and demand assumptions for a future (2030) level of development (future land use and development assumptions) based on historical hydroclimatic conditions. Regulations and associated operations are translated into operational requirements. The flow-salinity ANN, representing appropriate sea-level rise, is embedded into the system operations model.

As mentioned previously in this appendix, changes to the historical hydrology related to future climate are applied in the CalSim II model and combined with the assumed operations for each alternative. The CalSim II model simulates the operation of the major CVP and SWP facilities in the Central Valley and generates estimates of river flows, exports, reservoir storage, deliveries, and other parameters.

Agricultural and municipal and industrial deliveries resulting from CalSim II are used for assessing changes to groundwater resources and agricultural, municipal, and regional economics. Changes in land use reported by the agricultural economics model are subsequently used to assess changes in air quality.

The Delta boundary flows and exports from CalSim II are then used to drive the DSM2 Delta hydrodynamic and water quality models for estimating tidally based flows, stage, velocity, and salt transport within the estuary. DSM2 water quality and volumetric fingerprinting results are used to assess changes in concentration of selenium and methylmercury in Delta waters.

Power generation models use CalSim II reservoir levels and releases to estimate power use and generation capability of the projects.

River and temperature models for the primary river systems use the CalSim II reservoir storage, reservoir releases, river flows, and meteorological conditions to estimate reservoir and river temperatures under each scenario.

Results from these temperature models are further used as an input to fisheries models (e.g., SalMod, Reclamation Egg Mortality Model, and IOS) to assess changes in fisheries habitat due to flow and temperature. CalSim II and DSM2 results are also used for fisheries models (IOS, DPM) or aquatic species survival/habitat relationships developed based on peer-reviewed scientific publications.

The results from this suite of physically based models are used to describe the effects of each individual scenario considered in the EIS.

5A.A.4 Delta Hydrodynamics and Water Quality

Hydrodynamics and water quality modeling is essential to understanding the impacts of operation of the CVP and SWP on the Delta. The analysis of the hydrodynamics and water quality changes as a result of operational changes is critical in understanding the impacts on the habitats, species, and water users that depend on the Delta.

This section describes the methodology used for simulating Delta hydrodynamics and water quality for evaluating the alternatives. It discusses the primary tool (DSM2) used in this process.

5A.A.4.1 Overview of Hydrodynamics and Water Quality Modeling Approach

There are several tools available to simulate hydrodynamics and water quality in the Delta. Some tools simulate detailed processes, but are computationally intensive and have long runtimes. Other tools approximate certain processes and have short runtimes, while only compromising slightly on the accuracy of the results. For a planning analysis, it is ideal to understand the resulting changes over several years to cover a range of hydrologic conditions. So, a tool that can simulate the changed hydrodynamics and water quality in the Delta accurately with a short runtime is desired. DSM2 is a one-dimensional hydrodynamics and water quality model that serves this purpose.

DSM2 has a limited ability to simulate two-dimensional features such as tidal marshes and three-dimensional processes such as gravitational circulation, which is known to increase with sea-level rise in the estuaries. Therefore, it must be recalibrated or corroborated based on a data set that accurately represents the conditions in the Delta under sea-level rise. Because the proposed conditions are hypothetical, the best available approach to estimate the Delta hydrodynamics is to simulate higher dimensional models that can resolve the two- and three-dimensional processes well. These models would generate the data sets needed to corroborate or recalibrate DSM2 under those conditions so that it can simulate the hydrodynamics and salinity transport with reasonable accuracy. For the purposes of this EIS, a DSM2 model that was corroborated for 15-cm sea-level rise is used.

5A.A.4.2 Delta Simulation Model

DSM2 is a one-dimensional hydrodynamics, water quality, and particle-tracking simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta (Anderson and Mierzwa 2002). DSM2 represents the best available planning model for Delta tidal hydraulics and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations. The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates one-dimensional hydrodynamics including flows, velocities, depth, and water surface elevations. HYDRO provides the flow input for QUAL and PTM. QUAL simulates one-dimensional fate and transport of conservative and non-conservative water quality constituents given a flow field simulated by HYDRO. PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO.

DSM2 v8.0.6 was used in modeling of the EIS No Action Alternative, Second Basis of Comparison, and the other alternatives using a period of simulation consistent with the CalSim II model (water years 1922 to 2003).

DSM2 hydrodynamics and salinity (electrical conductivity, or EC) were initially calibrated in 1997 (DWR 1997). In 2000, a group of agencies, water users, and stakeholders recalibrated and validated DSM2 in an open process resulting in a model that could replicate the observed data more closely than the 1997 version (DSM2PWT 2001). In 2009, DWR performed a calibration and validation of DSM2 by including the flooded Liberty Island in the DSM2 grid, which allowed for an improved simulation of tidal hydraulics and EC transport in DSM2 (DWR 2009). The model used for evaluating the EIS scenarios was based on this latest calibration.

Simulation of dissolved organic carbon (DOC) transport in DSM2 was successfully validated in 2001 by DWR (Pandey 2001). The temperature and dissolved oxygen (DO) calibration was initially performed in 2003 by DWR (Rajbhandari 2003). Recent development efforts by Resource Management

Associates, Inc. (RMA) in 2009 allowed for improved calibration of temperature, DO, and the nutrient transport in DSM2.

5A.A.4.2.1 DSM2-HYDRO

The HYDRO module is a one-dimensional, implicit, unsteady, open-channel flow model that DWR developed from FOURPT, a four-point finite difference model originally developed by the U.S. Geological Survey (USGS) in Reston, Virginia. DWR adapted the model to the Delta by revising the input-output system, including open-water elements, and incorporating water project facilities, such as gates, barriers, and the Clifton Court Forebay. HYDRO simulates water surface elevations, velocities, and flows in the Delta channels (Nader-Tehrani 1998). HYDRO provides the flow input necessary for QUAL and PTM modules.

The HYDRO module solves the continuity and momentum equations using a fully implicit scheme. These partial differential equations are solved using a finite difference scheme requiring four points of computation. The equations are integrated in time and space, which leads to a solution of stage and flow at the computational points. HYDRO enforces an “equal stage” boundary condition for all the channels connected to a junction. The model can handle both irregular cross-sections derived from the bathymetric surveys and trapezoidal cross-sections. Even though, the model formulation includes a baroclinic term, the density is generally held constant in the HYDRO simulations.

HYDRO allows the simulation of hydraulic gates in the channels. A gate may have several associated hydraulic features (e.g., radial gates, flash boards, and boat ramps), each of which may be operated independently to control flow. Gates can be placed either at the upstream or downstream end of a channel. Once the location of a gate is defined, the boundary condition for the gated channel is modified from “equal stage” to “known flow,” with the calculated flow. The gates can be opened or closed in one or both directions by specifying a coefficient of zero or one.

Reservoirs are used to represent open bodies of water that store flow. Reservoirs are treated as vertical-walled tanks in DSM2, with a known surface area and bottom elevation and are considered instantly well-mixed. The flow interaction between the open water area and one or more of the connecting channels is determined using the general orifice formula. The flow in and out of the reservoir is controlled using the flow coefficient in the orifice equation, which can be different in each direction. DSM2 does not allow the cross-sectional area of the inlet to vary with the water level.

DSM2 v8 includes a new feature called “operating rules” under which the gate operations or the flow boundaries can be modified dynamically when the model is running based on the current value of a state variable (flow, stage, or velocity). The change can also be triggered based on a time series that is not currently simulated in the model (e.g., daily averaged EC) or based on the current time step of the simulation (for example, a change can occur at the end of the day or end of the season). The operating rules include many functions that allow derivation of the quantities to be used as trigger from the model data or outside time series data.

Operating rules allow a change or an action to occur when the trigger value changes from false to true.

5A.A.4.2.2 DSM2-QUAL

The QUAL module is a one-dimensional water quality transport model that DWR adapted from the Branched Lagrangian Transport Model originally developed by the USGS. DWR added many enhancements to the QUAL module, such as open water areas and gates. A Lagrangian feature in the formulation eliminates the numerical dispersion that is inherently in other segmented formulations, although the tidal dispersion coefficients must still be specified. QUAL simulates fate and transport of conservative and nonconservative water quality constituents given a flow field simulated by HYDRO. It can calculate mass transport processes for conservative and nonconservative constituents including salts, water temperature, nutrients, DO, and trihalomethane formation potential.

The main processes contributing to the fate and transport of the constituents include flow-dependent advection and tidal dispersion in the longitudinal direction. Mass-balance equations are solved for all quality constituents in each parcel of water using the tidal flows and volumes calculated by the HYDRO module. Additional information and the equations used are specified in the 19th annual progress report by DWR (Rajbhandari 1998).

The QUAL module is also used to simulate source water fingerprinting, which allows determining the relative contributions of water sources to the volume at any specified location. It is also used to simulate constituent fingerprinting, which determines the relative contributions of conservative constituent sources to the concentration at any specified location. For fingerprinting studies, six main sources are typically tracked: Sacramento River, San Joaquin River, Martinez, Eastside Streams (Mokelumne, Cosumnes and Calaveras combined), agricultural drains (all combined), and Yolo Bypass. For source water fingerprinting, a tracer with constant concentration is assumed for each source tracked, while the concentrations at other inflows are kept as zero. For constituent (e.g., EC) fingerprinting analysis, the concentrations of the desired constituent are specified at each tracked source, while the concentrations at other inflows are kept as zero (Anderson 2003).

5A.A.4.2.3 DSM2 Input Requirements

DSM2 requires input assumptions relating to physical description of the system (e.g., Delta channel, marsh, and island configuration); description of flow control structures such as gates; initial estimates for stage, flow, and EC throughout the Delta; and time-varying input for all boundary river flows and exports, tidal boundary conditions, gate operations, and constituent concentrations at each inflow. Figure 5A.A.4 illustrates the hydrodynamic and water quality boundary conditions required in DSM2. For long-term planning simulations, output from the CalSim II model generally provides the necessary input for the river flows and exports.

