Lower Tuolumne River Water Temperature Modeling
Final Study Plan

Prepared for
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1 BACKGROUND AND PURPOSE

The Federal Energy Regulatory Commission (FERC) issued a July 16, 2009 order ("Order") wherein Ordering paragraph (F) directed the Turlock Irrigation District (TID) and the Modesto Irrigation District (MID) to develop a water temperature model in conjunction with instream flow studies of the lower Tuolumne River (FERC 2009). The purpose of the temperature model is "to determine the downstream extent of thermally suitable habitat to protect summer juvenile *Oncorynchus mykiss* rearing under various flow conditions and to determine flows necessary to maintain water temperatures at or below 68 degrees Fahrenheit from La Grange Dam to Roberts Ferry Bridge". The Order further directs the Districts to include study plan elements of methodologies, schedules, progress reports, and consultation with fishery agencies ("Agencies", including the California Department of Fish and Game, National Marine Fisheries Service, and U.S. Fish and Wildlife Service) in developing the plan.

To examine potential water temperature management scenarios for the benefit of lower Tuolumne River salmonids, two overall study questions will be examined in response to the July 16, 2009 FERC Order:

1. What flows are required to maintain summer water temperatures (MWAT) of 68^{o}F or less downstream to Roberts Ferry Bridge at river mile (RM) 39.5?
2. What is the relationship between flow and water temperature at various time periods during the year in specified reaches of the lower Tuolumne River?

Two existing water temperature models have been previously developed for the lower Tuolumne River. Using water temperature and meteorological data collected from 1978–1988, a stream network temperature (SNTEMP) model (Theurer et al. 1984) was previously developed for the lower Tuolumne River during the late 1980's (TID/MID 1992, Appendix 18). The SNTEMP model used channel and basin geometry along with local meteorological data (i.e., air temperature, relative humidity, solar insolation, and wind speed) collected at the Modesto CIMIS weather station (with corrections for differences in elevation) to predict 5-day average instream temperatures from La Grange Dam (RM 52.2) to near the San Joaquin River confluence (RM 2.6) at various times throughout the year under different flow release scenarios. This SNTEMP model was used in conjunction with results of the CDFG instream flow study of habitat areas for key salmonid life stages (Appendices 4 and 5, TID/MID 1992) and the USFWS instream flow study (USFWS 1995), both conducted under the Don Pedro Project FERC fisheries study plan, in the development of the current flow schedule under Article 37 of the current Don Pedro Project (FERC No. 2299) license (FERC 1996).

More recently, a HEC-5Q model was developed for the Tuolumne River and other tributaries of the San Joaquin River as part of a CALFED-funded temperature model (RMA 2008). The Tuolumne River HEC-5Q sub-model was calibrated using updated water temperature and meteorological data collected from 1996–2006. Based upon statements at a November 2007 training session provided by the model developer, RMA Associates, the model reproduces this historical temperature record to within 1–2°F (0.6–1.1^{o}C) depending upon river location and time of year. This performance is more precise than the previous SNTEMP Model, which had a

predicted error of ± 2.7°F (1.5°C) with a 90% confidence interval of ± 5°F (3.0°C) (TID/MID 1992, Appendix 18). The model also has output on 6-hour intervals, providing more discrete time intervals than the SNTEMP model.

2 RECOMMENDED STUDY APPROACH

In response to the Order, TID and MID (the "Districts") propose to use the existing HEC-5Q model to simulate water temperatures at various flows and times of year. The study approach is to first validate the existing water temperature model against water temperature data not used in the initial model calibration. Second, the validated HEC-5Q model, will be used to test a series of flow scenarios to determine the flows needed to maintain specified water temperatures at particular river locations at various times of the year. Ultimately, the water temperature model predictions developed in this study will be used in conjunction with instream flow incremental methodology (IFIM) predictions of weighted usable area (WUA) developed under a separate study plan (Stillwater Sciences 2009). For example, IFIM estimates of WUA of suitable habitat meeting particular life-stage-specific criteria (i.e., depth, velocity, and substrate) determined at a particular flow and time of year will be superimposed upon areas meeting particular water temperature criteria to create an estimate of effective WUA, or EWUA.

3 STUDY AREA

As shown in Figure 1, the study area extends from La Grange Dam (RM 52.2) downstream to the San Joaquin River confluence (RM 0.0). The upper reach from La Grange to Robert's Ferry Bridge (RM 39.5) specified in the Order represents the downstream extent of most summer *O. mykiss* observations in past snorkel surveys (TID/MID 2009). It also contains the Dominant Spawning Reach (down to RM 46.6) and the Dredger Tailing Reach (down to RM 40.3) which typically have the majority of Chinook salmon spawning activity (McBain and Trush 2000).

