Appendix 11B Upstream Fisheries Impact Assessment Quantitative Methods

Appendix 11B Upstream Fisheries Impact Assessment Quantitative Methods

Temperature management is an important impact to consider for sensitive salmonids, water management, and power generation. Regulatory (California Department of Water Resources [DWR], Reclamation) and resource agencies (e.g., U.S. Fish and Wildlife Service [USFWS], National Marine Fisheries Service [NMFS], and California Department of Fish and Wildlife [CDFW]) put considerable effort into planning and assessing temperature management. This appendix summarizes fisheries impact assessment quantitative methods related to upstream temperature, spawning habitat weighted usable area, redd dewatering, redd scour/entombment, the SALMOD model, rearing flows, rearing habitat weighted usable area, juvenile stranding, and upstream migration of salmon and sturgeon adults. Other fisheries impact assessment quantitative methods are discussed in various other appendices.

11B.1 Upstream Temperature Methods

11B.1.1. Introduction

For the Sacramento River and American River, the water temperature analysis was completed utilizing daily modeled water temperature outputs from the HEC-5Q model, in addition to monthly modeled water temperature outputs from the Reclamation Temperature Model for the Feather River.

There were multiple methods used in this effects analysis to determine whether there would be effects of the Project on aquatic resources. The methods vary by river, race/species, and life stage (Table 11B-1). The first analysis evaluated the results of physical water temperature models that overlapped fish presence in space and time to assess potential water temperature-related effects to aquatic resources. The second analysis determined the frequency and magnitude that either exceeded or fell one or more water temperature index values or water temperature index ranges for each life stage, race/species, and location. The third and fourth methods involved an evaluation of water temperature-related mortality in the Sacramento River using the Martin and Anderson Egg Mortality Models (Martin and Anderson models) for winter-run Chinook salmon and SALMOD for all races of Chinook salmon.

No water temperature analyses were conducted for the Trinity River, Stanislaus River, San Joaquin River, and Clear Creek because preliminary review of the CalSim II flow outputs indicated that there were negligible differences in flows between the NAA and all alternatives in these waterways (Appendix 5B2, *River Operations*). The only water temperature model inputs affected by the alternatives would be flow. Therefore, because difference in flows would be negligible, difference in water temperatures would be negligible.

Table 11B-1. Water Temperature Analysis Methods Used in Each River, Species, and Life Stage

Life stage(s)	Method Used			
	Physical Model Output Characterization	**Water Temperature Index Value/Range Analysis**	**Martin and Anderson Egg Mortality Models**	**SALMOD – Temperature-Related Mortality**
Sacramento River				
Winter-run Chinook Salmon				
Spawning, egg incubation, and alevins	X	X	X	X
Fry and juvenile rearing	X	X		X
Juvenile emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Spring-run Chinook Salmon				
Spawning, egg incubation, and alevins	X	X		X
Fry and juvenile rearing	X	X		X
Juvenile emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Fall-/Late Fall-run Chinook Salmon				
Spawning, egg incubation, and alevins	X	X		X
Fry and juvenile rearing	X	X		X
Juvenile emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Steelhead				
Spawning, egg incubation, and alevins	X	X		
Kelt emigration	X	X		
Juvenile rearing	X	X		
Smolt emigration (not migrant parr)	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Green Sturgeon				
Spawning and egg incubation	X	X		
Pre- and post-spawn adult holding	X	X		
Post-spawn emigration	X	X		

Life stage(s)	Method Used			
	Physical Model Output Characterization	**Water Temperature Index Value/Range Analysis**	**Martin and Anderson Egg Mortality Models**	**SALMOD – Temperature-Related Mortality**
Larval to Juvenile rearing and emigration	X	X		
Adult immigration	X	X		
White Sturgeon				
Spawning and egg incubation	X	X		
Juvenile rearing and emigration	X	X		
Adult immigration and holding	X	X		
Pacific Lamprey				
Spawning and egg incubation	X	X		
Ammocoete rearing and emigration	X	X		
River Lamprey				
Spawning and egg incubation	X	X		
Ammocoete rearing and emigration	X	X		
Hardhead				
Non-spawning life stages	X	X		
Spawning	X	X		
Sacramento Hitch				
Spawning	X	X		
Sacramento Splittail				
Spawning	X	X		
Striped Bass				
Spawning, embryo incubation, and initial rearing	X	X		
Larvae, fry, and juvenile rearing and emigration	X	X		
American Shad				
Spawning, embryo incubation, and initial rearing	X	X		
Larvae, fry, and juvenile rearing and emigration	X	X		
Largemouth Bass				
Spawning	X	X		
Feather River				
Winter-run Chinook Salmon				
Non-natal rearing	X	X		
Spring-run Chinook Salmon				

Life stage(s)	Method Used			
	Physical Model Output Characterization	**Water Temperature Index Value/Range Analysis**	**Martin and Anderson Egg Mortality Models**	**SALMOD – Temperature-Related Mortality**
Spawning, egg incubation, and alevins	X	X		
Fry and juvenile rearing	X	X		
Juvenile emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Fall-run Chinook Salmon				
Spawning, egg incubation, and alevins	X	X		
Fry and juvenile rearing	X	X		
Juvenile emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Steelhead				
Spawning, egg incubation, and alevins	X	X		
Kelt emigration	X	X		
Juvenile rearing	X	X		
Smolt emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Green Sturgeon				
Spawning, egg incubation	X	X		
Pre- and post-spawn adult holding	X	X		
Post-spawn emigration	X	X		
Larval to Juvenile rearing and emigration	X	X		
Adult immigration	X	X		
White Sturgeon				
Spawning and egg incubation	X	X		
Juvenile rearing and emigration	X	X		
Adult immigration and holding	X	X		
Pacific Lamprey				
Spawning and egg incubation	X	X		
Ammocoete rearing and emigration	X	X		