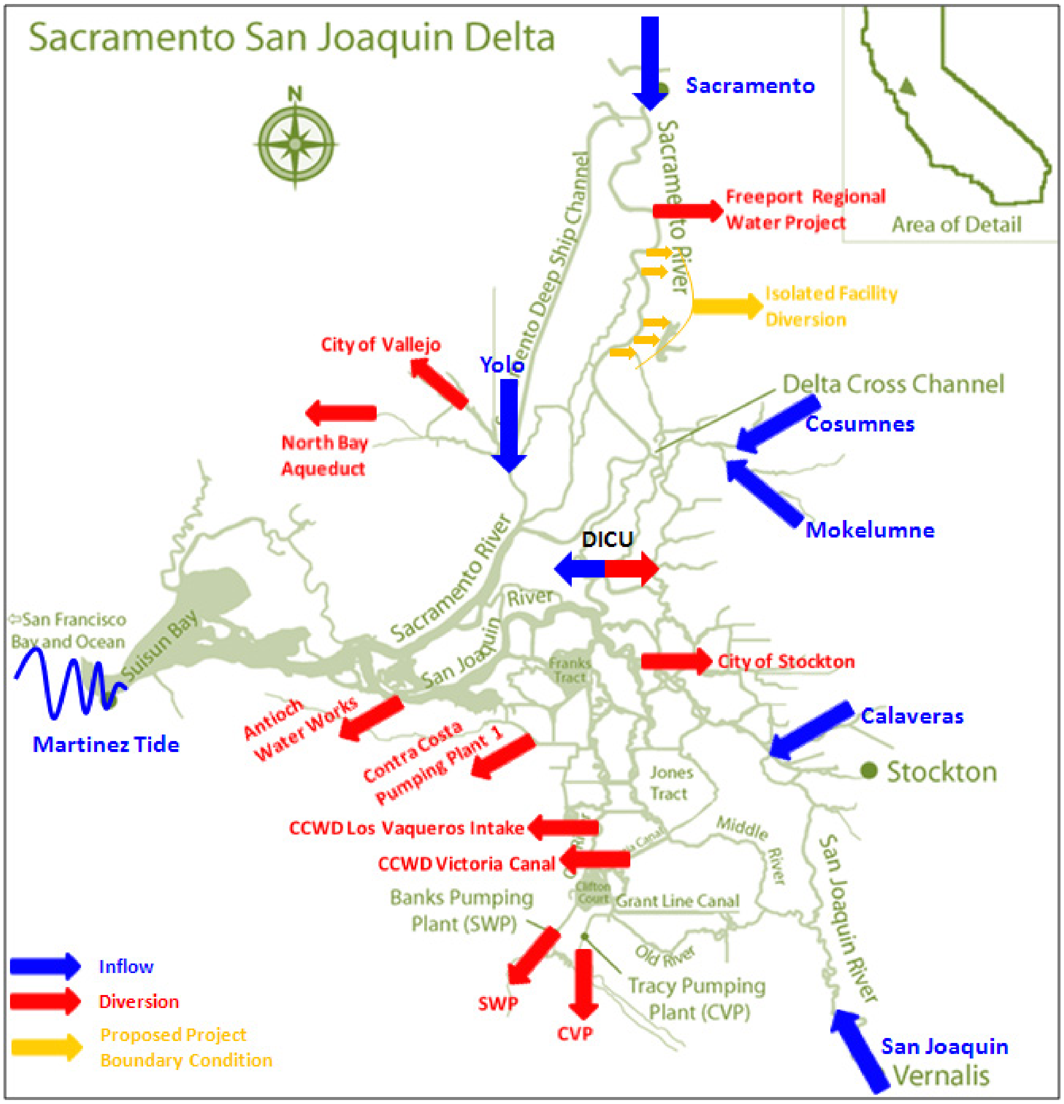


Figure 5A.A.4 Hydrodynamic and Water Quality Boundary Conditions in DSM2

Assumptions relating to Delta configuration and gate operations are directly input into the hydrodynamic models. Adjusted astronomical tide (Ateljevich 2001a) normalized for sea-level rise (Ateljevich and Yu 2007) is forced at the Martinez boundary. Constituent concentrations are specified at the inflow boundaries, which are estimated from either historical information or CalSim II results. The EC boundary condition at Vernalis is derived from the CalSim II results. The Martinez EC boundary condition is derived based on the simulated net Delta outflow from CalSim II and using a modified G-model (Ateljevich 2001b).

The major hydrodynamic boundary conditions are listed in Table 5A.A.1, and the locations at which constituent concentrations are specified for the water quality model are listed in Table 5A.A.2.

1 **Table 5A.A.1 DSM2 HYDRO Boundary Conditions**

Boundary Condition	Location/Control Structure	Typical Temporal Resolution
Tide	Martinez	15 minutes
Delta Inflows	Sacramento River at Freeport	1 day
	San Joaquin River at Vernalis	1 day
	Eastside Streams (Mokelumne and Cosumnes Rivers)	1 day
	Calaveras River	1 day
	Yolo Bypass	1 day
Delta Exports/Diversions	Banks Pumping Plant (SWP)	1 day
	Jones Pumping Plant (CVP)	1 day
	Contra Costa Water District Diversions at Rock Slough, Old River at Highway 4 and Victoria Canal	1 day
	North Bay Aqueduct	1 day
	City of Vallejo	1 day
	Antioch Water Works	1 day
	Freeport Regional Water Project	1 day
	City of Stockton	1 day
	Isolated Facility Diversion	1 day
Delta Island Consumptive Use	Diversion	1 month
	Seepage	1 month
	Drainage	1 month
Gate Operations	Delta Cross Channel	Irregular time series
	South Delta Temporary Barriers	Dynamically operated on 15-minute step
	Montezuma Salinity Control Gate	Dynamically operated on 15-minute step

Table 5A.A.2 DSM2 QUAL Boundary Conditions Typically Used in a Salinity Simulation

Boundary Condition	Location/Control Structure	Typical Temporal Resolution
Ocean Salinity	Martinez	15 minutes
Delta Inflows	Sacramento River at Freeport	Constant
	San Joaquin River at Vernalis	1 month
	Eastside Streams (Mokelumne and Cosumnes Rivers)	Constant
	Calaveras River	Constant
	Yolo Bypass	Constant
Delta Island Consumptive Use	Drainage	1 month (repeated each year)

Note: For other water quality constituents, concentrations are required at the same locations.

5A.A.4.3 Application of DSM2 to Evaluate EIS Alternatives

For EIS purposes, DSM2 was run for the 82-year period from water year 1922 to water year 2003 consistent with CalSim II, on a 15-minute time step. Inputs needed for DSM2—inflows, exports, and Delta Cross Channel (DCC) gate operations—were provided by the 82-year CalSim II simulations. The tidal boundary condition at Martinez was provided by an adjusted astronomical tide (Ateljevich and Yu 2007). Monthly Delta channel depletions (i.e., diversions, seepage, and drainage) were estimated using DWR's Delta Island Consumptive Use model (Mahadevan 1995).

CalSim II provides monthly inflows and exports in the Delta. Traditionally, the Sacramento and San Joaquin river inflows are disaggregated to a daily time step for use in DSM2, either by applying rational histosplines or by assuming that the monthly average flow is constant over the whole month. The splines allow a smooth transition between the months. The smoothing reduces sharp transitions at the start of the month, but still results in constant flows for most of the month. Other inflows, exports, and diversions were assumed to be constant over the month.

DCC gate operation input in DSM2 is based on CalSim II output. For each month, DSM2 assumes the DCC gates are open for the "number of the days open" simulated in CalSim II, from the start of the month.

The operation of the south Delta temporary barriers is determined dynamically in using the operating rules feature in DSM2. These operations generally depend on the season, San Joaquin River flow at Vernalis, and tidal condition in the south Delta. Similarly, the Montezuma Slough salinity control gate operations are determined using an operating rule that sets the operations based on the season, Martinez salinity, and tidal condition in the Montezuma Slough.

For salinity, EC at Martinez is estimated using the G-model on a 15-minute time step, based on the Delta outflow simulated in CalSim II and the pure astronomical tide at Martinez (Ateljevich 2001a). The monthly averaged EC for the San Joaquin River at Vernalis estimated in CalSim II for the 82-year period is used in DSM2. For other river flows, which have low salinity, constant values are assumed. Monthly average values of the EC associated with Delta agricultural drainage and return flows were estimated for three regions in the Delta based on observed data identifying the seasonal trend. These values are repeated for each year of the simulation.

5A.A.4.3.1 ANN Retraining

ANNs are used for flow-salinity relationships in CalSim II. They are trained on DSM2 outputs and therefore emulate DSM2 functionality. ANN requires retraining whenever the flow-salinity relationship in the Delta changes. EIS analysis assumes 15-cm sea-level rise at Year 2030 that results in a different flow-salinity relationship in the Delta and therefore required an ANN retrained for the 15-cm sea-level rise by DWR Bay-Delta Modeling Support Branch staff.

The ANN retraining process involves the following steps:

- The DSM2 model is corroborated for each scenario (changed sea level or Delta physical configuration).
- A range of example long-term CalSim II scenarios is used to provide a range of boundary conditions for DSM2 models.
- Using the grid configuration and the correlations from the corroboration process, several 16-year planning runs are simulated based on the boundary conditions from the identified CalSim II scenarios to create a training data set for each new ANN.
- ANNs are trained using the Delta flows and DCC operations from CalSim II, EC results from DSM2, and the Martinez tide.
- The training data set is divided into two parts; one is used for training the ANN, and the other to validate.
- Once the ANN is ready, a full-circle analysis is performed to assess the performance of the ANN.

Detailed description of the ANN training procedure and the full-circle analysis is provided in DWR’s 2007 annual report (Seneviratne and Wu 2007).

5A.A.4.4 Output Parameters

DSM2 HYDRO provides the following outputs on a 15-minute time step:

- Tidal flow
- Tidal stage
- Tidal velocity

The following variables can be derived from the above outputs:

- Net flows
- Mean sea level, mean higher high water, mean lower low water, and tidal range
- Water depth
- Tidal reversals
- Flow splits, etc.