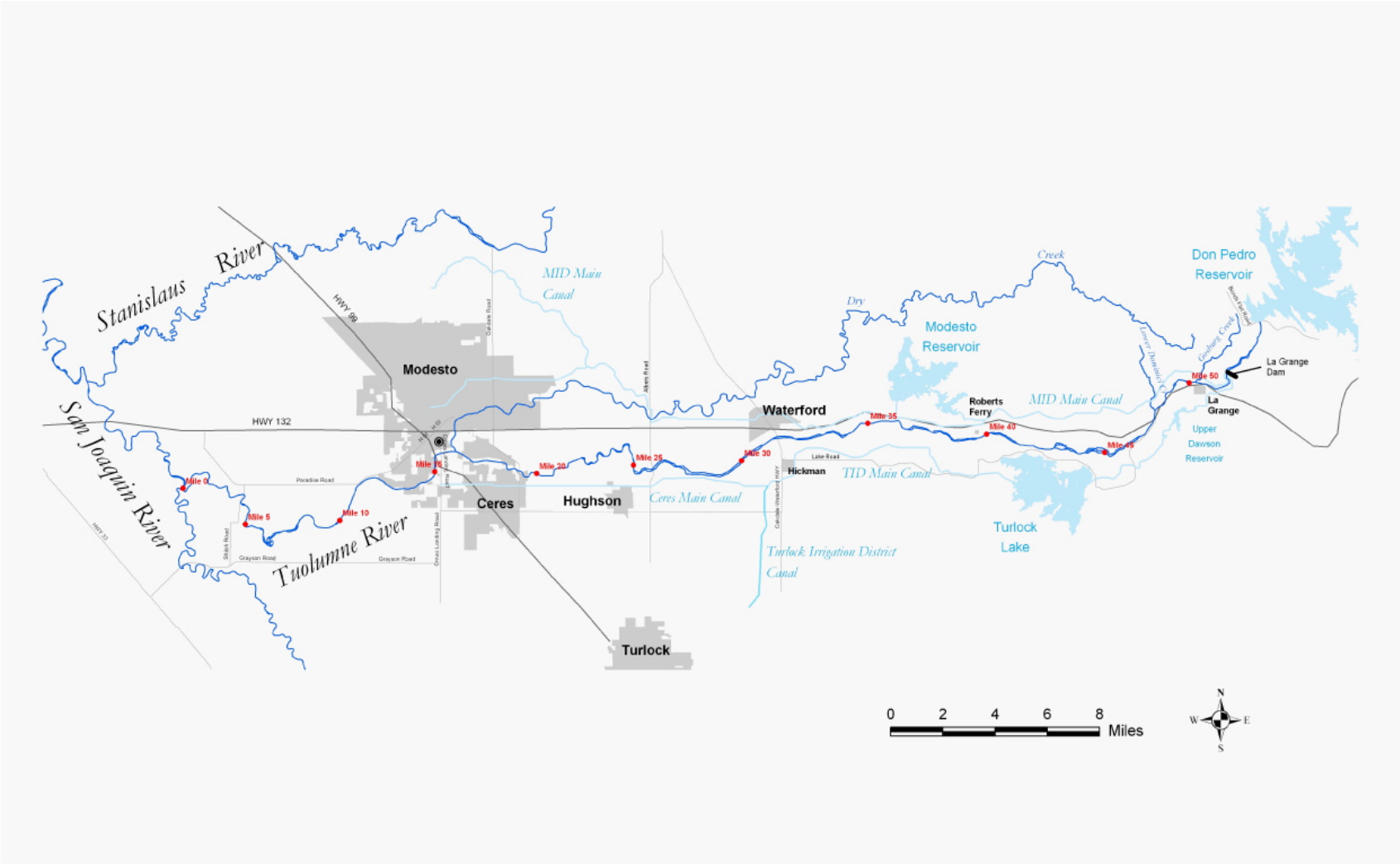

Figure 1. Vicinity map for the Tuolumne River water temperature modeling study.

4 METHODS

The methodology presented in the following sections of this study plan discuss in more detail the steps needed to be performed in order to complete the proposed water temperature modeling study, to inform the complementary IFIM study (Stillwater Sciences 2009), and to report the results to FERC and interested parties.