Life stage(s)	Method Used			
	Physical Model Output Characterization	Water Temperature Index Value/Range Analysis	Martin and Anderson Egg Mortality Models	SALMOD – Temperature-Related Mortality
River Lamprey				
Spawning and egg incubation	X	X		
Ammocoete rearing and emigration	X	X		
Hardhead				
Non-spawning life stages	X	X		
spawning	X	X		
Sacramento Hitch				
Spawning	X	X		
Sacramento Splittail				
Spawning	X	X		
Striped Bass				
Spawning, embryo incubation, and initial rearing	X	X		
Larvae, fry, and juvenile rearing and emigration	X	X		
American Shad				
Spawning, embryo incubation, and initial rearing	X	X		
Larvae, fry, and juvenile rearing and emigration	X	X		
Largemouth Bass				
Spawning	X	X		
American River				
Winter-run Chinook Salmon				
Non-natal rearing	X	X		
Steelhead				
Spawning, egg incubation, and alevins	X	X		
Kelt emigration	X	X		
Juvenile rearing	X	X		
Smolt emigration	X	X		
Adult immigration	X	X		
Adult holding	X	X		
Fall-run Chinook Salmon				
Spawning, egg incubation, and alevins	X	X		
Fry and juvenile rearing	X	X		
Juvenile emigration	X	X		
Adult immigration	X	X		

Life stage(s)	Method Used			
	Physical Model Output Characterization	**Water Temperature Index Value/Range Analysis**	**Martin and Anderson Egg Mortality Models**	**SALMOD – Temperature-Related Mortality**
Adult holding	X	X		
Pacific Lamprey				
Spawning and egg incubation	X	X		
Ammocoete rearing and emigration	X	X		
River Lamprey				
Spawning and egg incubation	X	X		
Ammocoete rearing and emigration	X	X		
Hardhead				
Non-spawning life stages	X	X		
Spawning	X	X		
Sacramento Hitch				
Spawning	X	X		
Sacramento Splittail				
Spawning	X	X		
Striped Bass				
Spawning, embryo incubation, and initial rearing	X	X		
Larvae, fry, and juvenile rearing and emigration	X	X		
American Shad				
Spawning, embryo incubation, and initial rearing	X	X		
Larvae, fry, and juvenile rearing and emigration	X	X		
Largemouth Bass				
Spawning	X	X		

11B.1.1. Detailed Methods

11B.1.1.1. Physical Model Output Characterization

Patterns in water temperatures at key locations within the Sacramento, Feather, and American rivers were evaluated for each month that a life stage of each race/species was present and were summarized at the beginning of the water temperature section for each impact statement. The purpose of this characterization was to identify whether there were any locations, months, or water year types in which differences in water temperatures between the NAA and each alternative could potentially cause an effect. It included an evaluation between the NAA and each alternative of exceedance plots of mean monthly water temperature by month and comparisons of exceedance values, long-term averages, and average water temperatures by month and water year type, all of which is reported in Appendix 6C, *River Temperature Modeling*. If a specific result appeared concerning based on best professional judgment, the month, water year type, and location with the concerning result was flagged as requiring close examination in the results of the remaining water temperature evaluation. In addition, specifics of the month, water year type, and location with the concerning result were closely reviewed to determine the cause of the result and to determine whether the modeled effect could be avoided during real time operations.

11B.1.1.2. Water Temperature Index Value Analysis

This analysis determined the frequency and magnitude of exceedance above one or more water temperature index values or outside one or more index ranges obtained from the scientific literature and U.S. Environmental Protection Agency (USEPA) guidance (USEPA 2003) for each race/species and life stage at multiple locations within the Sacramento River (Table 11B-2), Feather River (Table 11B-3), and American River (Table 11B-4). These index values and index ranges typically characterize the suitable, optimal, acceptable, and observed temperature range needed for survival, growth, or presence. The list of index values for salmonids and green sturgeon was originally compiled to assess potential upstream water temperature-related effects for the California WaterFix Section 7 consultation (NMFS 2016). The list of index values and ranges for other species were primarily taken from the 2017 Draft EIR/EIS (Sites Project Authority and US Bureau of Reclamation 2017), Appendix 12D, *Water Temperature Index Value Selection Rationale*, with supplemental information taken from the scientific literature as necessary.

For fish species not listed under the ESA or CESA, the frequency of exceedance above one or more water temperature index values or outside one or more index ranges was evaluated. For ESA-/CESA-listed fish species, both the frequency and magnitude of exceedance above water temperature index values was evaluated. Although sufficient information is available using only the frequency of exceedance to assess potential significant impacts or adverse effects for NEPA/CEQA purposes, NMFS has previously requested an analysis of both the frequency and magnitude of exceedance for Section 7 purposes because it provides additional information used in their jeopardy/adverse modification opinion. Therefore, this enhanced analysis was conducted for listed salmonids (plus fall-/late fall-run Chinook salmon) and green sturgeon for the Sites Reservoir Biological Assessment. Thus, the results of this analysis were available for this RDEIR/SDEIS.

Because USEPA (2003) criteria are provided as seven-day average daily maximum (7DADM) and water temperature model outputs are monthly means, an additional conversion step was performed to convert 7DADM values into monthly means, which involved first calculating daily mean and maximum values from historical stream gage data for multiple locations in the Sacramento, Feather, and American Rivers obtained from the California Data Exchange Center web site (cdec.ca.gov). The 7DADM was calculated for each day using the mean of that day and the preceding 6 days. Next, the difference between 7DADM and mean daily values was calculated for each day. Finally, for each location, the mean monthly difference between 7DADM and mean daily values was calculated. This difference was used as a conversion value to adjust water temperature index values. These conversion values are presented by month in Table 11B-5, Table 11B-6, and Table 11B-7 for the Sacramento, Feather, and American Rivers, respectively. No conversions were necessary for index values and index ranges that did not use USEPA 7DADM guidance.

The index value/range analysis consisted of three steps. First, for the NAA and each alternative, the total number of days (Sacramento and American Rivers) or months (Feather River) across the 82-year modeling period with a modeled temperature that exceeded a given index value or was outside a given index range in Table 11B-2, Table 11B-3, and Table 11B-4 was divided by the total number of days for each month of the year and water year type to provide the frequency of exceedance above the index value or occurrence outside the index range. The difference in frequency of exceedance or occurrence outside the range between NAA and each alternative was then calculated for each month and water year type.

