

APPENDIX E

HEC5Q Temperature and Temperature Dependent Modeling Methods and Assumptions

Spatially-explicit daily average Sacramento River water temperatures forecasts from the HEC-5Q model results are used as inputs to generate temperature-dependent egg mortality estimates. For this period, historical temperatures on the Sacramento River at Shasta Dam, Keswick Dam, above Clear Creek, Balls Ferry, Jelly's Ferry, and Bend Bridge are interpolated to estimate temperatures at river miles where simulated redds were located. Actual water temperatures at KWK and CCR were used from 1/1/21 to 7/11/21. HEC-5Q output estimates water temperatures at Keswick Dam; however, there is no temperature gauge at the Keswick Dam, and therefore, the KWK gauge was used for TDM temperature input for the time period 1/1/21 to 7/11/21.

Between September 15 and November 29, daily temperatures at the simulated redds' river miles are typically estimated based on a relationship between cold water pool volume less than 56 degrees F at the end of September in Shasta Lake and water temperatures above Clear Creek derived by Central Valley Operations. Reclamation thinks this relationship is more reliable in that time period than outputs from the HEC-5Q model. The 90% confidence interval value from this analysis was used as a conservative estimate. The average difference between the simulated temperatures above Clear Creek and the simulated temperatures at the redds' river miles during this period are used to adjust above Clear Creek estimated temperatures for each river mile. Forecasted water temperatures in degrees Fahrenheit temperatures shown below were used for TDM modeling, instead of HEC-5Q modeled temperatures for 9/15/2021-11/29/21.

No Action Alternative (i.e., Scenario 14) Forecasted Water Temperatures at Keswick:

$$-0.0067 * (\text{Cold Water Pool Storage}) + 58.9900 + 1.7$$

$$-0.0067 * 155 + 58.9900 + 1.7 = \mathbf{59.6 \text{ degrees Fahrenheit}}$$

No Action Alternative (i.e., Scenario 14) Forecasted Water Temperatures at Clear Creek:

$$-0.0062 * (\text{Cold Water Pool Storage}) + 59.2742 + 2.5$$

$$-0.0062 * 155 + 59.2742 + 2.5 = \mathbf{60.8 \text{ degrees Fahrenheit}}$$

Alternative 1 Forecasted Water Temperatures at Keswick:

$$-0.0067 * (\text{Cold Water Pool Storage}) + 58.9900 + 1.7$$

$$-0.0067 * 180 + 58.9900 + 1.7 = \mathbf{59.5 \text{ degrees Fahrenheit}}$$

Alternative 1 Forecasted Water Temperatures at Clear Creek:

$$-0.0062 * (\text{Cold Water Pool Storage}) + 59.2742 + 2.5$$

$$-0.0062 * 180 + 59.2742 + 2.5 = \mathbf{60.7 \text{ degrees Fahrenheit}}$$

Alternative 2 Forecasted Water Temperatures at Keswick:

$$-0.0067 * (\text{Cold Water Pool Storage}) + 58.9900 + 1.7$$

$$-0.0067 * 193 + 58.9900 + 1.7 = \mathbf{59.4 \text{ degrees Fahrenheit}}$$

Alternative 2 Forecasted Water Temperatures at Clear Creek:

$$-0.0062 * (\text{Cold Water Pool Storage}) + 59.2742 + 2.5$$

$$-0.0062 * 193 + 59.2742 + 2.5 = \mathbf{60.6 \text{ degrees Fahrenheit}}$$

Alternative 3 Forecasted Water Temperatures at Keswick:

$$-0.0067 * (\text{Cold Water Pool Storage}) + 58.9900 + 1.7$$

$$-0.0067 * 244 + 58.9900 + 1.7 = \mathbf{59.1 \text{ degrees Fahrenheit}}$$

Alternative 3 Forecasted Water Temperatures at Clear Creek:

$$\begin{aligned} & -0.0062 * (\text{Cold Water Pool Storage}) + 59.2742 + 2.5 = 60.286 \\ & -0.0062 * 244 + 59.2742 + 2.5 = \mathbf{60.3 \text{ degrees Fahrenheit}} \end{aligned}$$