4.1 Validate Existing HEC-5Q Water Temperature Model

Water temperatures have been recorded continuously by the Districts at various locations in the lower Tuolumne River since 1986 (TID/MID 2005). The HEC-5Q model will be validated against 1996–2009 thermograph data not used in the original model calibration. Data used in the original model calibration may be used if no data independent of the model are available. Because no documentation of the original model calibration was provided in the final CALFED summary report (RMA 2008), an initial step in this process will be to request documentation of thermograph locations, temperature data, and periods of record used in the model calibration so that unbiased goodness of fit statistics can be developed (i.e., observed vs. predicted temperatures) and model uncertainties can be identified. As noted in Section 5, delays in collection of the final HEC-5Q calibration data may result in changes to the proposed schedule. All data records and available metadata (i.e., thermograph model, measurement time-step, specified accuracy, etc) used in the validation exercise will be provided as an electronic data Appendix to the final report.

As recommended by the Agencies, the following temperature modeling goodness of fit metrics are adapted from Theurer et al (1984) using both 6-hr averaged (minimum time-step of the HEC-5Q model) as well as daily averaged thermograph data:

- Maximize the correlation coefficient ($R^2 \leq 1.0$) between modeled and observed water temperatures at individual thermograph locations, as well as across all locations not used in the original calibration data set.
- Determine the fraction of observed temperatures deviating from modeled temperatures by more than 0.5°C, 1°C, and 1.5°C
- Determine any trends in the residual errors (observed minus modeled) either spatially (across several locations) or temporally (at individual locations).

If the goodness of fit results indicate large errors between observed and predicted temperatures, updated model uncertainty estimates will be developed for particular locations or times of year.

4.2 Scenario Development

In addition to an evaluation of the current FERC (1996) flow schedules and the actual flow releases during the 1996–2009 periods as part of the model validation exercise (Section 4.1), the initial scenario will use the validated HEC-5Q model to determine the summer flows necessary to maintain 68°F downstream to Roberts Ferry Bridge (RM 39.5). While these flows are expected to range between 100–400 cfs, the initial model scenario flow range will be expanded if necessary.

In addition to the initial scenario included in the FERC Order (Study Question 1), four additional scenarios corresponding to Study Question 2 were recommended by the Agencies in their review of the Draft Study Plan that correspond to their recommended interim conditions for the protection of various life stages of California Central Valley steelhead (*O. mykiss*) and Fall–run Chinook salmon (*O. tshawytscha*).

1. What flows are required to maintain a summer MWAT of 18ºC (64.4ºF) downstream of La Grange Dam to Roberts Ferry Bridge (RM 39.5)?
2. What flows are required to maintain a MWAT of 18ºC (64.4ºF) downstream of La Grange Dam to the confluence with the San Joaquin River (RM 0) from October 15 to December 1?
3. What flows are required to maintain a MWAT of 13ºC (55.4ºF) downstream of La Grange Dam to Roberts Ferry Bridge (RM 39.5) from October 15 to February 15?
4. What flows are required to maintain a MWAT of 15ºC (59.0ºF) downstream of La Grange Dam to the confluence with the San Joaquin River (RM 0) from March 20 to May 15.

In addition, alternative scenarios (i.e., temperature, location, timing, etc.) may also be evaluated that draw upon findings from the literature or field observations, such as information provided to FERC by the Districts, CCSF, and the Agencies.

4.3 Model Simulations and Analysis

The HEC-5Q model will be used to determine the downstream extent of suitable water temperatures for key *O. mykiss* and *O. tshawytscha* life stages under normal and extreme meteorology. As with any temperature model, using the HEC-5Q model as a predictive tool is limited by the availability of meteorological data corresponding to the conditions of interest (e.g., hottest week of spring or summer), However, various reservoir operation and release scenarios may be simulated against the period-of-record meteorology to generate a range of predicted temperatures for various locations in the river under varying meteorologic conditions. It should be noted that since the reservoir operations modeling component of the existing HEC-5Q is not adequately reflective of actual basin hydrology and District operations of Don Pedro Reservoir, corresponding water storage estimates under various scenarios and water-year types will not be addressed as part of this Study Plan.

4.4 Develop Report

A documentation report will be prepared summarizing the results of the temperature model study, describing the HEC-5Q modeling background, validation, scenario development, model simulations and analysis. The report will include graphics depicting the longitudinal flow versus water temperature relationship under varying meteorologic conditions in order to allow a thermal analysis of various flow regimes. The report will be provided to the Agencies for review and comment prior to submittal to FERC. Periodic progress reports will be prepared as milestone steps under Section 5.

