Executive Summary

This report provides an independent review of the Chinook salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* population models developed by the Turlock Irrigation District and Modesto Irrigation District (collectively we refer to these as "the Districts"). The models were designed to assess the extent to which the abundance of Chinook salmon and *O. mykiss* in the Tuolumne River may be affected by in-river factors, identify factors that influence life-stage specific production and critical life stages, and compare relative changes in smolt population size and smolt productivity between potential alternative management scenarios. The review team consisted of five scientists with expertise in salmonid ecology, population dynamics, modeling, hydrology and engineering, geomorphology, sediment dynamics, and habitat restoration. Each member of the review team has over 35 years of professional experience.

We evaluated the models and supporting documents to determine if the models are usable and useful. That is, from our perspective, can the models be used to identify critical life stages, identify and evaluate life-stage-specific limiting factors, and compare relative changes in smolt population abundance and smolt productivity among alternative management scenarios? Given the large amount of information collected as part of the project, the models are used to help synthesize and distill the information into results that can be used to evaluate management scenarios. However, it is important to point out that all models make simplifying assumptions. This ensures that to a certain degree all models are ultimately wrong or at least incomplete. We viewed the models in this context. Our goal in this review was to determine if the models, their assumptions, and the data used to populate the models are adequate enough to make them useful tools for evaluating management scenarios, and whether they were designed in a such manner that they can be easily used by the Districts and stakeholders.

Our review was straightforward and included reviewing model and data reports prepared by the Districts along with scientific information from California's Central Valley and other regions. As part of our review, we considered how the Districts incorporated the Viable Salmonid Population concept developed by National Oceanic and Atmospheric Administration (NOAA) Fisheries to define the essential characteristics of a viable salmon population. The concept is used in recovery planning for populations listed as threatened or endangered under the Endangered Species Act (ESA), with a focus on abundance, intrinsic productivity, and biological diversity. We also found it helpful to consider both the inputs and outputs of the Tuolumne population models within a conventional stock-recruitment model. With considerable effort, we were able to evaluate model coding and run the models under different spawner escapement levels and assumed smolt-to-adult return rates to understand modeled relationships. To improve the quality of our review, we submitted a letter requesting additional information and clarification regarding the models (Appendix A). Their responses helped us in our review of the models and we greatly appreciated the quick response from the Districts and their consultants to our request (Appendix A). Finally, most members of the review team toured the lower Tuolumne River in January 2020 to gain a perspective of the Tuolumne River that is not available from reports.

Based on our review of the models, the supporting information, and other pertinent information, we conclude the following: 1) the three physical models developed to support the population models are useful and usable; 2) the Chinook salmon population model is useful but not usable by all stakeholders; and 3) the *O. mykiss* population model is neither useful nor usable. Below, we summarize our reasons for these findings.

Physical Models

We found no significant issues with the three physical models that support the population models. The Tuolumne River Operations Model represents observed operations relatively well; however, we recommend that an operations model with more capability and flexibility be used in the future, such as the RiverWare model that is commonly used by the U.S. Bureau of Reclamation for operational planning in complex river basins. The Don Pedro Reservoir Temperature Model results appear adequate for use in the Lower Tuolumne River Temperature Model, and the Lower Tuolumne River Temperature Model predictions are likely satisfactory for use in fish population modeling. We noted that the Lower Tuolumne River Temperature Model was not able to represent diurnal fluctuations accurately in some reaches of the river. This is likely due to unknown groundwater inflows or outflows and the presence of the special run pools that may act as a thermal buffer due to the large volume of water in the pools. Because the population models use daily average temperatures, the predictions from the Lower Tuolumne River Temperature Model are likely satisfactory for use in fish population modeling.

Chinook Salmon Population Model

The Chinook salmon population model is a complex, spatially explicit, individual-based model that tracks each fish within the modeled population along the river on a daily basis. Importantly, it is not a full life-cycle model, meaning that it makes no attempt to complete the life cycle of the surviving smolts. Therefore, it cannot predict equilibrium spawner abundance levels that would be expected to occur under a prescribed set of management actions. The model is written in the "R" statistical software package and we initially found it difficult to run, track, and alter different aspects of the inputs. The modeling reports were not helpful in this regard. Once we became familiar with the model, it was easier to operate. We doubt that many stakeholders will find the model usable. From our perspective, given that this is the river, fish conservation, and fisheries management tool that will be used for the term of the Federal Energy Regulatory Commission (FERC) license, the Districts should make the Chinook salmon population model available to stakeholders if they have not already done so, and the stakeholders need to learn how to operate and use the model to assess tradeoffs between flow alternatives. Model users would benefit by having the model developers incorporate model features to make it easier to evaluate customized water management scenarios such as a user-friendly interface like Shiny (an R package for developing interactive web applications).

