Appendix F, Life Cycle Analyses

Attachment F.2 CVPIA Winter-run and Spring-run Life Cycle Models

F.2.1 Model Overview

The U.S. Fish and Wildlife Service (USFWS) and U.S. Bureau of Reclamation (Reclamation) have been working to develop lifecycle models for use in structured decision making for the Central Valley Project Improvement Act (CVPIA). Through a participatory process, the Science Integration Team (SIT) has developed a winter-run Chinook Salmon decision support model (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: https://cvpia.scienceintegrationteam.com/cvpia-sit/resources. Reclamation used the SIT DSM in the long-term Operations (LTO) lifecycle analyses.

F.2.2 Methods

F.2.2.1 Model Development

The CVPIA SIT DSM models were developed by the SIT as part of a Structured Decision-Making (SDM) process. The SIT is a collaborative team of stakeholders and scientists. The resulting DSMs are open source and publicly available (https://cvpia.scienceintegrationteam.com/cvpia-sit/resources/dsm-r-packages). An early version of the DSMs has been published in a peer-reviewed publication (Peterson and Duarte 2020). The models were parameterized and calibrated using a combination of empirical data, existing models, analysis of existing data, and expert opinion.

DSMs were created for fall-, winter-, and spring-run Chinook salmon to compare how habitat restoration actions might improve natural production of each run. The DSMs are stochastic or deterministic stage-based life cycle models (LCMs) that track the number of Chinook salmon across juvenile size classes and adult stages of natural and hatchery origin. The transitions between stages are estimated with survival, growth, and movement submodels. Model inputs include existing habitat areas, fish harvest rates, water diversions, flows, and temperatures. Flow information was obtained from CalSim II outputs. Temperature data are primarily obtained from HEC-5Q outputs. Some areas for which HEC-5Q data were unavailable have temperatures modeled based on measured water temperatures, statistical models relating water temperature to air temperature, or matching of tributaries with similar hydrology and geomorphology. Habitat inputs are primarily based on previously published flow-habitat relationships. Where flow-habitat relationship information is not available, relationships were assumed to be similar to those of nearby, geomorphically similar watersheds. All other inputs except for predator prevalence are obtained from previously published sources.

For the purposes of LTO analyses, we used the model structure from the peer-reviewed, published version of the DSMs, instead of more recent versions with updated model processes and calibrations, based on recommendations from model developers and an emphasis on peer-reviewed model processes. The winter-run and spring-run DSMs were cloned by Reclamation staff from GitHub at the following URLs:

- https://github.com/CVPIA-OSC/winterRunDSM/tree/main
- https://github.com/CVPIA-OSC/springRunDSM/tree/v1.0

These models required Reclamation to download the following data repositories from the FlowWest GitHub site:

- cvpiaHabitat (https://github.com/FlowWest/ cvpiaHabitat)
- cvpiaFlow (https://github.com/FlowWest/cvpiaFlow)
- cvpiaTemperature (https://github.com/FlowWest/cvpiaTemperature)
- cvpiaData (https://github.com/FlowWest/ cvpiaData)

Reclamation updated the calculation of flow inputs to the DSM to use CalSim 3 data for alternatives of interest. CalSim 3 data was used in place of the original CalSim II data for the following reasons: 1) the original DSMs, as well as all subsequent versions, used CalSim II data and variable definitions because that was the most recent available version, 2) Reclamation has developed a new CalSim model, CalSim 3, for current application in LTO modeling and future modeling needs, and 3) base model structures, assumptions, and definitions differ between CalSim II and CalSim 3 (sometime substantially). A detailed description of this conversion is provided in Attachment 1, *Detailed Documentation on Updating CalSim Inputs to SIT DSMs*, as well as more succinctly in Section F.2.2.3, *Assumptions/Uncertainty*.

Reclamation also identified two primary concerns in the published versions in the SIT DSMs (i.e., those used in Peterson and Duarte 2020) that merited recalibration of core model parameters. First, values for total diversions in the Upper Sacramento, which influence expected rearing survival, were incorrectly calculated as proportional diversions. Second, when the model is run in the deterministic mode, size class-specific survival terms are incorrectly applied for fish rearing in migratory corridors (e.g., Upper-mid, Lower-mid, Lower Sacramento River); because deterministic model runs serve as the basis for model calibration, this issue was especially problematic for comparing old and new model outputs. Both of these concerns led us to recalibrate the winter-run DSM for application in LTO modeling efforts. Details on model recalibration are provided in Attachment 2, *Summary of Recalibration Efforts for the Winter-Run Chinook Salmon SIT DSM*.