Second, for listed species (plus fall-/late fall-run Chinook salmon) only, the magnitude of exceedance above a temperature index value was calculated. For all days (Sacramento and American Rivers) or months (Feather River) that the modeled temperature exceeded a given temperature index value as shown in Table 11B-2, Table 11B-3, and Table 11B-4, the cumulative degrees exceeded were summed as a degree-day or a degree-month total by month and water year type across the 82-year modeling period and divided by the total number of days or months, respectively, that the index value was exceeded, to provide the average daily/monthly magnitude of exceedance for those days/months that exceeded the index temperature. The difference in average daily/monthly magnitude of exceedance between NAA and each alternative was then calculated for each month and water year type. Combined, these calculations provided a magnitude and frequency of exceedance above a given temperature index value.

The final step identified in which months and water year types there would be a biologically meaningful effect. This differed between listed and non-listed species. For listed species (plus fall-/late fall-run Chinook salmon), this step evaluated both frequency and magnitude combined. A *biologically meaningful* effect was defined as the months and water year types in which water temperature results met two criteria: (1) the difference in frequency of exceedance between NAA and an alternative was greater than 5%, and (2) the difference in average daily exceedance was greater than 0.5°F. The 5% criterion was based on best professional judgment of fisheries biologists from NMFS, CDFW, DWR, and Reclamation. The 0.5°F criterion was based on: (1) a review of the water temperature-related mortality rates for steelhead eggs and juveniles (Swank pers. comm.), and (2) a reasonable water temperature differential that could be resolved through real-time reservoir operations. The 0.5°F value was applied to all species/races and life stages although it was based on data for steelhead eggs and juveniles. For those months and water year types that met these two conditions, a thorough review was conducted to determine whether these patterns were persistent across multiple years and whether the differences could be alleviated during real time operations (i.e., the results are due to a model artifact when in reality, the system would not be operated in this way). Further, when results from a month and/or water year type met these two criteria, exceedance plots were reviewed to determine whether the results may be due to one or two outliers. If this was found to be the case, it was concluded that the effect was not persistent enough to be biologically relevant.

The Tiered Management Approach for summer cold water pool management in the ROC on LTO proposed action (Reclamation 2019: 4-28 to 4-32) was evaluated in two ways. First, an additional daily average temperature value of 53.5°F was evaluated as an index value using the analysis described in this section. Second, the Anderson and Martin models described below were used to evaluate how each alternative would affect winter-run Chinook salmon mortality. The 53.5°F water temperature criterion is based on Martin et al. (2017), which is the genesis of the Martin model and from which the Anderson model is based. The Anderson and Martin models incorporate the biological mechanisms underlying water temperature-related effects to winter-run Chinook salmon egg incubation. As such, they provide more biologically relevant information for winter-run Chinook salmon egg incubation than the water temperature index value analysis. However, the index value analysis was used to evaluate the ability for operators to meet the 53.5°F criterion for Tier 1 and Tier 2 years. Following the summer cold water pool management approach described in Reclamation (2019:4-28 to 4-32), water temperature outputs at Clear Creek were evaluated for the index value analysis from May 15 through October 31. Because tiers are based on storage conditions in Shasta Lake and storage conditions can vary among alternatives for a given year, there were 4 years (1926, 1960, 1987, and 1990) in which alternatives had different tiers. In addition to Shasta Lake storage conditions, factors such as meteorological conditions, Shasta inflow, and CVP operations vary among years and can make a comparison among alternatives with different tiers challenging to interpret. Therefore, the 4 years in which the tier differed among alternatives were excluded from the index value analysis. This was not done for Anderson and Martin analyses because the analyses were not conducted by tier.

For non-listed species, the final step involved an evaluation of only the frequency of exceedance above a water temperature index value or occurrence outside a water temperature index range. A *biologically meaningful* effect was defined as the months and water year types in which the difference between NAA and an alternative in frequency of exceedance above a water temperature index value or occurrence outside a water temperature index range was greater than 5%. As with listed species, a thorough review was conducted to determine whether these patterns were persistent across multiple years and whether the differences could be alleviated during real time operations. Further, when results from a month and/or water year type met the criterion, exceedance plots were reviewed to determine whether the results may be due to one or two outliers. If this was found to be the case, it was concluded that the effect was not persistent enough to be biologically relevant.

Table 11B-2. Water Temperature Index Values and Index Ranges Used for Water Temperature Index Value/Range Analyses, Sacramento River

