Long-Term Operation – Biological Assessment

# Appendix F – Modeling

## Central Valley Project, California

### Interior Region 10 – California-Great Basin

U.S. Department of the Interior

November 2023

# Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Long-Term Operation – Biological Assessment

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# Appendix F Modeling

## F.1 Introduction

The LTO project team has developed model simulations to support analysis of the Central Valley Project (CVP) and State Water Project (SWP) long-term operations as part of reviewing proposed operations under the LTO. This appendix describes the overall analytical framework and contains descriptions of the key analytical tools and approaches used.

The assumptions used for each alternative and each model listed above are documented in the following sections:

- Appendix F, *Modeling*, Section 1-1, *Modeling Methodology*
- Appendix F, *Modeling*, Section 1-2, *Callouts Tables*
- Appendix F, *Modeling*, Section 1-3, *CalSim 3 Contracts*

Additional documentation of climate change, modeled representation of Old and Middle River actions, and model updates are documented in the following attachments:

- Appendix F, *Modeling*, Attachment 1-1, *Climate Change*
- Appendix F, *Modeling*, Attachment 1-2, *Modeled Representation of Old and Middle River Actions*
- Appendix F, *Modeling*, Attachment 1-3, *Model Updates*

CalSim 3, DSM2 and HEC5Q model results are documented in the following attachments:

- Appendix F, *Modeling*, Attachment 2-1, *CalSim 3 Storage and Elevation*
- Appendix F, *Modeling*, Attachment 2-2, *CalSim 3 Flow*
- Appendix F, *Modeling*, Attachment 2-3, *CalSim 3 Diversions*
- Appendix F, *Modeling*, Attachment 2-5, *DSM2 Salinity*
- Appendix F, *Modeling*, Attachment 2-6, *DSM2 X2*
- Appendix F, *Modeling*, Attachment 2-7, *DSM2 Chloride*
- Appendix F, *Modeling*, Attachment 2-11, *HEC5Q*

Note that Attachment 2-4, and Attachments 2-8 through 2-10 are intentionally not included in this document.

## F.2 Linkage Schematic

A suite of modeling tools was developed to support the quantitative assessment of the LTO. A framework of integrated analyses including hydrologic, operations, hydrodynamics, water quality, and fisheries analyses is required to provide information for the quantitative 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 factors 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 F-1, the model linkage schematic shows the analytical tools applied in these assessments and the relationship between these tools. Each model included in Figure F-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 model and combined with the assumed operations for each alternative. The CalSim 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 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.