F.2.2.2 Model Application

[TBD]

F.2.2.3 Assumptions/Uncertainty

[TBD]

F.2.3 Model Modifications for LTO Analyses

F.2.3.1 Modifying Model Flow Inputs with New CalSim II Runs

We created a workflow in R to generate comprehensive and new flow inputs using output files (DSS files) from CalSim II runs reflecting LTO alternatives. The R script responsible for generating new flow inputs is ‘DSS workflow_cvpiaFlow_clean.R’. New flow inputs were generated based on model annotation associated with the cvpiaData R package and detailed discussions with model developers. The following flow variables used by the DSMs were updated with new CalSim II data:

- Monthly flows, variability in flow, and proportion of natal flow (relative to larger watersheds) for each of 31 watersheds in the Sacramento-San Joaquin River basin
- Monthly flows at Freeport, Vernalis, and Stockton
- Monthly total exports from the Central Valley Project and State Water Project
- Diverted flows in each of the 31 watersheds in the Sacramento-San-Joaquin River basin (expressed both as total diversions and diversions relative to total flow)
- Proportion of Sacramento River flow into the Sutter and Yolo Bypasses
- Indications for whether gates downstream of Sutter and Yolo Bypasses are overtopped
- Monthly operations of the Delta Cross Channel gates
- Inflow into the North and South Sacramento–San Joaquin Delta (Delta)
- Diverted flows in the North and South Delta (expressed both as total diversions and diversions relative to inflow)

Only the input associated with monthly operations of the Delta Cross Channel gates required notable modifications in calculation and data structure. The input to the published model version used fixed monthly expectations of operations (i.e., number and proportion of days in which the gate was closed), as specified in the 2019 BiOp (National Marine Fisheries Service 2019). CalSim analyses allowed us to update gate operation with month- and year-specific values that varied among LTO alternatives. We modified this input to reflect these variable operations and subsequently modified its use in the life_cycle_model() function to reflect the new, more complex data structure.

We conducted internal validation to ensure our updates to flow inputs using new CalSim II runs did not result in unexpectedly large changes in flow values (i.e., resulting from user error). For each of the above inputs to the DSMs, we visualized and compared input values among the original DSM inputs and those based on each of the LTO alternatives.

The following demographic parameters are expected to be influenced by the updated flow inputs based on CalSim II runs reflecting LTO alternatives:

- Adult straying rates among spawning tributaries (*spring-run only*)
- Adult en route survival
- Juvenile river rearing survival
- Juvenile movement as a function of pulse flows
- Juvenile river migratory survival
- Juvenile entrainment into the South Delta from the Sacramento River
- Juvenile routing and survival in the South Delta, following entrainment
- Juvenile routing and survival in the North Delta

We note these new flow inputs based on CalSim II runs are intended to be replaced eventually by flow inputs generated from CalSim 3 runs (described below).

F.2.3.2 Modifying Model Flow Inputs with New CalSim 3 Runs

We also created a workflow in R to generate comprehensive and new flow inputs using output files (DSS files) from CalSim 3 runs reflecting LTO alternatives. The R script responsible for generating new flow inputs is 'DSS workflow_cvpiaFlow_clean_CalSim 3.R'. New flow inputs were generated based both on the CalSim II variables used for the previously described updates to flow inputs and guidance from CalSim modelers on mapping between CalSim II and CalSim 3 outputs. Because CalSim 3 includes different assumptions and operates at a greater resolution than CalSim II, and thus often provides multiple flow or diversion terms for what was captured by a single variable in CalSim II, extensive modifications and numerous judgement calls were required with these modifications. In some instances, we were able to assign tributary-specific flow and/or diversion variables for watersheds that lacked specific flow estimates in CalSim II. All modifications and supporting rationales are documented in the annotation included with the workflow R script. We recommend future model users interested in running DSMs with new CalSim 3 runs carefully examine and revise, as necessary, our modifications and model annotation. The same flow inputs listed for CalSim II, above, were updated using CalSim 3 runs.

We again modified the input associated with operation of the Delta Cross Channel gate to reflect month- and year-specific gate operations that are allowed to vary with LTO alternatives. We also conducted internal validation to ensure our updates to flow inputs using new CalSim 3 runs did not result in unexpectedly large changes in flow values (i.e., resulting from user error). For each of the above inputs to the DSMs, we visualized and compared input values among the original DSM inputs and those based on each of the LTO alternatives using both CalSim II and CalSim 3. The same demographic parameters listed in the previous section are also expected to be influenced by updated flow inputs based on CalSim 3 runs.