We found the Chinook salmon population model to be a useful tool for evaluating the production of emigrant Chinook salmon smolts in the Tuolumne River in relation to habitat conditions, including flow regimes and predation effects. The model can provide important insights to scientists and managers alike about the status of the population and factors affecting population performance. More specifically, we found that it appears to have utility to help diagnose the effects of various conditions threatening population performance and identify and evaluate management actions that can improve performance. That said, there are several areas in which the model can be improved. In addition, reports prepared by the Districts and their consultants do not clearly present all the results from the model. Below, we summarize a few important findings and issues we identified during our review of the Chinook salmon population model (more detailed comments are provided in the body of the report).

- We conclude that the model indicates that the Chinook salmon population is most threatened by extremely low intrinsic productivity. This means that the population is being most adversely affected by habitat quality (not quantity), which would include the effects of predator populations. According to the model, a shortage of habitat quantity, including spawning habitat and gravel availability, is not a limitation on the population at abundance levels that are of concern. Thus, gravel augmentation would not significantly improve population performance. Similarly, increasing flow during spawning to increase available spawning habitat would likely have only small or negligible effects on the population.
- The model, as configured, indicates that the status of the Chinook salmon population is extremely precarious and bold actions will be needed to prevent extirpation. This need, according to the model, would best be met by very substantial increases in flow releases during spring (the period of active smolt outmigration from the river). The model suggests that management actions with the most certainty in providing real benefits would involve increases in flows during smolt outmigration. Other actions would be expected to provide relatively low benefits compared to spring flow increases. These include reductions in predation rates (unless those reductions could be of a significant magnitude) and increases in spawning habitat through gravel augmentation (even if those increases were large).
- The model is not a full life cycle, which hampers its utility for evaluating potential benefits of management actions to the overall population. The model also does not account for population components that contribute to overall adult production other than fish that smolt while in the river. Fry migrants (newly emerged fry), slightly older fry emigrants, juveniles that emigrant prior to smolting, and juveniles that residualize and continue to rear in the river are treated as mortalities in terms of their contribution to population productivity. In this regard,

the model has a very narrow scope that omits important life histories that are known to contribute to the population based on analysis of otoliths. While the model can be used to inform relative differences between management alternatives without including these life history expressions, the assessment will be incomplete without considering how the entire population responds to the actions. Thus, in our view, the model falls short of meeting the guidance provided by FERC on model development. Because it is not a full life-cycle model, the Chinook salmon population model as configured is inadequate for managing the Chinook salmon population for conservation or fisheries over the term of a FERC license because it does not inform surplus over replacement, as discussed in the body of this report. It is an in-river smolt production model that estimates the smolt production resulting from a pre-set number of spawners.

- Uncertainties exist with the model, particularly with regard to parameters related to predation effects. Estimates of mortality during the smolt-to-smolt life stage based on the rotary screw trap (RST) studies are the largest driver of the results produced from the model. Smolt-to-smolt mortality refers to the loss of fish in the river from the point of attaining smolt status to the point of leaving the river as an emigrant. We found the model did not calibrate well to observed smolts arriving at the Waterford RST, which brings into question its ability to estimate life-stage transitions and survival to this sampling location. The relationship between flow and survival based on the RST data can take several forms, all of which appeared to incorporate a high degree of variability in the data at certain flow levels. We believe there is a need to improve the estimates of smolt-to-smolt survival if the model is to be used for evaluating management alternatives, or at the very least, to improve the confidence in the estimates and the relationships between survival and flow developed based on the estimates.
- The volume of water available for fish conservation and fisheries management is limited. Given this, stakeholders should use the model to explore tradeoffs among 1) winter flow augmentation to displace fry downstream (knowing that displaced fry in the model do not contribute to smolt-to-smolt survival but some do return as adults); 2) winter flow augmentation for rearing (early rearing flows during March and possibly February have been found to be particularly important factors controlling adult recruitment in the San Joaquin River Basin); 3) spring pulse flows during April and May as proposed by the Districts; and 4) the value of fall pulse flows for adult attraction.
- We estimated the number of adult recruits that would be produced from the modeled estimates of smolt emigrants leaving the Tuolumne River, and using an optimistic average smolt-to-adult recruit survival (SAR) of 5% for illustration, the estimated intrinsic productivity of Chinook salmon is 0.14, which is well below the spawner replacement level of 1. Therefore, if all assumptions in the Chinook salmon population model are correct, the model suggests that the population has already been extirpated or will be soon. The situation is likely worse

than indicated by the model because harvest is not incorporated into the model nor is the effect of hatchery strays on reproductive success, and because an assumed SAR of 5% is unrealistically high.