DSM2 QUAL provides the following outputs on a 15-minute time step:

- Salinity (EC)
- DOC
- Source water and constituent fingerprinting

The following variables can be derived from the above QUAL outputs:

- Bromide, chloride, and total dissolved solids
- Selenium and mercury

In a planning analysis, the flow boundary conditions that drive DSM2 are obtained from the monthly CalSim II model. The agricultural diversions, return flows, and corresponding salinities used in DSM2 are on a monthly time step. The implementation of DCC gate operations in DSM2 assumes that the gates are open from the beginning of a month, irrespective of the water quality needs in the south Delta.

The input assumptions stated earlier should be considered when DSM2 EC results are used to evaluate performance of a baseline or an alternative against the standards. Even though CalSim II releases sufficient flow to meet the standards on a monthly average basis, the resulting EC from DSM2 may be over the standard for part of a month and under the standard for part of the month, depending on the spring/neap tide and other factors (for example, simplification of operations). It is recommended that the results are presented on a monthly basis. Frequency of compliance with a criterion should be computed based on monthly average results. Averaging on a sub-monthly (14-day or more) scale may be appropriate as long as the limitations with respect to the compliance of the baseline model are described in detail and the alternative results are presented as an incremental change from a baseline model.

In general, it is appropriate to present DSM2 QUAL results including EC, DOC, volumetric fingerprinting, and constituent fingerprinting on a monthly time step. When comparing results between two scenarios, computing differences based on these mean monthly statistics is appropriate.

5A.A.4.5 Modeling Limitations

DSM2 is a one-dimensional model with inherent limitations in simulating hydrodynamic and transport processes in a complex estuarine environment such as the Delta. DSM2 assumes that velocity in a channel can be adequately represented by a single average velocity over the channel cross-section, meaning that variations both across the width of the channel and through the water column are negligible. DSM2 does not have the ability to model short-circuiting of flow through a reach, where a majority of the flow in a cross-section is confined to a small portion of the cross-section. DSM2 does not conserve momentum at the channel junctions and does not model the secondary currents in a channel. DSM2 also does not explicitly account for dispersion due to flow accelerating through channel bends. It cannot model the vertical salinity stratification in the channels.

It has inherent limitations in simulating the hydrodynamics related to the open water areas. Since a reservoir surface area is constant in DSM2, it impacts the stage in the reservoir and thereby impacts the flow exchange with the adjoining channel. Due to the inability to change the cross-sectional area of the reservoir inlets with changing water surface elevation, the final entrance and exit coefficients were fine-tuned to match a median flow range. This causes errors in the flow exchange at breaches during the extreme spring and neap tides. Using an arbitrary bottom elevation value for the reservoirs representing the proposed marsh areas to get around the wetting-drying limitation of DSM2 may increase the dilution of salinity in the reservoirs. Accurate representation of tidal marsh areas, bottom elevations, location of breaches, breach widths, cross-sections, and boundary conditions in DSM2 is critical to the agreement of corroboration results.

For open waterbodies DSM2 assumes uniform and instantaneous mixing over the entire open water area. Thus, it does not account for any salinity gradients that may exist within the open waterbodies. Significant uncertainty exists in flow and EC input data related to in-Delta agriculture, which leads to uncertainty in the simulated EC values. Caution needs to be exercised when using EC outputs on a sub-monthly scale. Water quality results inside the waterbodies representing the tidal marsh areas were not validated specifically, and because of the bottom elevation assumptions, preferably should not be used for analysis.

5A.A.4.6 Linkages to Other Models

The Delta boundary flows and exports from CalSim II are used to drive the DSM2 Delta hydrodynamic and water quality models for estimating tidally based flows, stage, velocity, and salt transport within the estuary. DSM2 water quality and volumetric fingerprinting results are used to assess changes in concentration of selenium and methylmercury in Delta waters.

DSM2 results are also used for fisheries models (IOS, DPM) or aquatics species survival/habitat relationships developed based on peer-reviewed scientific publications.

5A.A.5 Climate Change and Sea-Level Rise

The EIS uses a representation of potential climate change and sea-level rise change in numerical models that simulate hydrologic and hydrodynamic conditions in the study area in addition to changes in river flows due to changes in operations and diversions. This section provides brief information on methods used for EIS simulations.

5A.A.5.1 Climate Change

A growing body of evidence indicates that Earth's atmosphere is warming. Records show that surface temperatures have risen about 0.7°C since the early twentieth century and that 0.5°C of this increase has occurred since 1978 (NAS 2006). Observed changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend (NAS 2006, IPCC 2007). The temperature of Earth's atmosphere is directly related to the concentration of atmospheric greenhouse gases. Growing scientific consensus suggests that climate change will be inevitable as the result of increased concentrations of greenhouse gases and related temperature increases (IPCC 2007, Kiparsky and Gleick 2003, Cayan et al. 2009, USGRP 2013).

Observed climate and hydrologic records indicate that more substantial warming has occurred since the 1970s and that this is likely a response to the increases in greenhouse gas (GHG) increases during this time. The recent suite of global climate models (GCMs), a part of the Coupled Model Intercomparison Project Phase 3 (CMIP3)[1] and Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), when simulated under future GHG emission scenarios and current atmospheric GHGs, exhibit warming globally and regionally over California. In the early part of the twenty-first century, the amount of warming produced by the higher-emission A2 scenario is not very different from the lower-emission B1 scenario, but becomes increasingly larger through the middle and especially the latter part of the century. Six GCMs selected for the 2009 scenarios project by the California Climate Action Team project a mid-century temperature increase of about 1°C to 3°C (1.8°F to 5.4°F), and an end-of-century increase from about 2°C to 5°C (3.6°F to 9°F) (Cayan et al. 2009). Precipitation in most of California is dominated by extreme variability, seasonally, annually, and over decade time scales. The GCM simulations of historical climate capture the historical range of variability reasonably well (Cayan et al. 2009), but historical trends are not well captured in these models. Projections of future precipitation are much more uncertain than those for temperature. As climate changes, California is expected to be subjected to alterations in natural hydrologic conditions, including changes in snow accumulation and stream flow availability.

5A.A.5.2 Sea-Level Rise

Global and regional sea levels have been increasing steadily over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gages along the California coast has

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[1] At the time of methods selection for the EIS, Coupled Model Intercomparison Project Phase 3 (CMIP3) projections were the most recently available ensembles. Even though Coupled Model Intercomparison Project Phase 5 (CMIP5) was released by the IPCC (after the methods selection for the EIS) in 2013, the use of CMIP3 ensembles are deemed appropriate because the differences in the projected changes in annual precipitation and temperature between the CMIP3 and CMIP5 projections are relatively small over the Central Valley by the end of 2030.

risen at a rate of about 17 to 20 cm (6.7 to 7.9 inches) per century (Cayan et al. 2009). While there is considerable variability among the gages along the Pacific Coast, primarily reflecting local differences in vertical movement of the land and length of gage record, this observed rate in mean sea level is similar to the global mean trend (NOAA 2012). Global estimates of sea-level rise made in the most recent assessment by the IPCC (2007) indicate a range of 18 to 59 cm (7.1 to 23.2 inches) this century. However, since the release of the IPCC AR4, advances have occurred in the understanding of sea-level rise. These advances in the science have led to criticism of the approach used by the IPCC. Recent work by Rahmstorf (2007), Vermeer and Rahmstorf (2009), and others suggests that the sea-level rise may be substantially greater than the IPCC projections.

Empirical models based on the observed relationship between global temperatures and sea levels have been shown to perform better than the IPCC models in reconstructing recent observed trends. Rahmstorf (2007) and Vermeer and Rahmstorf (2009) demonstrated that such a relationship, when applied to the range of emission scenarios of IPCC (2007), results in a mid-range rise this century of 70 to 100 cm (28 to 39 inches), with a full range of variability of 50 to 140 cm (20 to 55 inches). The CALFED Science Program (CALFED 2007), State of California, and others have made assessments of the range of potential future sea-level rise throughout 21st century.

In 2011, the United States Army Corps of Engineers (USACE) issued guidance on incorporating sea-level change in civil works programs (USACE 2011). The guidance document reviews the existing literature and suggests use of a range of sea-level change projections, including the “high probability” of accelerating global sea-level rise. The ranges of future sea-level rise were based on the empirical procedure recommended by the National Research Council and updated for recent conditions (NRC 2007). The three scenarios included in the USACE guidance suggest end-of-century sea-level rise in the range of 50 to 150 cm (20 to 59 inches), consistent with the range of projections by Rahmstorf (2007) and Vermeer and Rahmstorf (2009). The USACE Bulletin expired in September 2013.[2]

The recent NRC study (NRC 2012) on west coast sea-level rise relies on estimates of the individual components that contribute to sea-level rise and then sums those to produce the projections. The recent NRC sea-level rise projections for California have wider ranges, but the upper limits are not as high as those from Vermeer and Rahmstorf’s (2009) global projections. The California State Sea-Level Rise Guidance Document (CO-CAT 2013) was updated in March 2013 with the scientific findings of the 2012 NRC report.

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[2] At the time of methods selection for the EIS, USACE 2011 was the most recent guidance. Current most recent guidance (USACE 2013) suggests evaluation of a low, medium, and high sea-level rise. The projected mean sea level rise ranges between 10 cm and 14 cm at 2030 relative to year 2000 based on the recent NRC (2012) study and using the USACE Sea Level Change Curve Calculator (2015.46) located at http://www.corpsclimate.us/ccaceslcurves.cfm. The mean projected sea-level rise is similar to the EIS assumption of 15 cm at Year 2030. Due to the considerable uncertainty in the future sea-level change projections and the state of sea-level rise science, the use of 15 cm sea-level rise for the EIS was deemed reasonable.

As sea-level rise progresses during the century, the hydrodynamics of the San Francisco Bay-Sacramento-San Joaquin Delta estuary will change, causing the salinity of water in the Delta estuary to increase. This increasing salinity will most likely have significant impacts on water management throughout the Central Valley and other regions of the state.

5A.A.5.3 Incorporating Climate Change and Sea-Level Rise in EIS Simulations

Incorporation of climate change in water resources planning continues to be an area of evolving science, methods, and applications. Several potential approaches exist for incorporating climate change in the resources impact analyses. Currently, there is no standardized methodology that has been adopted by either the State of California or the Federal agencies for use in impact assessments. The courts have ruled that climate change must be considered in the planning of long-term water management projects in California, but have not been prescriptive in terms of methodologies to be applied. Climate change could be addressed in a qualitative and/or quantitative manner, could focus on global climate model projections or recent observed trends, and could explore broader descriptions of observed variability by blending paleoclimate information into this understanding.