F.2.3.3 Modifying Model Temperature Inputs with New HEC-5Q Runs

The best source of new temperature estimates linked to CalSim is the HEC-5Q model, which is typically run for only the Upper Sacramento River, American River, and Stanislaus River. Temperature estimates from previous HEC-5Q runs were used to generate select temperature inputs to the published version of the DSMs, specifically monthly average temperatures and degree-day accumulations in modeled watersheds; temperature inputs for watersheds not included in HEC-5Q models were generated using a combination of supplemental models and historical data sources. Based predominantly on spawning and rearing locations of winter-run Chinook salmon, we updated monthly average temperature and degree-day accumulation inputs for only the Upper Sacramento River, but we note we could update temperature inputs for Clear Creek and Battle Creek for spring-run Chinook salmon, if desired.

Model documentation for the original HEC-5Q variables used in the Upper Sacramento River temperature inputs is inconsistent with their actual application in the published DSMs: temperature inputs for both Cottonwood Creek and the Upper Sacramento were reportedly derived from the same HEC-5Q variable, but actual inputs differed between watersheds without clear explanation. In light of this uncertainty, we calculated the average temperature values below Keswick (BLW KESWICK) and at Red Bluff Diversion Dam (RED BLUFF DAM) to characterize expected temperature conditions in the Upper Sacramento River.

The following temperature inputs were updated with this modification:

- Monthly average temperature for the Upper Sacramento River
- Monthly degree day accumulation for the Upper Sacramento River

The following demographic parameters are expected to be influenced by the updated temperature inputs:

- In-channel and floodplain juvenile rearing survival in the Upper Sacramento River
- Adult pre-spawn survival during holding in the Upper Sacramento River

Depending on whether we updated flow inputs with CalSim II or CalSim 3 flow estimates for a particular analysis, we used the HEC-5Q model runs corresponding to the appropriate CalSim version.

F.2.3.4 Modifying Model Habitat Inputs

Model habitat inputs for the Peterson and Duarte (2020) version of the DSMs were based on a combination of expert judgment and flow to habitat relationships specific to both watershed and run type. Due to the considerable complexity associated in updating these values using new CalSim runs, we left habitat inputs unchanged from the published version of the DSMs.

F.2.3.5 Model Caveats and Assumptions

We note some demographic rates are not constructed to vary as a function of changing flow and temperature inputs in this model version, despite potential expectations to the contrary; an incomplete list of examples is provided below:

- Timing of adult arrival to the spawning grounds and subsequent spawning
- Egg-to-fry survival
- Juvenile growth rates

Throughout efforts to update flow and temperature inputs as a function of new CalSim and HEC-5Q estimates, we sought to ensure updated data inputs matched those in the original, published model as closely as possible. We did this to avoid using inputs far outside the range of inputs used to calibrate the model. In some cases, as described below, this led us to calculate inputs using equations that matched the original data and code but contradicted accompanying model documentation. We recommend future applications of this model update model inputs using more accurate calculations and conduct a formal recalibration to these new model inputs.

There were two inconsistencies between model documentation and model implementation that needed to be addressed while updating flow inputs. These inconsistencies applied to updates using both CalSim II and CalSim 3 runs. First, model documentation stated total diversions for the Upper Sacramento River should have been based solely on the diversion variable *D104* from CalSim II. Instead, inputs to the original DSM used proportional diversions, relative to flow variable *C104*, for both the total and proportional diversion data objects. Because correcting this mistake led to much higher diversion terms than used in the model calibration and subsequently caused updated estimates of rearing survival to decrease to unreasonably low values, we retained the incorrect total diversion calculation when updating flow inputs for both CalSim II and 3. This decision likely means that rearing survival in the Upper Sacramento River will not be sensitive to differences in diversions among alternatives. Second, model documentation suggests multiple CalSim II diversion variables should be used when calculating proportion of Sacramento River flow diverted into the Sutter Bypass (*D117*, *D124*, *D125*, *D126*), but only one diversion term that only infrequently exceeds 0 cfs is used in the final model input (*D117*). Similarly, because correcting this mistake would greatly increase fish routing into the Sutter Bypass and alter fundamental population dynamics relative to those used in model calibrations, we retained the incorrect diversion calculation. Therefore, differences in the neglected diversion terms among LTO alternatives will not translate to different model outcomes.