- It is quite likely that predation is the reason for the apparent poor smolt-to-smolt survival. Therefore, it is reasonable to try and reduce predation effects during the smolt migration period. While predation effects are estimated to be large, the Chinook salmon production model cannot identify the number of predators that would need to be removed or how much of a reduction in consumption would be required to achieve a significant increase in smolt-to-smolt survival. The response from predator control is assumed, not predicted. In contrast, the model predicts, and does not assume, changes in smolt-to-smolt survival associated with flow. That is, the model demonstrates a clear and positive relationship between mean April flows and smolt-to-smolt survival in the Tuolumne River.
- A modeling report needs to be prepared that provides greater clarity and transparency for how the model is structured and operated with clear and concise instructions for application. Modeling results need to be presented in a manner that provides clear guidance on interpreting model outputs for application to management. These aspects should be developed in collaboration with stakeholders and potential users.

O. mykiss Population Model

The *O. mykiss* population model is a complex, spatially explicit, individual-based model. It uses an individual-based framework to represent the major life history processes affecting *O. mykiss* maturation, spawning, egg incubation, juvenile growth, movement, mortality, and anadromy rates to estimate juvenile and smolt production and end-of-year age-2 and older fish (assumed to reflect adult abundance) as a function of varying flows and water temperatures in the lower Tuolumne River. As with the Chinook salmon population model, the *O. mykiss* population model is not usable by most stakeholders. In addition, the *O. mykiss* modeling report is confusing and difficult to follow given the complexity of the model. It took us a large amount of time to become competent enough to run and understand the model. It is not user-friendly, which means that few will be able to run and understand the model results. This is unfortunate in that regulatory agencies probably cannot use the model to evaluate various management strategies. As with the Chinook salmon population model, a user-friendly interface is needed to make the model more useful to all stakeholders for modeling scenarios other than those packaged with the model.

Unlike the Chinook salmon population model, after our review and analysis of the *O. mykiss* population model, we conclude that the *O. mykiss* population model is not useful at this time. Although it is evident that the investigators did a large amount of work in developing the model, we found that the structure and conceptual underpinnings of the *O. mykiss* population model are not well supported for this species in the Tuolumne River. Because of very limited data for *O. mykiss* in the river, and particularly with regard to the possibilities for anadromy, and the obvious adaptation of the model from the Chinook salmon model including its parameterization, the *O. mykiss* model seems contrived with questionable utility. Perhaps most confusing to us is the use of a combination of a part of the steelhead life history together with a resident population, which also does not incorporate a full life cycle. The outputs from this mixture are difficult to interpret and apply. Below, we summarize a few important concerns we have with the *O. mykiss* population model (more detailed comments are provided in the body of the report).

- The *O. mykiss* population model should not be used for diagnosing or evaluating management actions related to the anadromous form of this species, given the model's current structure, its parameterization, and its calibration and validation.
- The model attempts to combine an artificial and unrealistic number of steelhead spawners with two different levels of resident fish spawners in a manner that is unnatural, not transparent, and difficult to follow in both the model and the model documentation. The conceptual underpinnings of doing this in the model are not well supported. We found several significant inconsistencies between the original and updated modeling results that are difficult to understand, which raised further concerns to us about the reliability of the model.
- The model is structured and parameterized based on concepts and parameter settings used in the Chinook salmon model. The life histories and behaviors of these two species are dramatically different. A model structured to accommodate juvenile Chinook salmon is inappropriate to address the needs for *O. mykiss* modeling, especially for the anadromous form. Movement patterns of fry and juveniles of ocean-type Chinook salmon are much different than those of juvenile *O. mykiss*, whether in the anadromous or resident form. Models developed to assess responses of these two species to freshwater environmental factors, therefore, need to account for differences in life history patterns between the species in how each individual model is structured and parameterized.
- A key assumption in the *O. mykiss* model is that predation by predatory fishes is a major cause of poor performance of *O. mykiss*, and presumably to the production of the anadromous form of the species. Three parameters within the model were informed by the results of the RST data as it was used to estimate smolt-to-smolt survival of Chinook salmon. However, there is no evidence that predation on *O. mykiss* is comparable to or similar in any way to that of juvenile Chinook salmon. In fact, as far as we can tell, there is no evidence of predation on juvenile *O. mykiss* by predatory fishes in the Tuolumne River.
- Because of limited amounts of information available for *O. mykiss* in the river, the model cannot be adequately calibrated or validated. The authors of the *O. mykiss* modeling report recognized this limitation. They stated: "In the absence of reliable information on the numbers and timing of any anadromous *O. mykiss* spawning and the factors contributing to anadromy in the Tuolumne River, the relative changes in the production of *O. mykiss* smolts resulting

from different flow and temperature conditions within the Tuolumne River cannot be reliably assessed using the TROm model." We agree with this assessment.

- We found that the factors affecting anadromy of *O. mykiss* in the Tuolumne River were not adequately addressed. It would be more useful to apply a framework like the one described by Satterthwaite et al. (2009, 2010) to *O. mykiss* in the Tuolumne River to examine potential anadromy because it is the anadromous form of the species that is listed under ESA, not the resident form.