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
Winter-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Apr-Oct	Keswick		55.4	USEPA 2003
			Clear Creek		55.4	USEPA 2003
			Balls Ferry		55.4	USEPA 2003
			Bend Bridge		55.4	USEPA 2003
			Red Bluff		55.4	USEPA 2003
	Fry and Juvenile Rearing and Emigration	Jul-Mar	Keswick		61	USEPA 2003; core juvenile rearing[2]
			Clear Creek		61	USEPA 2003; core juvenile rearing
			Balls Ferry		61	USEPA 2003; core juvenile rearing
			Bend Bridge		61	USEPA 2003; core juvenile rearing
			Red Bluff		61	USEPA 2003; core juvenile rearing
			Hamilton City		64	USEPA 2003; non-core juvenile rearing[3]
	Adult Immigration	Dec-Aug	Keswick		68	USEPA 2003
			Bend Bridge		68	USEPA 2003
			Red Bluff		68	USEPA 2003
	Adult Holding	Jan-Aug	Keswick		61	USEPA 2003
			Balls Ferry		61	USEPA 2003
			Red Bluff		61	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
Spring-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Aug-Dec	Keswick		55.4	USEPA 2003
			Clear Creek		55.4	USEPA 2003
			Balls Ferry		55.4	USEPA 2003
			Bend Bridge		55.4	USEPA 2003
			Red Bluff		55.4	USEPA 2003
	Fry and Juvenile Rearing and Emigration	Year-round	Keswick		61	USEPA 2003; core juvenile rearing
			Clear Creek		61	USEPA 2003; core juvenile rearing
			Balls Ferry		61	USEPA 2003; core juvenile rearing
			Bend Bridge		61	USEPA 2003; core juvenile rearing
			Red Bluff		61	USEPA 2003; core juvenile rearing
			Hamilton City		64	USEPA 2003; non-core juvenile rearing
	Adult Immigration	Mar-Sep	Keswick		68	USEPA 2003
			Bend Bridge		68	USEPA 2003
			Red Bluff		68	USEPA 2003
	Adult Holding	Apr-Sep	Keswick		61	USEPA 2003
			Balls Ferry		61	USEPA 2003
			Red Bluff		61	USEPA 2003
Fall-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Sep-Jan	Keswick		55.4	USEPA 2003
			Clear Creek		55.4	USEPA 2003
			Balls Ferry		55.4	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
			Bend Bridge		55.4	USEPA 2003
			Red Bluff		55.4	USEPA 2003
	Fry and Juvenile Rearing and Emigration	Dec-Jun	Keswick		61	USEPA 2003; core juvenile rearing
			Clear Creek		61	USEPA 2003; core juvenile rearing
			Balls Ferry		61	USEPA 2003; core juvenile rearing
			Bend Bridge		61	USEPA 2003; core juvenile rearing
			Red Bluff		61	USEPA 2003; core juvenile rearing
			Hamilton City		64	USEPA 2003; non-core juvenile rearing
	Adult Immigration	Jul-Dec	Keswick		68	USEPA 2003
			Bend Bridge		68	USEPA 2003
			Red Bluff		68	USEPA 2003
	Adult Holding	Jul-Aug	Keswick		61	USEPA 2003
			Balls Ferry		61	USEPA 2003
			Red Bluff		61	USEPA 2003
Late Fall-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Dec-Jun	Keswick		55.4	USEPA 2003
			Clear Creek		55.4	USEPA 2003
			Balls Ferry		55.4	USEPA 2003
			Bend Bridge		55.4	USEPA 2003
			Red Bluff		55.4	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
	Fry and Juvenile Rearing and Emigration	Mar-Jan	Keswick		61	USEPA 2003; core juvenile rearing
			Clear Creek		61	USEPA 2003; core juvenile rearing
			Balls Ferry		61	USEPA 2003; core juvenile rearing
			Bend Bridge		61	USEPA 2003; core juvenile rearing
			Red Bluff		64	USEPA 2003; non-core juvenile rearing
			Hamilton City		64	USEPA 2003; non-core juvenile rearing
	Adult Immigration	Nov-Apr	Keswick		68	USEPA 2003
			Bend Bridge		68	USEPA 2003
			Red Bluff		68	USEPA 2003
Steelhead	Spawning, Egg Incubation, and Alevins	Nov-Apr	Keswick	53		McCullough et al. 2001
				56		NMFS 2009
			Clear Creek	53		McCullough et al. 2001
				56		NMFS 2009
			Balls Ferry	53		McCullough et al. 2001
				56		NMFS 2009
			Bend Bridge	53		McCullough et al. 2001
				56		NMFS 2009
			Red Bluff	53		McCullough et al. 2001
				56		NMFS 2009
	Kelt Emigration	Feb-May	Keswick		68	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			Bend Bridge		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			Red Bluff		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
	Juvenile Rearing	Year-round	Keswick	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000
			Clear Creek	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
			Balls Ferry	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000
			Bend Bridge	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000
			Red Bluff	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000
	Smoltification	Jan-Mar	Keswick	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
			Clear Creek	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988

Species	Life Stage	Period	Location	Index Value/Range (°F) Mean Daily	Index Value/Range (°F) 7DADM[1]	Source/Notes
			Balls Ferry	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
			Bend Bridge	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
			Red Bluff	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
	Smolt Emigration (excludes migrant parr)	Nov-Jun	Keswick		61	USEPA 2003
					64	USEPA 2003
			Clear Creek		61	USEPA 2003
					64	USEPA 2003
			Balls Ferry		61	USEPA 2003
					64	USEPA 2003
			Bend Bridge		61	USEPA 2003
					64	USEPA 2003
			Red Bluff		61	USEPA 2003
					64	USEPA 2003
	Adult Immigration	Aug-Mar	Keswick		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			Bend Bridge		68	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			Red Bluff		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
	Adult Holding	Sep-Nov	Keswick		61	USEPA 2003
			Balls Ferry		61	USEPA 2003
			Red Bluff		61	USEPA 2003
Green Sturgeon	Spawning and Embryo Incubation	Mar-Jul	Bend Bridge	63		Upper end of optimal range for embryonic development (Van Eenennaam 2005)
			Red Bluff	63		
			Hamilton City	63		
	Non-Spawning Adult Presence (Immigration, Pre- and Post-Spawn Holding)	Aug-Feb	Bend Bridge	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles
				73		Houston 1988; Erickson et al. 2002
			Red Bluff	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles
				73		Houston 1988; Erickson et al. 2002
			Hamilton City	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
				73		Houston 1988; Erickson et al. 2002
		Year-round	Knights Landing	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles
				73		Houston 1988; Erickson et al. 2002
	Larval to Juvenile Rearing and Emigration	Year-round	Bend Bridge	66		Upper end of optimal range for bioenergetics performance of Age 0/1 sturgeon with full or reduced food supply (Mayfield and Cech 2004)
			Red Bluff	66		
			Hamilton City	66		
White Sturgeon	Spawning and Embryo Incubation	Feb-May	Hamilton City	61		Optimal egg incubation range upper limit (Israel et al. 2011)
				68		Embryo hatching upper limit (Israel et al. 2011)
	Juvenile Rearing and Emigration	Year-round	Hamilton City	66		Stress observed in juvenile white sturgeon above 66°F (Israel et al. 2011)
	Adult Immigration and Holding	Nov-May	Hamilton City	77		Upper limit of suitable water temperatures for adults (Israel et al. 2011)
Pacific Lamprey		Apr-Aug	Keswick	50-64		