One of the recent publicly available studies that have incorporated potential climate change and sea-level rise scenarios in the modeling is the Bay Delta Conservation Plan (BDCP). At the time of incorporating climate change in EIS simulations, the methodology in the BDCP Environmental Impact Report/EIS had the greatest level of detail incorporating climate change and sea-level rise scenarios for water resources planning in published documents. Therefore, for the purposes of the EIS simulations, BDCP methodology is used.

5A.A.5.3.1 Incorporating Climate Change

The approach uses five statistically representative climate change scenarios to characterize the central tendency, also known as Q5, and the range of the ensemble uncertainty including projections representing drier, less warming; drier, more warming; wetter, more warming; and wetter, less warming conditions than the median projection. For the purposes of the EIS, Q5 climate change scenario for the period centered on 2025 is used. This period is considered because EIS extends only up to 2030. The Q5 scenario was derived from the central tending “consensus” of the climate projections and thus represents the median ensemble projection.

The climate change scenarios were developed from an ensemble of 112 bias-corrected, spatially downscaled GCM simulations from 16 climate models for SRES emission scenarios A2, A1B, and B1 from the CMIP3 that are part of the IPCC AR4. The future projected changes over the 30-year climatological period centered on 2025 (i.e., 2011-2040 to represent 2025 timeline) (early long-term) and 2060 (i.e., 2046-2075 to represent 2060 timeline) (late long-term) were combined with a set of historically observed temperatures and precipitation to generate climate sequences that maintain important multi-year variability not always reproduced in direct climate projections.

Figures 5A.A.5 through 5A.A.8 present projected changes in temperature and precipitation for the 2025 timeline. The modified temperature and precipitation inputs were used in the VIC hydrology model to simulate hydrologic processes on the 1/8th degree scale to produce watershed runoff (and other hydrologic variables) for the major rivers and streams in the Central Valley. Figures 5A.A.9 through 5A.A.18 present projected changes in watershed runoff for the major rivers and streams in the Central Valley for the 2025 timeline.

These simulated changes in runoff were applied to the CalSim II inflows as a fractional change from the observed inflow patterns (simulated future runoff divided by historical runoff). These fraction changes were first applied for every month of the 82-year period consistent with the VIC simulated patterns. A second correction was then applied to ensure that the annual shifts in runoff at each location are consistent with that generated from the VIC modeling. Once the changes in flows had been resolved, water year types and other hydrologic indices that govern water operations or compliance were adjusted to be consistent with the new hydrologic regime.

The changes in reservoir inflows, key valley floor accretions, and water year types and hydrologic indices were translated into modified input time series for the CalSim II model.

5A.A.5.3.2 Incorporation of Sea-Level Rise

For sea-level rise simulation, using the work conducted by Rahmstorf, it was assumed the projected sea-level rise at the early long-term timeline (2025) would be approximately 12 to 18 cm (5 to 7 inches). At the late long-term timeline (2060), the projected sea-level rise was assumed to be approximately 30 to 60 cm (12 to 24 inches).

These sea-level rise estimates were consistent with those outlined in the recent USACE guidance circular for incorporating sea-level changes in civil works programs (USACE 2013). Due to the considerable uncertainty in these projections and the state of sea-level rise science, it was proposed to use the mid-range of the estimates of 15 cm (6 inches) by 2025 and 45 cm (18 inches) by 2060.

For the purposes of the EIS, the sea-level rise scenario for the period centered on 2025 is used (DWR et al. 2013). This period is considered because the EIS extends only up to 2030. These changes were simulated in Bay-Delta hydrodynamics models, and their effect on the flow-salinity relationship in the Bay-Delta was incorporated into CalSim II modeling through the use of ANNs.

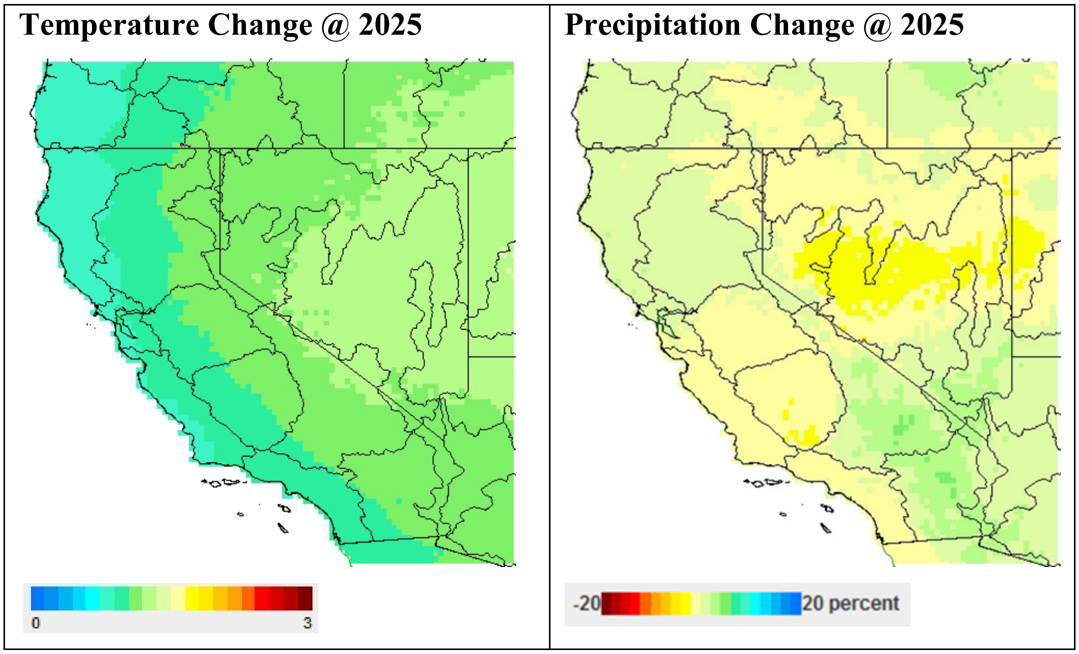
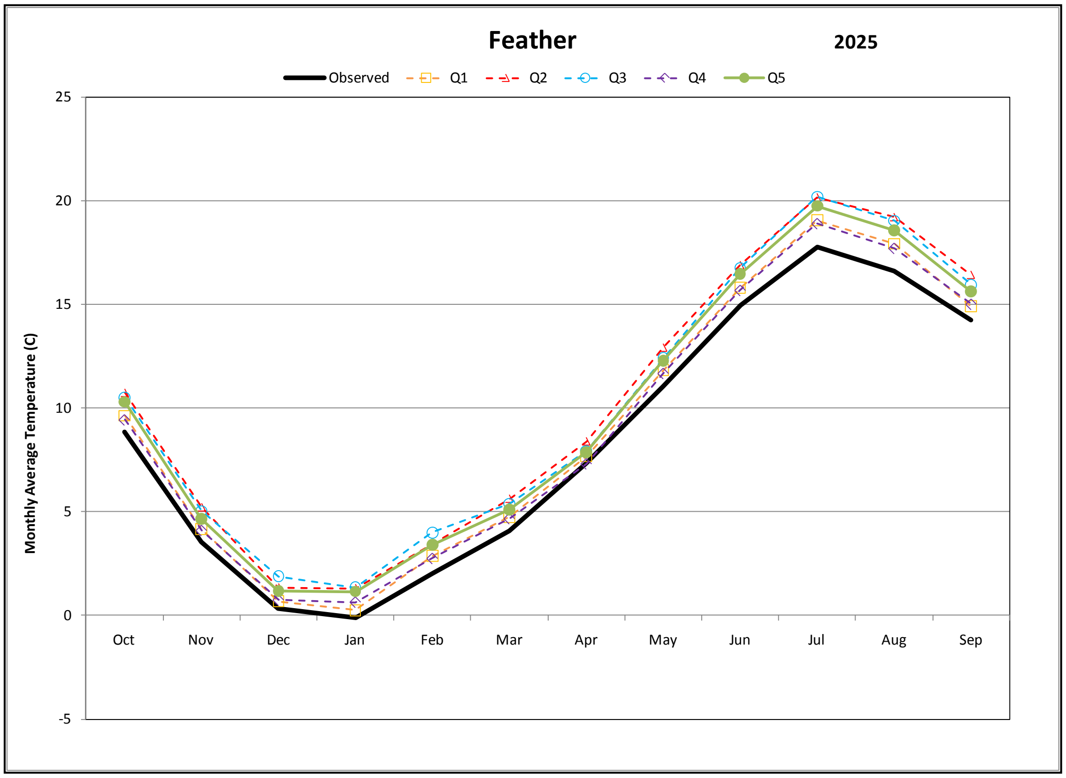
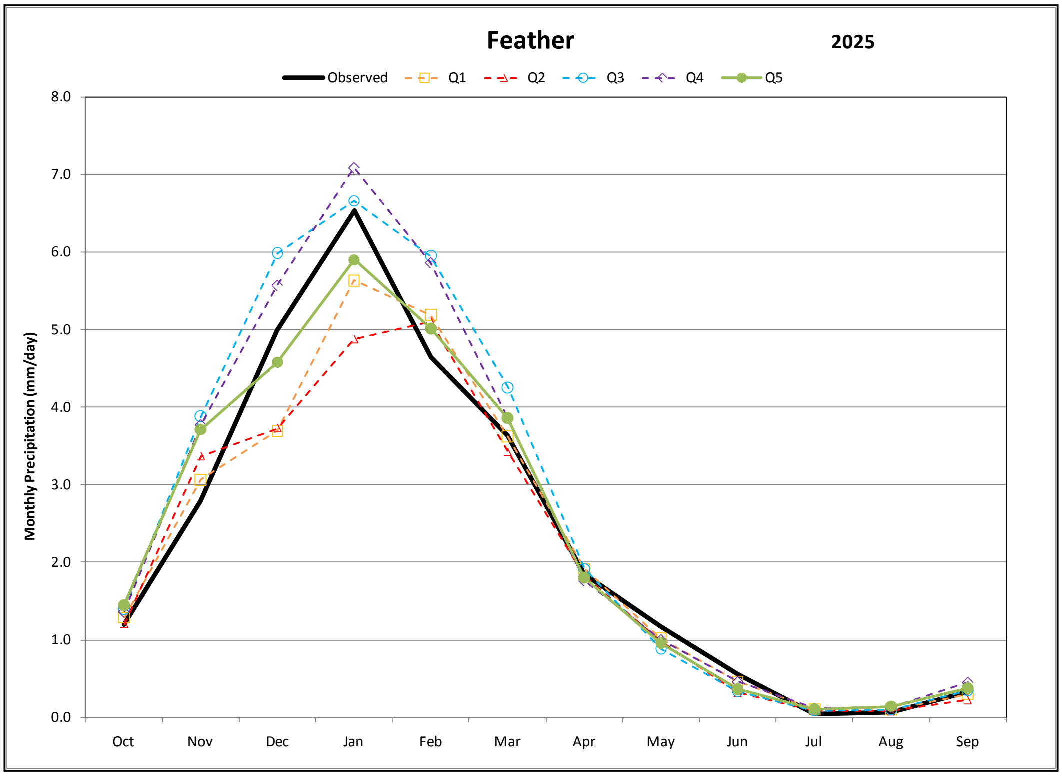