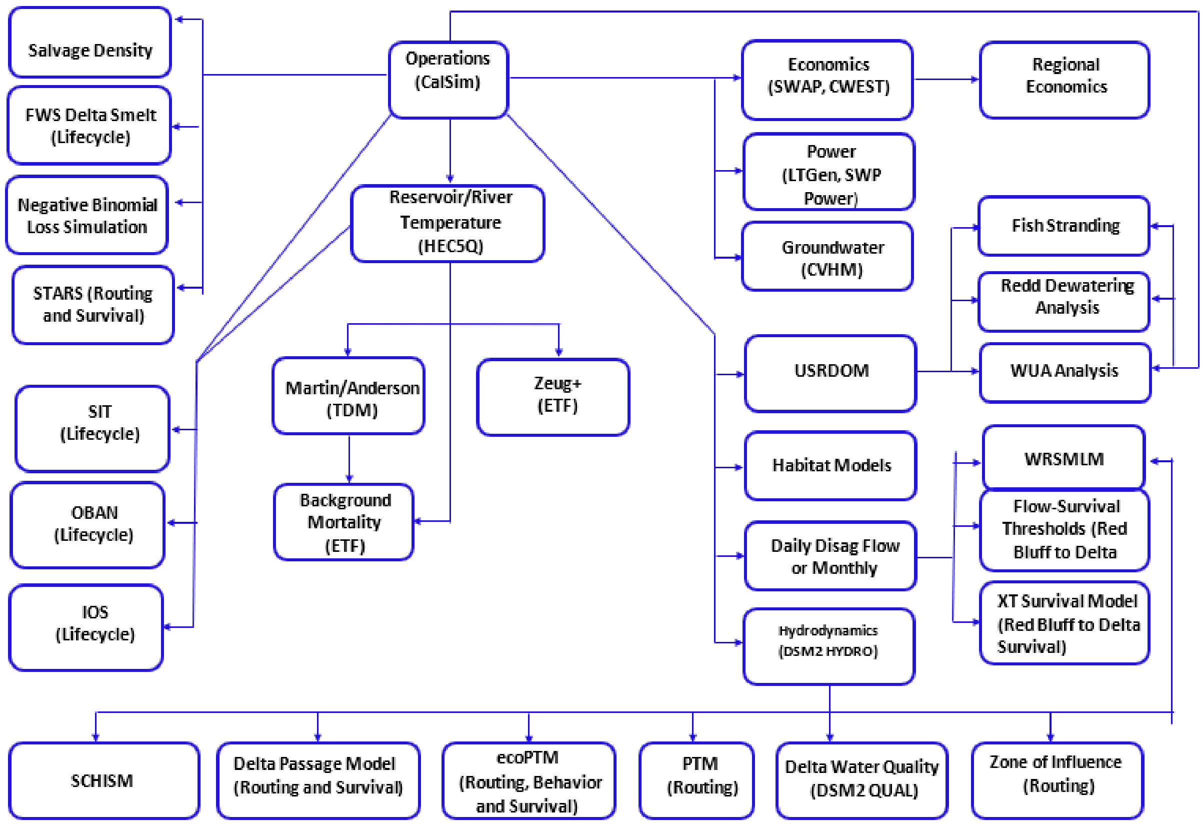


Figure F-1. Model Linkage Schematic

The Delta boundary flows and exports from CalSim 3 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 3 reservoir levels and releases to estimate power use and generation capability of the CVP.

Temperature models for the primary river systems use the CalSim 3 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 3 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.

A brief description of the hydrologic and hydrodynamic models is provided below. All other subsequent models presented int the Model Linkage Schematic are described in detail in the respective Appendix where their results are used.

# F.3 Model Description

## F.3.1 Climate Change and Sea Level Rise

The LTO project team has developed model simulations to support analysis of the CVP and SWP long-term operations as part of reviewing proposed operations under the LTO. Climate change impact representing 2022±15 climate conditions were analyzed by updating CalSim 3 meteorologic and hydrologic boundary conditions for Long Term Operations. The 2022±15 future climate condition was developed with 40 Coupled Model Intercomparison Project Phase 5 (CMIP5) global climate projections, selected for LTO. Future climate change analysis was based on the 2022 median climate change scenario. Additional information on this Climate Scenario can be found in Appendix F Attachment 1-1 Climate Change.

Model simulations also include 15 cm of assumed sea level rise (SLR). CalSim 3 uses an Artificial Neural Network (ANN) algorithm developed by DWR to translate water quality standards into flow equivalents that are to be met through SWP and CVP simulated operations (Sandhu et al. 1999). The ANN mimics the flow-salinity relationships as simulated in DSM2 and provides a rapid transformation of this information into a form usable by CalSim 3 operations. Additional information on the ANN can be found in Appendix F Attachment 1-3 Model Updates under DSM2 Updates.

## F.3.2 CalSim 3

The U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) jointly developed CalSim 3 as a planning model to simulate operations of the Central Valley Project (CVP) and State Water Project (SWP) over a range of hydrologic conditions. The model represents the best available planning-level analytical tool for SWP and CVP system operations and is an improved and expanded version of CalSim II, which has been the standard planning model for system operations since the early 2000s. A detailed description of CalSim 3 is available at [https://data.cnra.ca.gov/dataset/2395530a-5421-487e-921e-d6e594f23ac6/resource/2d4160d7-cbe1-4e63-8cdd-98f322e74cf2/download/cs3_mainreport_updates.pdf]. Additional updates since this report are provided in Appendix F, Attachment 1-3 Model Updates.

Inputs to CalSim 3 include unimpaired inflows and rainfall runoff, agricultural, urban, and wetland water demands, return flows, and groundwater recharge from precipitation and irrigation. Sacramento and San Joaquin Valley and tributary rim basin hydrology are developed using a process designed to adjust the historical sequence of monthly stream flows over a 100-year period (1922-2021) to represent a sequence of flows at existing and future levels of development.

CalSim 3 outputs include river and stream flows, water diversions and return flows, reservoir storage, Delta channel flows, Delta diversions and exports, Delta outflow, deliveries to project and non-project users, and controlling factors on project operations. These can be used to assess effects resulting from the proposed project and project alternatives.

CalSim 3 outputs are used as boundary conditions for and inputs to other hydrologic, hydrodynamic, and biological models and analyses.

### F.3.3 DSM2 Version 8.2.2

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate tidal flows, water quality, and particle tracking in the Delta (California Department of Water Resources 2021b). DSM2 represents the best available planning-level analytical tool for Delta flow 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.

DSM2 model has three separate components or modules that are run sequentially: HYDRO, QUAL, and PTM. HYDRO simulates velocities and water surface elevations and provides the flow input for QUAL and PTM. HYDRO outputs are used to predict changes in flow rates and depths, and their effects resulting from the proposed project and project alternatives. QUAL 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 resulting from the project alternatives.