5 SCHEDULE

A proposed schedule is provided in Table 1 and Figure 2. The schedule is predicated on an anticipated study plan acceptance by FERC on or about January 12, 2010, and assumes timely response by the model developer and CDFG in providing requested calibration data and documentation (Section 4.1). In the event that the these responses are not received on a timely basis, or in the event that the validation of the existing model reveals major inconsistencies with observed temperatures in the lower Tuolumne River, the schedule below may be adjusted in consultation with FERC and the stakeholders.

Table 1. Proposed schedule for implementation of FERC-ordered Temperature Modeling Study Plan.

Item	Dates (duration)	Days from FERC Approval of Study Plan
Develop Study Plan and Submit to FERC for Approval	October 14, 2009	--
FERC Response to Study Plan	January 12, 2010 (90d)	
Validate Existing Water Temperature Model	January 13 to April 12, 2010 (90d)	90
Scenario Development	January 13 to May 31, 2010 (139d)	139
Model Simulations and Analysis	June 1 to July 30, 2010 (60d)	199
Progress Report	July 30, 2010 (NA)	199
Prepare Report	October 28, 2010 (90d)	289
Instream Flow and Effective Habitat Evaluations	September 27, 2011 (180d)	623

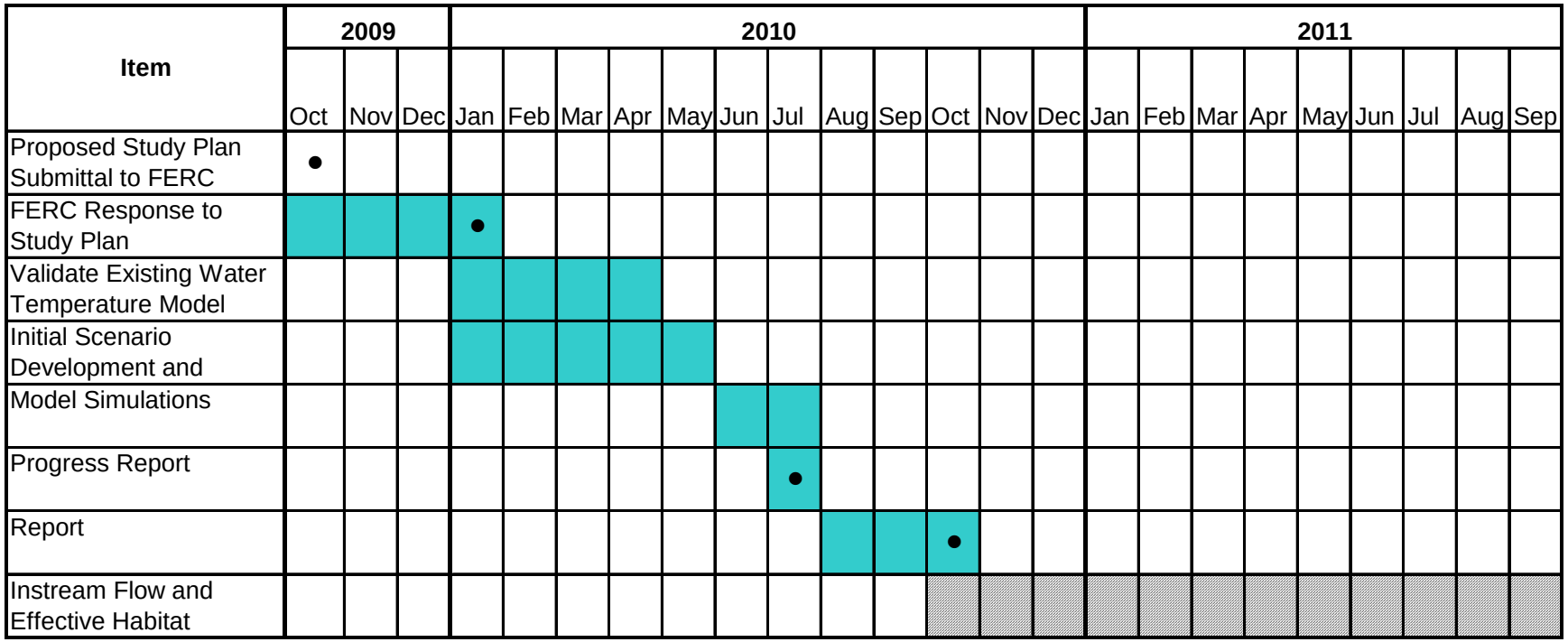

Figure 2. Proposed timeline for implementation of FERC-ordered Temperature Modeling Study Plan.

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