Species	Life Stage	Period	Location	Index Value/Range (°F) Mean Daily	Index Value/Range (°F) 7DADM[1]	Source/Notes
	Spawning and Egg Incubation		Red Bluff	50-64		High survival and low occurrence of embryonic developmental abnormalities observed in this range (Meeuwig et al. 2002, 2005)
	Ammocoete Rearing and Emigration	Year-round	Keswick	72		Significant decrease in survival and increase in developmental abnormalities observed above 72°F (Meeuwig et al. 2002, 2005)
			Red Bluff	72		
River Lamprey	Spawning and Egg Incubation	Feb-Jul	Keswick	50-64		High survival and low occurrence of embryonic developmental abnormalities observed in this range (Meeuwig et al. 2002, 2005)
			Red Bluff	50-64		
	Ammocoete Rearing and Emigration	Year-round	Keswick	72		Significant decrease in survival and increase in developmental abnormalities observed above 72°F (Meeuwig et al. 2002, 2005)
			Red Bluff	72		
Hardhead	Spawning	Apr-Jun	Keswick	59-64		Optimal range (Wang 1986)
			Red Bluff	59-64		
	Non-spawning Life Stages	Year-round	Keswick	65-82		Widest observed range (Cech et al. 1990, Moyle 2002, Southern California Edison Company 2007)
			Red Bluff	65-82		
Sacramento Hitch	Spawning	Mar-Jul	Red Bluff	57-79		Moyle 2002
			Butte City	57-79		Moyle 2002

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Notes
				Mean Daily	7DADM[1]	
Sacramento Splittail	Spawning	Feb-May	Hamilton City	45-75		Observed range of suitable water temperatures (Moyle et al. 2004)
Striped Bass	Spawning, Embryo Incubation, and Initial Rearing	Apr-Jun	Butte City	59-68		Optimal range (Moyle 2002)
	Larvae, Fry, and Juvenile Rearing and Emigration	Year-round	Butte City	61-71		Optimal range (Fay et al. 1983)
American Shad	Spawning, Embryo Incubation, and Initial Rearing	Apr-Jun	Red Bluff	60-70		Optimal range (Bell 1986, Painter et al. 1980, Leggett and Whitney 1972, Painter et al. 1979, Rich 1987)
			Butte City	60-70		
	Larvae, Fry, and Juvenile Rearing and Emigration	Year-round	Red Bluff	63-77		Optimal range (Moyle 2002)
			Butte City	63-77		
Largemouth Bass	Spawning	Mar-Jun	Keswick	54-75		Acceptable range for spawning and incubation (Moyle 2002)
			Red Bluff	54-75		

[1] 7DADM = Seven Day Average Daily Maximum
[2] Core = "moderate to high density" (USEPA 2003)
[3] Non-core = "low to moderate density" (USEPA 2003)

Table 11B-3. Water Temperature Index Values and Index Ranges Used for Water Temperature Index Value/Range Analyses, Feather River

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Monthly	7DADM[1]	
Winter-run Chinook Salmon	Non-Natal Rearing	Jul-Mar	LFC above Thermalito		64	USEPA 2003; non-core juvenile rearing[2]
			HFC at Gridley		64	USEPA 2003; non-core juvenile rearing
Spring-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Sep-Feb	LFC below Fish Dam		55.4	USEPA 2003
			HFC below Thermalito		55.4	USEPA 2003
	Fry and Juvenile Rearing and Emigration	Nov-Jun	LFC below Fish Dam		61	USEPA 2003; core juvenile rearing[3]
			HFC below Thermalito		64	USEPA 2003; non-core juvenile rearing
	Adult Immigration	Mar-Jun	LFC below Fish Dam		68	USEPA 2003
			HFC below Thermalito		68	USEPA 2003
	Adult Holding	Apr-Sep	LFC below Fish Dam		61	USEPA 2003
			HFC below Thermalito		61	USEPA 2003
Fall-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Oct-Feb	LFC below Fish Dam		55.4	USEPA 2003
			HFC below Thermalito		55.4	USEPA 2003
	Fry and Juvenile Rearing and Emigration	Nov-May	LFC below Fish Dam		61	USEPA 2003; core juvenile rearing
			HFC below Thermalito		64	USEPA 2003; non-core juvenile rearing
	Adult Immigration	Aug-Dec	LFC below Fish Dam		68	USEPA 2003
			HFC below Thermalito		68	USEPA 2003
	Adult Holding	Aug-Dec	LFC below Fish Dam		61	USEPA 2003
			HFC below Thermalito		61	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Monthly	7DADM[1]	
Steelhead	Spawning, Egg Incubation, and Alevins	Dec-May	LFC below Fish Dam	53		McCullough et al. 2001
			HFC below Thermalito	53		McCullough et al. 2001
	Kelt Emigration	Feb-May	LFC below Fish Dam		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			HFC below Thermalito		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
	Juvenile Rearing	Year-round	LFC below Fish Dam	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	USEPA 2003
			HFC below Thermalito	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	USEPA 2003
	Smoltification	Jan-Mar	LFC below Fish Dam	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
			HFC below Thermalito	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
	Smolt Emigration	Dec-Jun	LFC below Fish Dam		61	USEPA 2003
			HFC below Thermalito		64	USEPA 2003
	Adult Immigration	Aug-Mar	LFC below Fish Dam		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
					68	USEPA 2003

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Monthly	7DADM[1]	
			HFC below Thermalito	70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
	Adult Holding	Sep-Nov	LFC below Fish Dam		61	USEPA 2003
			HFC below Thermalito		61	USEPA 2003
Green Sturgeon	Spawning and Embryo Incubation	Mar-Jul	LFC below Fish Dam	63		Upper end of optimal range for embryonic development (Van Eenennaam 2005)
			HFC below Thermalito	63		
			HFC at Gridley	63		
	Non-Spawning Adult Presence (Immigration, Pre- and Post-Spawn Holding)	Aug-Nov	LFC below Fish Dam	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles
				73		Houston 1988; Erickson et al. 2002
			HFC below Thermalito	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles
				73		Houston 1988; Erickson et al. 2002
			HFC at Gridley	66		Assumes that adults are at least as tolerant to temperatures as larvae and juveniles
				73		Houston 1988; Erickson et al. 2002
	Larval to Juvenile Rearing and Emigration	Year-round	LFC below Fish Dam	66		Upper end of optimal range for bioenergetics performance of Age 0/1 sturgeon with full or reduced food supply (Mayfield and Cech 2004)
			HFC below Thermalito	66		
			HFC at Gridley	66		
White Sturgeon	Spawning and Embryo Incubation	Feb-May	LFC below Fish Dam	61		Optimal egg incubation range upper limit (Israel et al. 2011)
			HFC below Thermalito	61		
			HFC at Mouth	61		
	Juvenile Rearing and Emigration	Year-round	LFC below Fish Dam	66		Stress observed in juvenile white sturgeon above 66°F (Israel et al. 2011)
			HFC below Thermalito	66		
			HFC at Mouth	66		
		Nov-May	LFC below Fish Dam	77		