Alternative 4 Forecasted Water Temperatures at Keswick:

$$\begin{aligned} & -0.0067 * (\text{Cold Water Pool Storage}) + 58.9900 + 1.7 \\ & -0.0067 * 176 + 58.9900 + 1.7 = \mathbf{59.5 \text{ degrees Fahrenheit}} \end{aligned}$$

Alternative 4 Forecasted Water Temperatures at Clear Creek:

$$\begin{aligned} & -0.0062 * (\text{Cold Water Pool Storage}) + 59.2742 + 2.5 \\ & -0.0062 * 176 + 59.2742 + 2.5 = \mathbf{60.7 \text{ degrees Fahrenheit}} \end{aligned}$$

Temperature-dependent egg mortality estimates are calculated by modeling a redd's lifetime based on the days required to cross a known cumulative degree-day threshold and estimating mortality as an increasing function of temperature past a temperature threshold. Two models were used: 1. Martin et al (2017)¹ for stage independent modeling whereby a single temperature threshold is used from spawning and incubation through emergence; and 2. Anderson et al. (2018)² for stage dependent modeling for targeting different temperatures before, during, and after the most sensitive stages during egg incubation. The methods are applied to a set of simulated redds representative of redd construction timing and location from 2012-2020 and the results summarized on a seasonal level for comparison. Further information about the model's assumptions are documented in Table 1 below.

¹ Martin B.T. et al. (2017). Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters 10:50-59.

² Anderson, J. (2018). Using river temperature to optimize fish incubation metabolism and survival: a case for mechanistic models. ResearchGate Preprint. 10.1101/257154.

7/21/21

Table 1. Water temperature and winter-run Chinook salmon temperature-dependent mortality assumptions with adjusted end of season water temperatures.

Parameter	NAA, Alternatives 1, 2, 3, 4 Run Date 7/13/21	NAA, Alternatives 1, 2, 3, 4 7/13/21
Meteorology source	Forecasted Meteorology 25% L3MTO	Forecasted Meteorology 25% L3MTO
Operations Forecast	June forecast (based on June 1 90% hydrology)	June forecast (based on June 1 90% hydrology)
Time period	HEC5Q forecast: 7/12/21-11/29/21 TDM Input: 1/1/2021-11/29/2021	HEC5Q forecast: 7/12/21-11/29/21 TDM Input: 1/1/2021-11/29/2021
Reservoir Model used	HEC-5Q	HEC-5Q
River Model used	HEC-5Q until 9/14 then historic relationship to end of September storage below 56 degrees F	HEC-5Q until 9/14 then historic relationship to end of September storage below 56 degrees F
Shasta Profile date	7/7/21	7/7/21
TCD Gate operations	HEC-5Q	HEC-5Q
Sacramento water temperatures used for TDM	<ul style="list-style-type: none"> 1/1/2021-7/11/21: Actual KWK and CCR water temperatures. 7/12/21-9/14/21: HEC-5Q output at Keswick Dam and Clear Creek 9/15/21-12/31/21: Regression relationship at KWK and CCR 	<ul style="list-style-type: none"> 1/1/2021-7/11/21: Actual KWK and CCR water temperatures. 7/12/21-9/14/21: HEC-5Q output at Keswick Dam and Clear Creek 9/15/21-12/31/21: Regression relationship at KWK and CCR
Biological Model used	SacPAS Fish model	SacPAS Fish model
Temperature Mortality Model	Stage-independent mortality (Martin)	Stage-dependent mortality (Anderson)
Egg emergence timing model	Linear. 958 ATUs (degrees C), as indicated for Zeug et al. on SacPAS under Egg to emergence timing model.	487 (degree C days)
TDM redd time distribution	Observed 2012-2020	Observed 2012-2020
TDM redd space distribution	Observed 2012-2020	Observed 2012-2020
TDM Tcrit (50th percentile)	53.7°F (12.056°C)	53.7°F (12.056°C)
TDM bT (50th percentile)	0.026°C ⁻¹ d ⁻¹ (0.0144°F ⁻¹ d ⁻¹)	1.17°C ⁻¹ d ⁻¹ (0.65°F ⁻¹ d ⁻¹)
Critical Days	All	3
TDM Output (%)	NAA: 86% Alternative 1: 86% Alternative 2: 87% Alternative 3: 88% Alternative 4: 88%	NAA: 92% Alternative 1: 93% Alternative 2: 93% Alternative 3: 93% Alternative 4: 94%