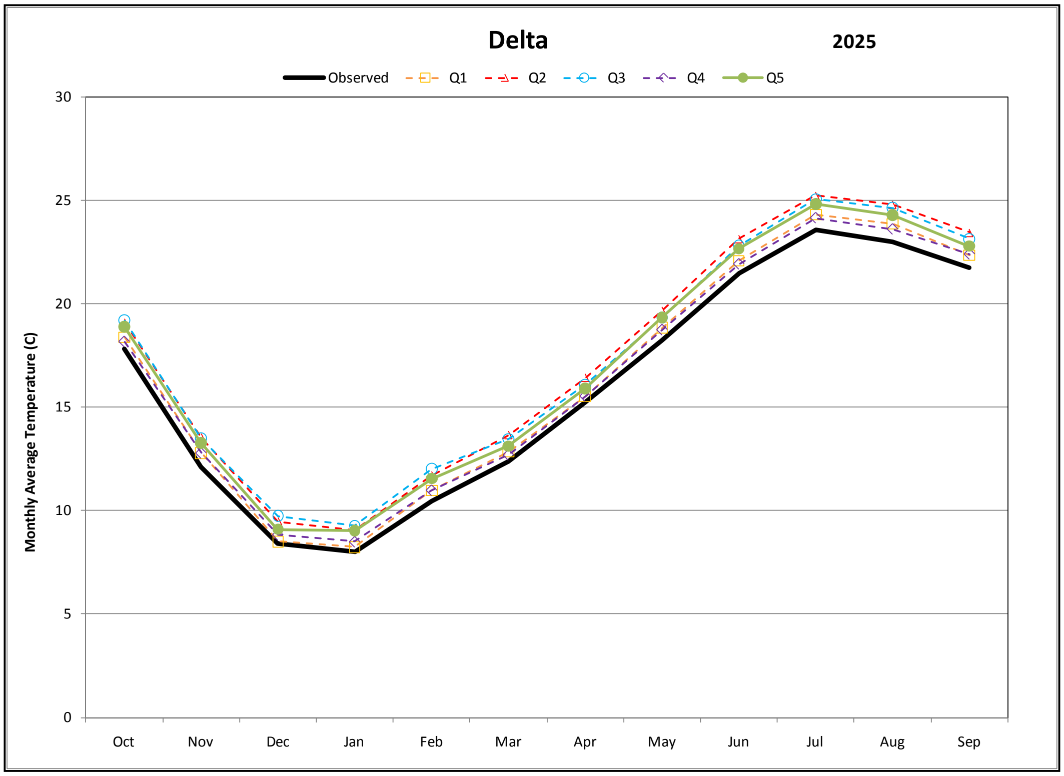
Figure 5A.A.5 Projected Changes in Annual Temperature (as degrees C) and Precipitation (as percent change) for the Period 2011-2040 (2025) as Compared to the 1971-2000 Historical Period

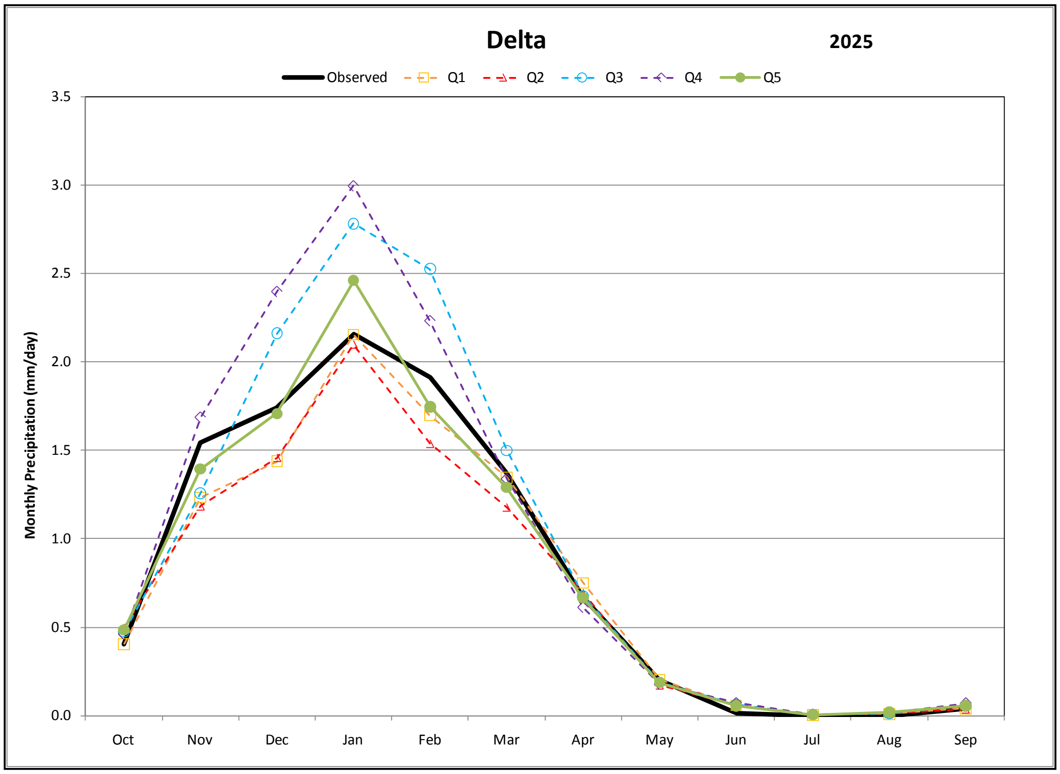
Derived from Daily Gridded Observed Meteorology (Maurer et al. 2002).