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Monthly	7DADM[1]	
	Adult Immigration and Holding		HFC below Thermalito	77		Upper limit of suitable water temperatures for adult (Israel et al. 2011)
			HFC at Mouth	77		
Pacific Lamprey	Spawning and Egg Incubation	Apr-Aug	LFC below Fish Dam	50-64		High survival and low occurrence of embryonic developmental abnormalities observed in this range (Meeuwig et al. 2002, 2005)
			HFC below Thermalito	50-64		
			HFC at Mouth	50-64		
	Ammocoete Rearing and Emigration	Year-round	LFC below Fish Dam	72		Significant decrease in survival and increase in developmental abnormalities observed above 72°F (Meeuwig et al. 2002, 2005)
			HFC below Thermalito	72		
			HFC at Mouth	72		
River Lamprey	Spawning and Egg Incubation	Feb-Jul	LFC below Fish Dam	50-64		High survival and low occurrence of embryonic developmental abnormalities observed in this range (Meeuwig et al. 2002, 2005)
			HFC below Thermalito	50-64		
			HFC at Mouth	50-64		
	Ammocoete Rearing and Emigration	Year-round	LFC below Fish Dam	72		Significant decrease in survival and increase in developmental abnormalities observed above 72°F (Meeuwig et al. 2002, 2005)
			HFC below Thermalito	72		
			HFC at Mouth	72		
Hardhead	Spawning	Apr-Jun	LFC below Fish Dam	59-64		Optimal range (Wang 1986)
			HFC below Thermalito	59-64		
			HFC at Mouth	59-64		
	Non-Spawning Life Stages	Year-round	LFC below Fish Dam	65-82		Widest observed range (Cech et al. 1990, Moyle 2002, Southern California Edison Company 2007)
			HFC below Thermalito	65-82		
			HFC at Mouth	65-82		
Sacramento Hitch	Spawning	Mar-Jul	LFC below Fish Dam	57-79		Moyle 2002
			HFC below Thermalito	57-79		

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Monthly	7DADM[1]	
Sacramento Splittail	Spawning	Feb-May	HFC at Mouth	45-75		Observed range of suitable water temperatures (Moyle et al. 2004)
Striped Bass	Spawning, Embryo Incubation, and Initial Rearing	Apr-Jun	HFC below Thermalito	59-68		Optimal range (Moyle 2002)
			HFC at Mouth	59-68		
	Larvae, Fry, and Juvenile Rearing and Emigration	Year-round	HFC below Thermalito	61-71		Optimal range (Fay et al. 1983)
			HFC at Mouth	61-71		
American Shad	Spawning, Embryo Incubation, and Initial Rearing	Apr-Jun	HFC below Thermalito	60-70		Optimal range (Bell 1986, Painter et al. 1980, Leggett and Whitney 1972, Painter et al. 1979, Rich 1987)
			HFC at Mouth	60-70		
	Larvae, Fry, and Juvenile Rearing and Emigration	Jul - Nov	HFC below Thermalito	63-77		Optimal range (Moyle 2002)
			HFC at Mouth	63-77		
Largemouth Bass	Spawning	Mar-Jun	HFC below Thermalito	54-75		Acceptable range for spawning and incubation (Moyle 2002)
			HFC at Mouth	54-75		

[1] 7DADM = Seven Day Average Daily Maximum
[2] Core = "moderate to high density" (USEPA 2003)
[3] Non-core = "low to moderate density" (USEPA 2003)

Table 11B-4. Water Temperature Index Values and Index Ranges Used for Water Temperature Index Value/Range Analyses, American River

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Daily	7DADM[1]	
Winter-run Chinook Salmon	Non-Natal Rearing	Jul-Apr	Watt Ave		64	USEPA 2003; non-core location[2]
Fall-run Chinook Salmon	Spawning, Egg Incubation, and Alevins	Oct-Feb	Below Nimbus		55.4	USEPA 2003
			Watt Ave		55.4	USEPA 2003
	Fry and Juvenile Rearing and Emigration	Jan-May	Below Nimbus		61	USEPA 2003; core juvenile rearing[3]
			Watt Ave		64	USEPA 2003; non-core juvenile rearing
	Adult Immigration	Sep-Dec	Below Nimbus		68	USEPA 2003
			Watt Ave		68	USEPA 2003
	Adult Staging	Jul-Dec	Below Nimbus		61	USEPA 2003
			Watt Ave		61	USEPA 2003
Steelhead	Spawning, Egg Incubation, and Alevins	Dec-May	Below Nimbus	53		McCullough et al. 2001
			Watt Ave	53		McCullough et al. 2001
	Kelt Emigration	Feb-May	Below Nimbus		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			Watt Ave		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
	Juvenile Rearing	Year-round	Below Nimbus	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Daily	7DADM[1]	
			Watt Ave	63		Intermediate value of ranges of optimal growth from Grabowski 1973; Hokanson et al. 1977; Wurtsbaugh and Davis 1977; Myrick and Cech 2005; and Beakes et al. 2014
					69	Sullivan et al. 2000
	Smoltification	Jan-Mar	Below Nimbus	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
			Watt Ave	54		Zaugg and Wagner 1973; Adams et al. 1975; Zaugg 1981; Hoar 1988
	Smolt Emigration	Dec-Jun	Below Nimbus		61	USEPA 2003; core location
			Watt Ave		64	USEPA 2003; non-core location
	Adult Immigration	Oct-Apr	Below Nimbus		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
			Watt Ave		68	USEPA 2003
				70		Average of studies cited in Richter and Kolmes 2005 (for upper end of suboptimal range)
	Adult Holding	Oct-Nov	Below Nimbus		61	USEPA 2003
			Watt Ave		61	USEPA 2003
Pacific Lamprey	Spawning and Egg Incubation	Mar-Jul	Below Nimbus	50-64		High survival and low occurrence of embryonic developmental abnormalities observed in this range (Meeuwig et al. 2002, 2005)
			Watt Ave	50-64		
			Mouth	50-64		
	Ammocoete Rearing and Emigration	Year-round	Below Nimbus	72		Significant decrease in survival and increase in developmental abnormalities observed above 72°F (Meeuwig et al. 2002, 2005)
			Watt Ave	72		
			Mouth	72		
River Lamprey	Spawning and Egg Incubation	Feb-Jul	Below Nimbus	50-64		High survival and low occurrence of embryonic developmental abnormalities observed in this range (Meeuwig et al. 2002, 2005)
			Watt Ave	50-64		
			Mouth	50-64		