Despite these shortcomings, it bears noting that the model, as developed, found water temperatures to be the major environmental factor driving juvenile *O. mykiss* productivity downstream of the dam. Flows released below La Grange Dam are apparently the major factor affecting water temperatures.

Recommendations

We concluded that the Chinook salmon population model is useful but not usable by all stakeholders and the *O. mykiss* population model is neither useful nor usable. From our perspective, solutions exist for the issues we raised with the models. Based on our review and analyses of the population models, we offer the recommendations listed below to gather additional information and conduct additional analyses to increase confidence with the models, characterize scientific uncertainty, and address key aspects of managing the river over the term of the FERC license that are missing from the current analytical framework. For the *O. mykiss* population model, we offer a suggested path forward focused on understanding how to stimulate anadromy and what that implies in terms of water management and project operations. However, from our perspective, even if the *O. mykiss* model in its present configuration could be improved to address the shortcomings we identified, it is a rainbow trout model that is not useful to NOAA Fisheries as a steelhead recovery tool. Implementing these recommendations will improve the understanding of key relationships between the species modeled and their environment and analyses of alternatives designed to improve salmonid productivity in the lower Tuolumne River.

- For both species:
  - Develop an analytical framework that will allow an evaluation of both target species at the same time. Currently, each species is addressed separately. We found no discussion of optimizing management alternatives for both species at the same time or identifying tradeoffs between species and alternatives. A key attribute of quantitative models is that they support these types of analyses and discussions.
  - Incorporate climate change into the modeling framework for both species to assess the potential effects changes in hydrology and water temperatures will have on river management alternatives and salmon and steelhead populations over the course of the FERC license.

- For Chinook salmon:
  - Characterize the variability in modeled flow-to-survival relationships to inform the sensitivity of model outputs to key relationships and data points incorporated into the model. Estimating uncertainty is a critical element of communicating model results.
  - Conduct additional analysis of Tuolumne River RST data because it appears that multiple factors associated with fry and smolt catch are interacting (e.g., absolute catch, flow, and rearing and behavior). These factors influence estimated catch and survival between RSTs, and thus the number of smolts estimated to be emigrating from the Tuolumne River. The influence of these factors on the magnitude and variability of smolt production should to be addressed in an analytical framework, including the influence and sensitivity of RST catch during periods of ascending flow that were not incorporated into the Chinook salmon smolt flow-to-survival relationship used in the population model.
  - Estimate survival using mark-recapture methods that incorporate estimated detection probability into survival estimates to independently validate RST-based estimates and inform flow-to-survival relationships. Conduct the studies over multiple years and under all major flow conditions (water year types) and within each year and across reaches. This is needed to develop a better understanding of how survival varies with multiple environmental factors and location.
  - Incorporate the effects of hatchery strays on the overall productivity of the population into the Chinook salmon model. Based on our analysis, Chinook salmon in the Tuolumne River may already be close to being extirpated—the population appears to be precarious at best. The effects of hatchery strays on the overall productivity of the population were not incorporated into the Chinook salmon population model. This needs to be included to inform whether river management alternatives can reduce the negative impact of strays on the natural population and increase population productivity.
  - Conduct additional Chinook salmon otolith analyses to quantify stray rates, reconstruct the in-river conditions conducive to juvenile survival and adult escapement, and inform water management alternatives.
  - Conduct a detailed study of parentage from deoxyribonucleic acid (DNA) to help inform the effects of redd superimposition on Chinook salmon egg-to-fry survival.
- For *O. mykiss*:
  - Model growth as a function of environmental conditions and use sensitivity analyses to predict likely evolutionary endpoints to assess how best to express anadromy in the Tuolumne River and what that implies in terms of water management and project operations. With that information in hand, implications and tradeoffs between

management goals for Chinook salmon and steelhead and recovery goals for steelhead can be discussed and decisions made on the best operations and water management scenarios for both species.

- Consider recruitment from "outside" sources in the model because the influence of increased flow effects in the lower Tuolumne River cannot be separated from effects on estimated population size due to recruitment from above La Grange Dam in high-flow years such as 2011.
- Conduct a detailed study of parentage from DNA to help inform the effects of redd superimposition on *O. mykiss* egg-to-fry survival.

Acknowledgements

Finally, we want to acknowledge the tremendous amount of work and effort conducted by the Districts, their consultants, and the stakeholders to gather the information needed to parameterize and develop the models. Although we found faults with both population models and concluded that the *O. mykiss* population model is not currently useful, we believe the investigators did their best to develop models with the available information. We also thank NOAA Fisheries for giving us the opportunity to review the models. We hope the Districts and stakeholders find our independent review helpful and constructive.