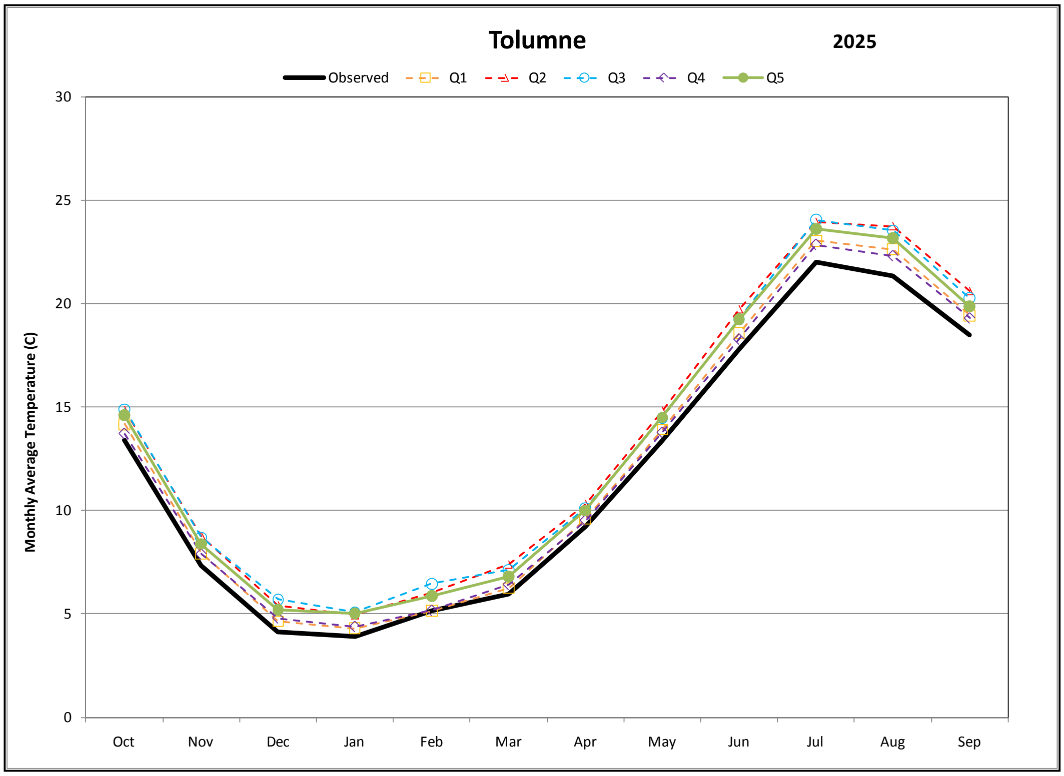


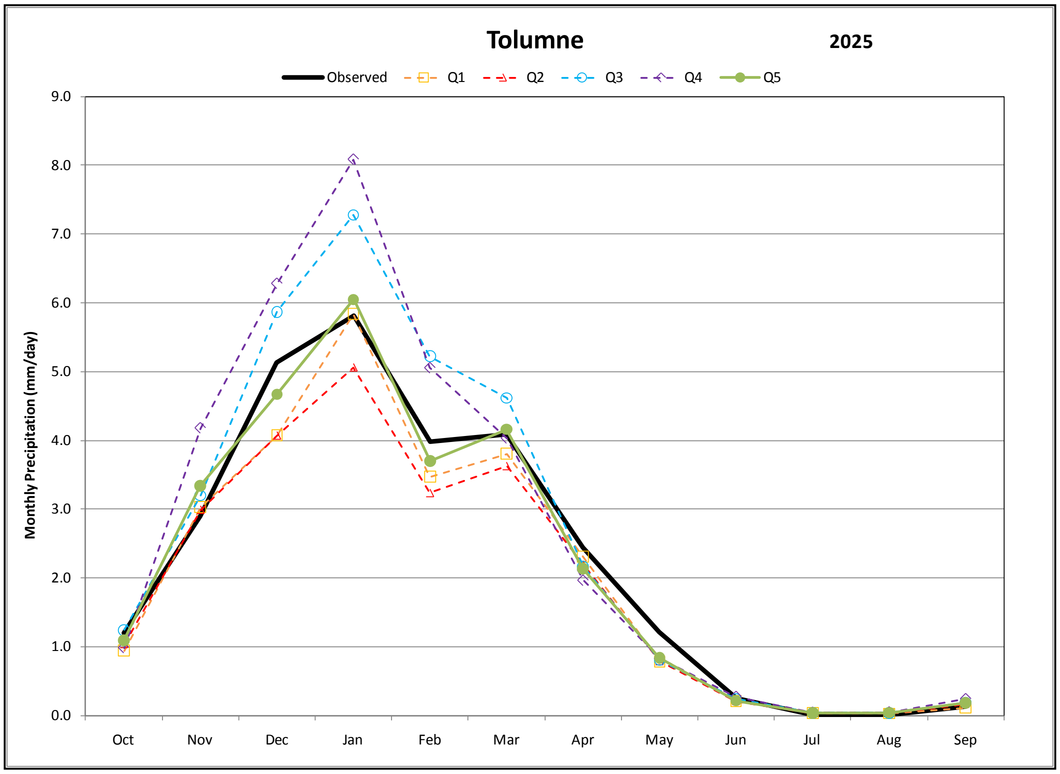
1 **Figure 5A.A.6 Projected Changes in Seasonal Temperature (top) and Precipitation**
2 **(bottom) for a Grid Cell in the Feather River Basin**





1 **Figure 5A.A.7 Projected Changes in Seasonal Temperature (top) and Precipitation**
2 **(bottom) for a Grid Cell in the Delta**





1 **Figure 5A.A.8 Projected Changes in Seasonal Temperature (top) and Precipitation**
2 **(bottom) for a Grid Cell in the Tuolumne River Basin**

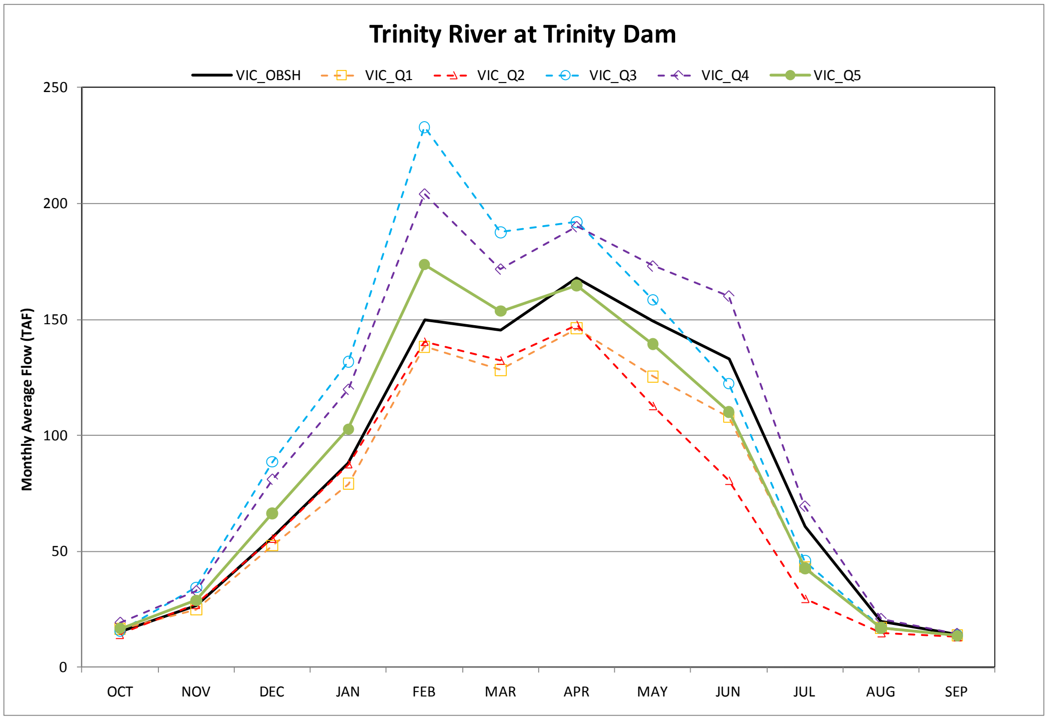


Figure 5A.A.9 Simulated Changes in Monthly Natural Streamflow for Trinity River at Trinity Dam (for the 2025 timeline)

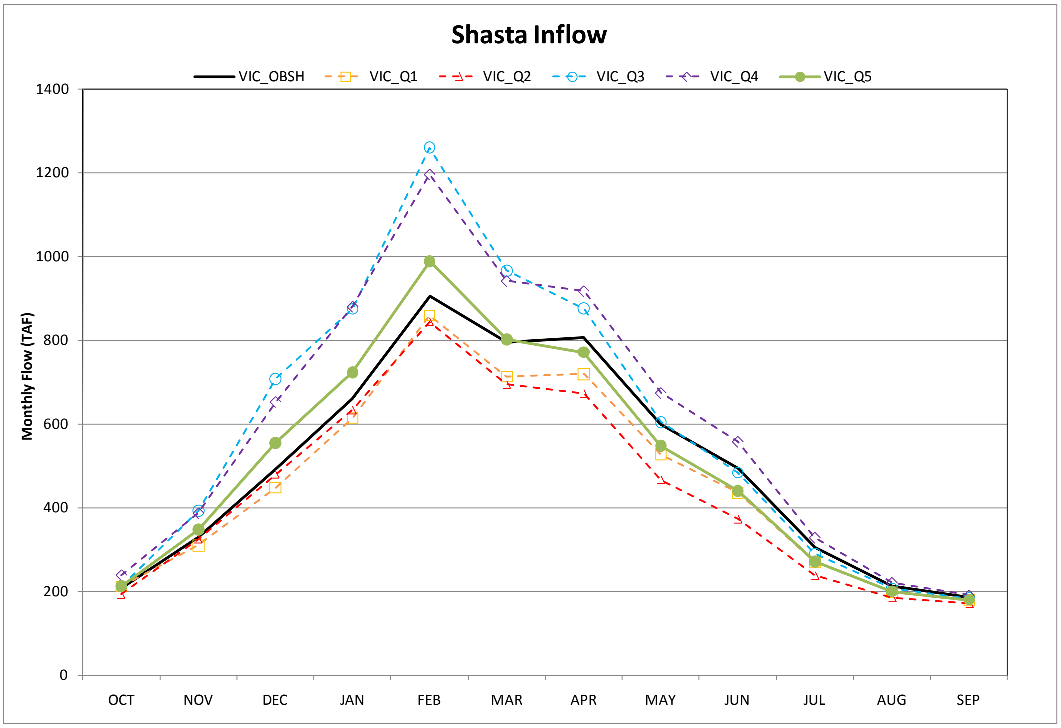


Figure 5A.A.10 Simulated Changes in Monthly Natural Streamflow for Shasta Inflow (for the 2025 timeline)

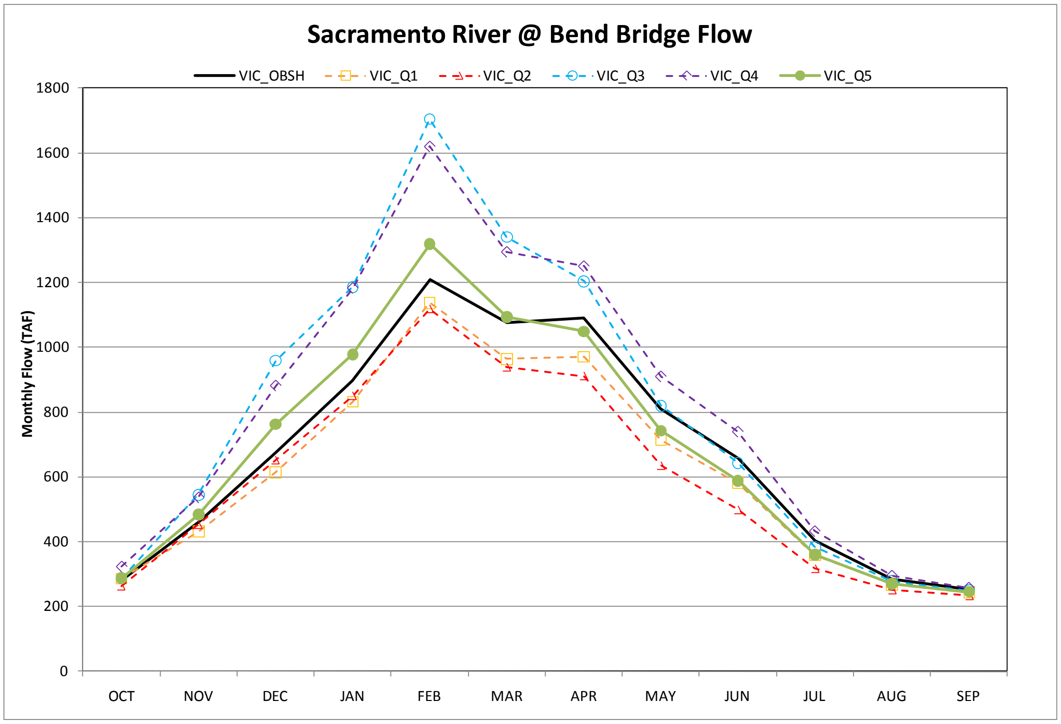


Figure 5A.A.11 Simulated Changes in Monthly Natural Streamflow for Sacramento River at Bend Bridge (for the 2025 timeline)