Species	Life Stage	Period	Location	Index Value/Range (°F)		Source/Note
				Mean Daily	7DADM[1]	
	Ammocoete Rearing and Emigration	Year-round	Below Nimbus	72		Significant decrease in survival and increase in developmental abnormalities observed above 72°F (Meeuwig et al. 2002, 2005)
			Watt Ave	72		
			Mouth	72		
Hardhead	Spawning	April - June	Below Nimbus	59-64		Optimal range (Wang 1986)
	Non-Spawning Life Stages	Year-round	Watt Ave	65-82		Widest observed range (Cech et al. 1990, Moyle 2002, Southern California Edison Company 2007)
Sacramento Hitch	Spawning	Mar-July	Below Nimbus	57-79		Moyle 2002
			Watt Ave	57-79		
Sacramento Splittail	Spawning	Feb-May	Mouth	45-75		Observed range of suitable water temperatures (Moyle et al. 2004)
Striped Bass	Spawning, Embryo Incubation, and Initial Rearing	Apr-Jun	Watt Ave	59-68		Optimal range (Moyle 2002)
			Mouth	59-68		
	Larvae, Fry, and Juvenile Rearing and Emigration	Year-round	Watt Ave	61-71		Optimal range (Fay et al. 1983)
			Mouth	61-71		
American Shad	Spawning, Embryo Incubation, and Initial Rearing	Apr-Jun	Watt Ave	60-70		Optimal range (Bell 1986, Painter et al. 1980, Leggett and Whitney 1972, Painter et al. 1979, Rich 1987)
			Mouth	60-70		
	Larvae, Fry, and Juvenile Rearing and Emigration	Jul-Nov	Watt Ave	63-77		Optimal range (Moyle 2002)
			Mouth	63-77		
Largemouth Bass	Spawning	Mar-Jun	Watt Ave	54-75		Acceptable range for spawning and incubation (Moyle 2002)

[1] 7DADM = Seven Day Average Daily Maximum
[2] Non-core = "low to moderate density" (USEPA 2003)
[3] Core = "moderate to high density" (USEPA 2003)

Table 11B-5. Conversion Factors (°F) for USEPA (2003) Seven-Day Average Daily Maximum (7DADM) Water Temperature Index Values to Monthly Mean, Sacramento River[1].

Month	Keswick	Clear Creek	Balls Ferry	Bend Bridge	Red Bluff	Wilkins Slough[2]
January	-0.36	-1.01	-0.75	-0.67	-0.86	0.0
February	-0.28	-1.11	-0.86	-0.62	-0.97	-0.3
March	-0.17	-1.29	-0.94	-0.66	-1.23	-0.3
April	-0.25	-1.66	-1.47	-0.95	-1.55	-0.6
May	-0.36	-1.73	-2.18	-1.59	-1.47	-1.4
June	-0.32	-1.55	-2.25	-1.87	-0.96	-1.2
July	-0.36	-1.41	-2.18	-2.01	-0.90	-1.3
August	-0.43	-1.74	-2.06	-1.61	-0.94	-1.3
September	-0.30	-2.00	-1.76	-1.16	-1.70	-2.0
October	-0.25	-1.73	-1.25	-0.91	-1.83	-1.4
November	-0.38	-1.37	-1.10	-0.99	-1.53	-1.3
December	-0.82	-1.42	-1.30	-1.24	-1.48	-1.0

1 Based on historical data from 2003-2014 for all sites except Wilkins Slough, which is based on historical data from November 2012 through June 2015. For a given location and month, values in this table were added to 7DADM index values in Table 11B-2 such that actual values used in the evaluation for each month were lower than those listed in Table 11B-2.

2 Because there is no flow gage at Hamilton City, Wilkins Slough data were used to calculate the conversion factor for Hamilton City

Table 11B-6. Conversion Factors (°F) for USEPA (2003) Seven-Day Average Daily Maximum (7DADM) Water Temperature Index Values to Monthly Mean, Feather River[1,2].

Month	RM 66.3 (Downstream of Hatchery)	RM 58.7 (Downstream of Afterbay Outlet)	RM 25.5 (Shanghai Bend)
January	-0.76	-0.52	-0.45
February	-0.83	-0.56	-0.58
March	-0.93	-0.60	-0.60
April	-0.88	-0.78	-1.06
May	-1.06	-0.87	-1.34
June	-1.10	-1.37	-1.74
July	-1.82	-1.41	-1.30
August	-2.08	-1.37	-1.04
September	-2.16	-1.58	-1.48
October	-1.36	-1.20	-1.51
November	-0.92	-1.15	-1.45
December	-0.94	-0.78	-0.96

[1] Based on historical data from 2002-2014. For a given location and month, values in this table were added to 7DADM index values in Table 11B-3 such that actual values used in the evaluation were lower than those listed in Table 11B-3.

[2] RM 66.3 conversion factors were used for both locations in the LFC (below Fish Dam and above Thermalito); RM58.7 conversion factors were used for the HFC below Thermalito Afterbay Outlet; RM 25.5 conversion factors were used for the HFC at Gridley Bridge.

Table 11B-7. Conversion Factors (°F) for USEPA (2003) Seven-Day Average Daily Maximum (7DADM) Maximum Water Temperature Index Values to Monthly Mean, American River[1].