Additional information on DSM2 is available from DWR (California Department of Water Resources 2021b). Further updates were performed under the LTO and are described in Appendix F, Attachment 1-3 Model Updates.

### F.3.4 HEC 5Q

HEC-5Q is a generalized FORTRAN-based code that simulates reservoir and river water temperatures based on input storage, flow, and meteorological data. HEC-5Q consists of two model components, HEC-5 and HEC-5Q. HEC-5 is the daily flow simulation component of the model, whereby daily storage and flows are simulated at specific nodes (U.S. Army Corps of Engineers, Hydrologic Engineering Center 1998). HEC-5Q is the temperature simulation component of the model, where 6-hour input meteorological data (equilibrium temperatures, exchange rates, shortwave radiation, and wind speed) are applied to the simulated storage and flows from the HEC-5 model to simulate water temperatures at specified locations (RMA 1998).

The Trinity-Sacramento River, American River, and Stanislaus HEC-5Q models used for the project are specific implementations of the general HEC-5Q model described above. The models use inputs derived from CalSim 3 outputs that have been temporally downscaled to daily timeseries, and 6-hour meteorological data derived from calculated and observed data. These models were previously used in Reclamation's Biological Assessment for the 2019 Reinitiation of Consultation on the Coordinated Long-Term Operation of the CVP and SWP (Bureau of Reclamation 2019) but have been updated to use CalSim 3 outputs Further methodological updates were performed under the LTO and are described in Appendix F, Attachment 1-3 Model Updates.

The temperature analysis contains three separate models that simulate reservoir and river temperatures:

- The Trinity River from Trinity Dam to below Lewiston Dam and the Sacramento River from Shasta Dam to the Feather River confluence. Reservoir temperatures are simulated for Trinity Lake, Lewiston Reservoir, Shasta Lake, Keswick Reservoir, and Black Butte Reservoir.
- The American River from Folsom Dam to the confluence with the Sacramento River. Reservoir temperatures were simulated for Folsom Lake and Lake Natoma.
- The Stanislaus River from upstream of New Melones Reservoir to the confluence with the San Joaquin River and the lower San Joaquin River from the Stanislaus River confluence to below Vernalis. Reservoir temperatures were simulated for New Melones Reservoir

### F.3.5 Temperature Dependent Mortality (TDM)

The Anderson and Martin temperature dependent mortality (TDM) models were used to estimate temperature-dependent egg mortality for Sacramento River Winter run chinook salmon (*Oncorhynchus tshawytscha*) using different egg mortality estimation methods (Martin et al. 2017; Anderson 2018). The two models were applied using HEC-5Q Sacramento River temperature results. Sensitivity to the spatial-temporal distribution of redds in each year was estimated by using the $80^{th}$ TDM percentile of redd distributions from carcass surveys from 2001-2021. Both models simulate redds' lifetime by counting the days required to cross a known cumulative degree-days threshold, and both models estimate mortality as a linear, increasing function of temperature past a known temperature threshold, but each uses a different set of assumptions to implement this conceptual model. The methods were applied to a set of simulated redds, and the results are summarized on a seasonal level for comparison of mortality outcomes between scenarios.

### F.3.6 OBAN

The OBAN and IOS models were developed by a private research team, have been peer-reviewed, but are not publicly available. Reclamation's LTO consultant includes staff able to run OBAN models.

[Placeholder for Attachment F. OBAN.]

### F.3.7 IOS

The IOS models were developed by a private research team, have been peer-reviewed, but are not publicly available. Reclamation will use the IOS and SIT WRLCM in the LTO lifecycle analyses.

[Placeholder for Attachment F. IOS.]

### F.3.8 CVPIA Winter-run Chinook salmon decisions support model

USFWS and Reclamation have been developing lifecycle models for use in structured decision making for CVPIA. Through a participatory process, the Science Integration Team (SIT) has developed a winter-run Chinook Salmon decision support model, or DSM. This model has been peer-reviewed and is publicly available. The participatory team's model proposals and meeting notes, background, documentation, and code for the model are available at [Resources - CVPIA Science Integration Team]. Reclamation used the SIT DSM in the LTO lifecycle analyses.

Model description, assumptions, and results are presented in Attachment F.X CVPIA Winter-run LCM.

### F.3.9 CVPIA Spring-run Chinook salmon decision support model

USFWS and Reclamation have been working to develop lifecycle models for use in structured decision making for CVPIA. Through a participatory process, the Science Integration Team (SIT) has developed a model for spring-run Chinook Salmon (SIT SRLCM) has been peer-reviewed, and, is publicly available. The participatory team's model proposals and meeting notes, background, documentation, and code for the model is available at [Resources - CVPIA Science Integration Team].