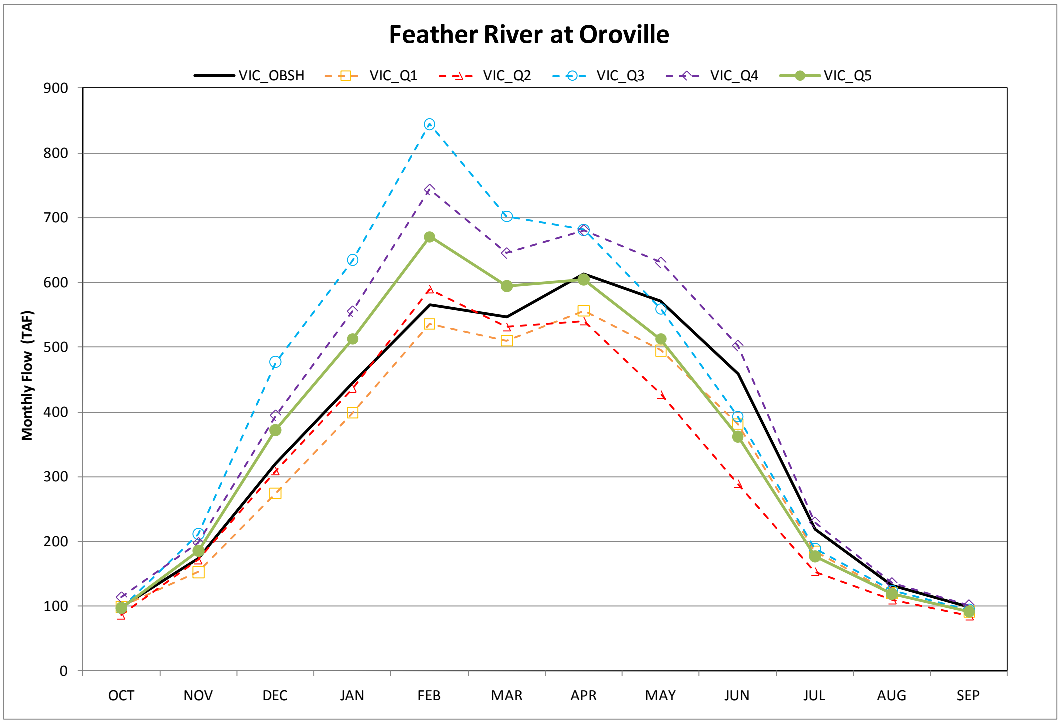


Figure 5A.A.12 Simulated Changes in Monthly Natural Streamflow for Feather River at Oroville (for the 2025 timeline)

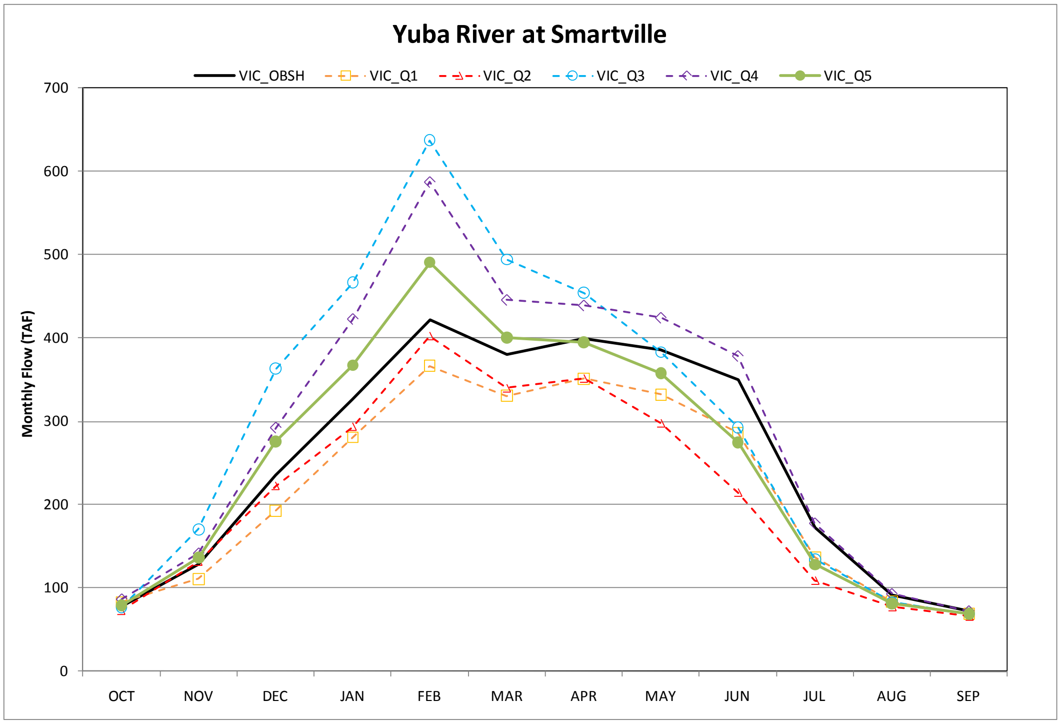


Figure 5A.A.13 Simulated Changes in Monthly Natural Streamflow for Yuba River at Smartville (for the 2025 timeline)

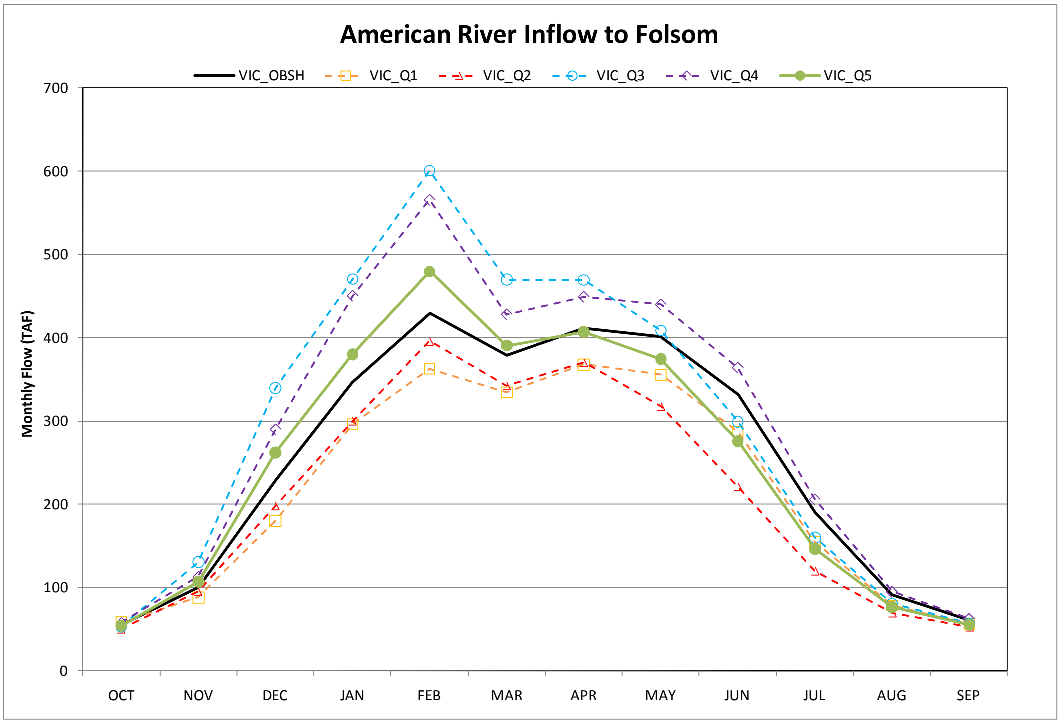


Figure 5A.A.14 Simulated Changes in Monthly Natural Streamflow for American River Inflow to Folsom (for the 2025 timeline)

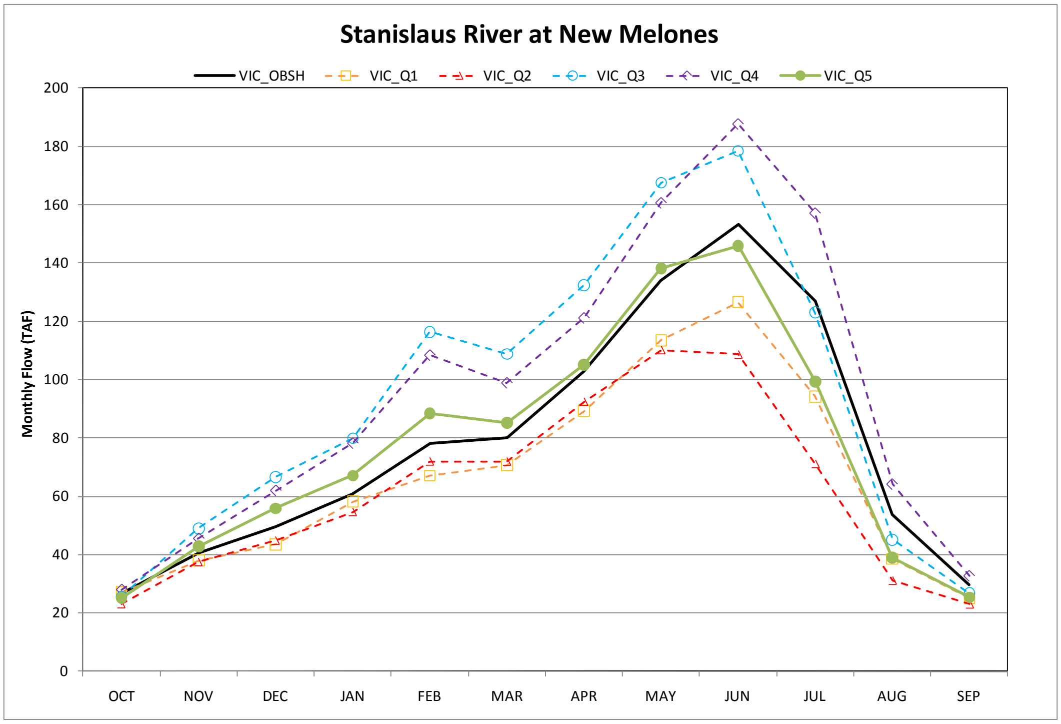


Figure 5A.A.15 Simulated Changes in Monthly Natural Streamflow for Stanislaus River at New Melones (for the 2025 timeline)