For updated flow inputs based on CalSim II estimates, we could not dynamically update estimates of flow for the Mokelumne River as data for this system were provided by the East Bay Municipal Utility District. Therefore, updated flow inputs based on CalSim II estimates were left unchanged for the Mokelumne River, including total and proportional diversions, proportion of natal flow, and flow variability. In contrast, we were able to update flow inputs for the Mokelumne River using data from CalSim 3 runs.

As mentioned in Section F.2.3.2, *Modifying Model Flow Inputs with New CalSim 3 Runs*, extensive changes and judgment calls were required as part of updating flow inputs based on new CalSim 3 runs. Here we describe several notable challenges and areas for future discussion. First, when identifying CalSim 3 variables related to watershed diversions, we removed the use of all ‘Closure-Terms’ in CalSim 3 that would have corresponded to previous ‘Depletion’ terms in CalSim II (i.e., ‘Depletion’ terms were used as proxies for diversion effects); differing usage of these variable types in CalSim II and 3 made simple substitution of variable types nonsensical. Second, updated diversion and flow terms for several tributaries, including Thomes, Mill, and

Deer Creek, resulted in proportional diversions exceeding 1 in some instances; in these cases, we capped proportional diversions at 1. Third, we note that we largely updated diversions on the Sacramento River reaches (i.e., Upper, Upper-mid, Lower-mid, and Lower) using geographic information on diversion terms and boundary definitions. However, two diversion variables fell precisely on the split between the Upper and Upper-mid Sacramento River (i.e., Red Bluff Diversion Dam); we assigned these diversion variables to the Upper-mid Sacramento River to be consistent with diversion mapping with CalSim II variables but note a different ruleset can be applied. Finally, mapping of diversions and flows in the Sutter and Yolo Bypasses, and particularly as they related to overtopping of downstream gates, was challenging due to more complex connections among watersheds in CalSim 3. Updated flow inputs based on best judgment from CalSim modelers resulted in permanent overtopping of the Sutter Bypass gates. We recommend the use of diversion terms, flow variables, and flow threshold for overtopping be reevaluated in future uses of the DSMs with CalSim 3 inputs.

Additionally, flow variables (from both CalSim II and 3) related to deliveries of exported water from the Delta are used to modify the probability of entrainment at the CVP and SWP facilities. CalSim modelers recommend these variables be replaced with alternative variables that represent diversions instead of export deliveries. Detailed variable recommendations are available in the R script annotation for interested users.

There are numerous additional model assumptions that bear mentioning. First, in order to seed the starting number of returning adults from the ocean (i.e., necessary to calculate numbers of returning spawners), the model is run for 5 preliminary years using a fixed number of spawners (2787) in each of those five years. Additionally, in each of the 20 tracked model years, a specified number of hatchery fish is added to the pool of spawners; this number is either 565 or a randomly selected number based on the uniform distribution bounded by 355 and 755, depending on whether the model is run deterministically or stochastically. Finally, for winter-run Chinook salmon only, the model assumes returning adults only spawn in the Upper Sacramento River, with no straying to other watersheds.

F.2.3.6 Running the Models and Summarizing Results

We modified the R scripts originally used for running the life cycle models by Peterson and Duarte (2020) to improve and streamline recording and summarizing of results. Specifically, we created a stand-alone wrapper script (‘Wrapper script.R’) that loads data using a separate function (load_model_inputs(), in ‘Load Model Inputs.R’), runs the model using another separate life cycle function (life_cycle_model(), in ‘Life cycle model.R’), and saves model results. Different data inputs are loaded depending on the user-specified LTO alternative. The life cycle model function was modified to allow users to run the model using either the original input data files from 2019 or new data files (some with new data structures), depending on the specified alternative. The model can be run deterministically (without process variability, like variability in survival rates) or stochastically. The new life_cycle_model() function also summarizes additional model output during each model run, including month-, year-, watershed-, size class-, and/or iteration-specific demographic rates (i.e., which vary as a function of model inputs).

[Summary of running the model either/both deterministically/stochastically]

[Summary of model output summaries, performance metrics, and summary plots]

F.2.4 Results

F.2.4.1 Validating Updates to Flow and Temperature Inputs

[TBD]

F.2.4.2 Model Results from CalSim II Analyses

[TBD]

F.2.4.3 Model Results from CalSim 3 Analyses

[TBD]

F.2.5 References

National Marine Fisheries Service. 2019. *Biological Opinion on Long-Term Operation of the Central Valley Project and the State Water Project.* National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. WCRO-2016-00069

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