Model description, assumptions, and results are presented in Attachment F.X CVPIA Spring-run LCM.

### F.3.10 Delta Smelt Lifecycle model – Entrainment

Polansky et al. (2021) developed a hierarchical stage-structured state-space life cycle model for Delta Smelt to identify factors with the strongest statistical support for having influence on the species' recruitment and survival. This modeling approach is useful as an ecological modeling tool because it can separate descriptions of state and observation processes and permit the integration of disparate data sets. This Delta Smelt life cycle model was later expanded from four to seven life stages with a component that separately describes the entrainment process at the Delta export facilities (Smith et al. 2021). This model produces expected values for larval recruitment and survival at the subsequent life stages. The most statistically supported model variant in Smith et al. (2021) used means of December-June OMR values and June-August outflow aggregated from monthly values and therefore, CalSim output for the alternatives can be directly incorporated into the model framework. As such, Reclamation can use this model to calculate expected annual population growth rate ($\lambda$) for alternative flow scenarios. The metric of interest will be geometric mean of $\lambda$ for a specified time period (e.g., 1995-2014), which will be compared across alternatives. For the purpose of this text, Smith et al.'s (2021) model will be referred to as the Delta Smelt Life Cycle Model with Entrainment (LCME).

Model description, assumptions, and results are presented in Attachment F.X LCA Delta Smelt LCME.

### F.3.11 Maunder and Deriso in R Model

The Delta Smelt life cycle model published by Maunder and Deriso (2011) was updated in 2021 following the approach of Polansky et al. (2021) as far as practical, by modifying and generalizing the originally published model. This update to the publication version (henceforth referred to as the Maunder and Deriso model in R, or MDR) models a single cohort life strategy species that dies after it reproduces (i.e. the final transition is from adults to recruits and very few adults survive to the next time period e.g. an annual species). It is modelled in a Frequentist state-space framework allowing for both process variation and observation error. Transition between stages (i.e. survival and the stock-recruitment relationship) can be a function of density and covariates, in addition to unexplained temporal variation (process error). Covariates can also be used to influence the density dependent relationship or the survey catchability (bias). The model can be fitted to any number of surveys representing any of the stages.

Relative to the 2011 publication, the MDR includes an additional stage (sub-adults), with stages adjusted appropriately, fit to two additional indices of abundance for adults (spring midwater trawl prior to 2001 and spring Kodiak trawl for 2001 and later). Additionally, catchability (survey bias) is now estimated for the spring midwater trawl, and the likelihood function was changed to a log normal. The time period was also extended and now includes cohorts between 1995 and 2015. Potential covariates of survival and recruitment were borrowed from Smith et al., (2021). The surveys were fitted at the start of the stage before any other processes occurred. Covariates and process variation were added after density dependence when it was included.

Model description, assumptions, and results are presented in Attachment F. Maunder and Deriso in R Model.

## F.4 Model Limitations and Appropriate Use of Model Results

Numerical models developed and applied for the LTO are generalized and simplified representations of a complex water resources system. The models are not predictive models of project operations and results cannot be considered as absolute with a quantifiable confidence interval. The model results are only useful in a comparative analysis and can only serve as an indicator of conditions.

Due to the assumptions involved in the input data sets and model logic, care must be taken to select the most appropriate timestep for the reporting of model results. Sub-monthly (e.g., weekly, or daily) reporting of raw model results is not consistent with how the models were developed, and results should be presented on a monthly or more aggregated basis.

Absolute differences computed at a point in time between model results from an alternative and a baseline to evaluate impacts is an inappropriate use of model results (e.g., computing differences between the results from a baseline and an alternative for a particular month and year within the period of record of simulation). Likewise computing absolute differences between an alternative or a baseline and a specific threshold value or standard is an inappropriate use of model results. Statistics computed based on the absolute differences at a point in time (e.g., average of monthly differences) are an inappropriate use of model results. Computing the absolute differences in this way disregards the changes in antecedent conditions between individual scenarios and distorts the evaluation of impacts of a specific action.

Reporting seasonal patterns from long-term averages and water year-type averages is appropriate. Statistics computed based on long-term and water year-type averages are an appropriate use of model results. Computing differences between long-term or water year-type averages of model results from two scenarios are appropriate.

All models include simplifications and generalizations compared to the "real-world" scenarios that they represent. Therefore, all models will have limitations to how accurately they can represent the real world. It is necessary to understand these limitations to correctly interpret results. Some of these limitations are discussed in general terms above, but because limitations are often model-specific, each section of the Modeling Technical Appendix includes subsections that further describe model limitations specific to the model being discussed and appropriate presentation and use of model results.

## F.5 References


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