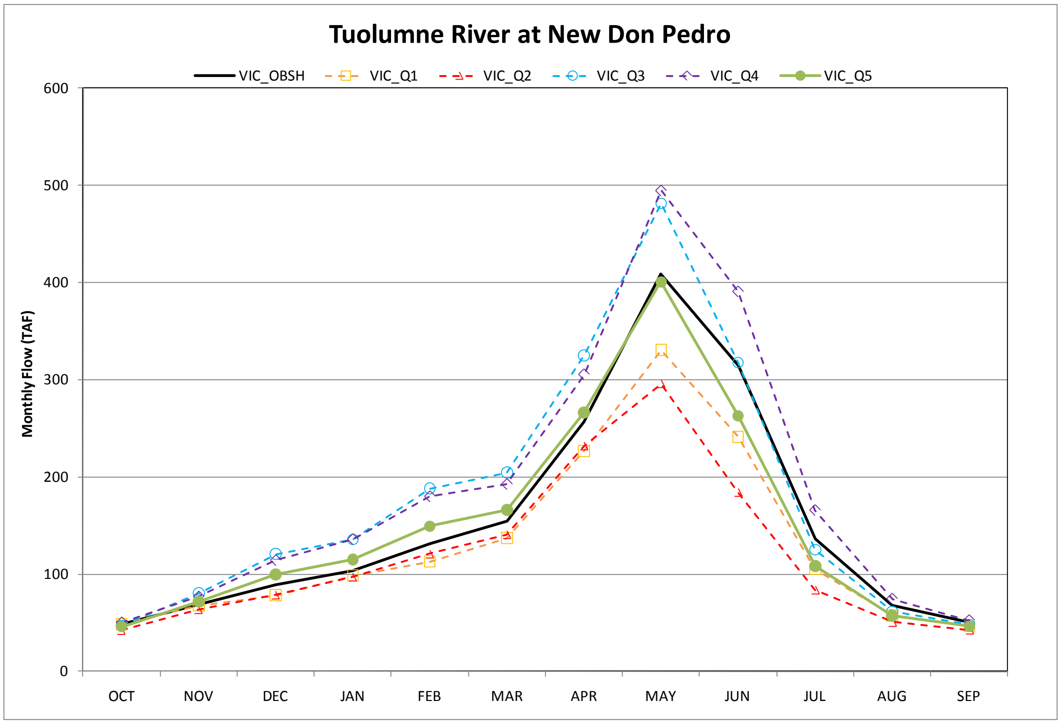


Figure 5A.A.16 Simulated Changes in Monthly Natural Streamflow for Tuolumne River at New Don Pedro (for the 2025 timeline)

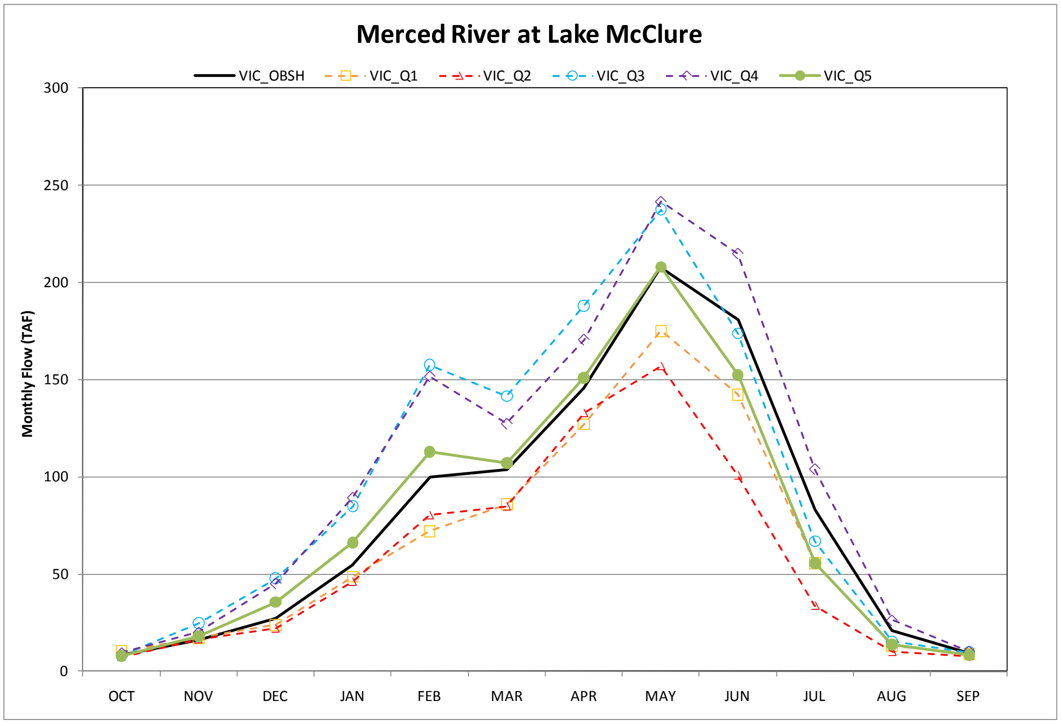


Figure 5A.A.17 Simulated Changes in Monthly Natural Streamflow for Merced River at Lake McClure (for the 2025 timeline)

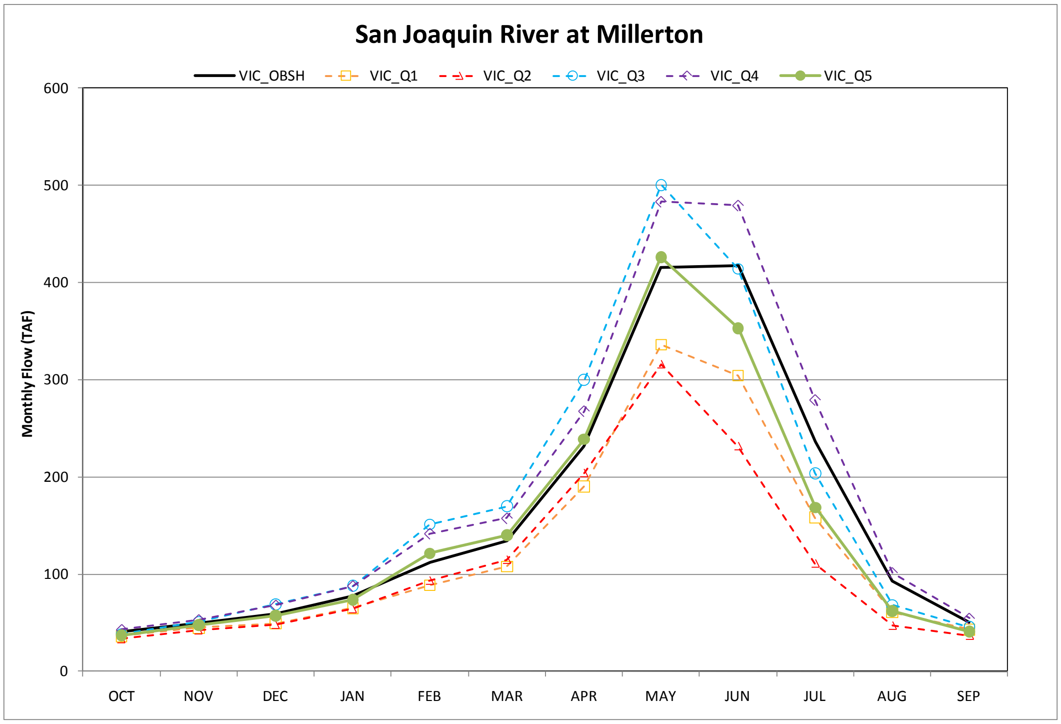


Figure 5A.A.18 Simulated Changes in Monthly Natural Streamflow for San Joaquin River at Millerton (for the 2025 timeline)

5A.A.5.4 Climate Change and Sea-Level Rise Modeling Limitations

GCMs represent different physical processes in the atmosphere, ocean, cryosphere, and land surface. GCMs are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. However, several of the important processes are either missing or inadequately represented in today's state-of-the-art GCMs. GCMs depict the climate using a three dimensional grid over the globe at a coarse horizontal resolution. A downscaling method is generally used to produce finer spatial scale that is more meaningful in the context of local and regional impacts than the coarse-scale GCM simulations.

In this study, downscaled climate projections using the Bias-correction and Spatial Disaggregation (BCSD) method is used (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#About). The BCSD downscaling method is well tested and widely used, but it has some inherent limitations such as stationary assumptions used in the BCSD downscaling method (Maurer et al. 2007; Reclamation 2013) and also due to the fact that bias correction procedure employed in the BCSD downscaling method can modify climate model simulated precipitation changes (Maurer and Pierce, 2014). The downscaling method also carries some of the limitations applicable to native GCM simulations.

A median climate change scenario that was based on more than a hundred climate change projections was used for characterizing the future climate condition for the purposes of the EIS. Although projected changes in future climate contain significant uncertainty through time, several studies have shown that use of the median climate change condition is acceptable (for example, Pierce et al. 2009). The median climate change is considered appropriate for the EIS because of the comparative nature of the NEPA analysis. Therefore, a sensitivity analysis using the different climate change conditions was not conducted for this study.

Projected change in stream flow is calculated using the VIC macroscale hydrologic model. The use of the VIC model is primarily intended to generate changes in inflow magnitude and timing for use in subsequent CalSim II modeling. While the model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local-scale phenomena. The VIC model is currently best applied for the regional-scale hydrologic analyses. There are several limitations to long-term gridded meteorology related to spatial-temporal interpolation due to limited availability of meteorological stations that provide data for interpolation. In addition, the inputs to the model do not include any transient trends in the vegetation or water management that may affect stream flows; they should only be analyzed from a "naturalized" flow change standpoint. Finally, the VIC model includes three soil zones to capture the vertical movement of soil moisture, but does not explicitly include groundwater. The exclusion of deeper groundwater is not likely a limiting factor in the upper watersheds of the Sacramento and San Joaquin river watersheds that contribute approximately 80 to 90 percent of the runoff to the Delta. However, in the valley floor, interrelation of groundwater and surface water management is considerable. Water management models such as CalSim II should be used to characterize the heavily "managed" portions of the system.

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