Month	Below Nimbus Dam	Watt Ave
January	-0.44	-1.01
February	-0.15	-1.05
March	-0.25	-1.29
April	-0.40	-1.72
May	-0.60	-2.05
June	-0.44	-2.55
July	-0.50	-3.17
August	-0.70	-3.11
September	-0.59	-2.52
October	-0.60	-2.01
November	-0.80	-1.65
December	-0.77	-1.26

[1] Based on historical data from 2003-2014. For a given location and month, values in this table were added to 7DADM index values in Table 11B-4 such that actual values used in the evaluation were lower than those listed in Table 11B-4.

11B.1.1.3. Winter-Run Chinook Salmon Egg Mortality Analysis based on Martin et al. (2017)

Background

The dissolved oxygen content of the water passing through the gravel substrate and sustaining Winter-Run Chinook Salmon eggs is positively correlated with temperature; warm, anoxic conditions result in egg mortality. This analysis attempted to isolate the thermal component of egg mortality from other components such as density-dependent mortality and redd dewatering. Both the Martin et al. (2017) model described in this section and the Anderson (2018) model (described below in Section 11B.1.2.4, *Winter-Run Chinook Salmon Egg Mortality Analysis based on Anderson (2018)*) begin by modeling a redd's lifetime by counting the days required to cross a known cumulative degree-days threshold, and both estimate mortality as a linear, increasing function of temperature past a known temperature threshold, but each model uses a different set of assumptions to implement this conceptual model. The methods were applied to a set of simulated redds and the results were summarized on a seasonal level for comparison of mortality outcomes between DCR 2015 Without and With Project scenario HEC5Q model runs.

Martin et al. (2017) identified a discrepancy between laboratory and field estimates of egg mortality and proposed a mechanism based on differing flow velocities in the laboratory and field environments. They then outlined a model for estimating temperature-dependent egg mortality in the field and fit its parameters to Sacramento River Winter-Run Chinook Salmon population data collected between 1996 and 2015 (Martin et al., 2017).

Mortality Calculations

The first step in the Martin et al. (2017) model is to estimate a redd's date of emergence. Individual eggs within the redd hatch but stay within the gravel substrate of the redd and become alevins. These alevins later depart the redd in the emergence stage. The redd's estimated date of emergence is intended to represent the point in the average egg's life span where it leaves the gravel substrate of the redd.

The Martin et al. (2017) model estimates the date of emergence using a linear relationship between water temperature (T, in °F) and maturation: Rate of maturation = 0.00058 * T - 0.018 (Zeug et al. 2012). For each simulated redd, the Zeug et al. (2012) equation was applied to daily temperatures starting the day after redd creation until the cumulative sum of daily maturation rates is greater than one. The day on which this occurs is considered the date of emergence for the redd.

Daily survival is then calculated for every day of the redd's lifespan. Below a temperature threshold of 11.9°C, no temperature-dependent mortality is recorded, and the survival is 1. For each degree C above the threshold, 0.024 is subtracted from the daily survival. The product of the natural exponents of daily survivals is the total survival, and one minus survival is the estimated mortality fraction for that simulated redd.

In summary, the Martin et al. (2017) model uses the Zeug et al. (2012) equation to estimate date of emergence, then estimates daily mortality for each day of the redd's lifespan using a linear relationship.

Spatiotemporal Distribution of Simulated Winter-Run Chinook Salmon Eggs

The Martin et al. (2017) model was applied to HEC5Q Sacramento River temperature results using the same spatiotemporal distribution of redds in each year. The distribution is the averaged location and timing of redds counted in California Department of Fish and Wildlife Winter-Run aerial survey data from 2007 to 2014. Simulated redds were created and subjected to mortality calculations. All simulated redds’ mortalities were combined in a sum, weighted by the spatiotemporal distribution, to estimate the total seasonal mortality fraction.

No assumption was made regarding the total number of redds, as density-dependent mortality is not considered in this calculation; results indicate only the percentage of the total seasonal Winter-Run Chinook Salmon egg population in the upper Sacramento River that is estimated to have succumbed to temperature-dependent mortality. Because a large percentage of modeled redds survived into October and the HEC5Q simulation ends at September of 2003, temperature-dependent egg mortality was only estimated for the 1922–2002 water years.

Tables 11B-8 and 11B-9 indicate the river miles and dates for which simulated redds were created as well as the proportion of the total Winter-Run Chinook Salmon egg population which each location or time represents. The same temporal distribution was assumed for all locations.

Table 11B-8. Spatial Distribution of Simulated Redds Used in the Martin et al. (2017) Model of Winter-Run Chinook Salmon Egg Mortality

River Reach	River Mile	Mean Percentage (2007-2014)
Keswick to A.C.I.D. Dam.	298	46.4%
A.C.I.D. Dam to Highway 44 Bridge	296	46.1%
Highway 44 Br. to Airport Rd. Br.	284	6.7%
Airport Rd. Br. to Balls Ferry Br.	275	0.3%
Balls Ferry Br. to Battle Creek.	271	0.2%
Battle Creek to Jellys Ferry Br.	266	0.2%
Jellys Ferry Br. to Bend Bridge	257	0.1%
Bend Bridge to Red Bluff Diversion Dam	242	0.0%

Table 11B-9. Temporal Distribution of Simulated Redds Used in the Martin et al. (2017) Model of Winter-Run Chinook Salmon Egg Mortality

Date (month/day)	Mean Percentage (2007-2014)
5/15	5.4%
6/1	5.9%
6/9	7.8%
6/16	13.3%
6/24	16.0%
7/1	15.9%
7/9	14.2%
7/16	10.4%
7/24	6.7%
8/1	3.1%
8/16	1.4%

11B.1.1.4. Winter-Run Chinook Salmon Egg Mortality Analysis based on Anderson (2018)

Anderson (2018) developed a model that built on Martin et al.'s (2017) findings but differed in two key assumptions. While Martin et al. (2017) applied mortality to each day of a redd's lifespan from birth past hatching to emergence, Anderson (2018) used a short critical period instead. Using field data from 2002 through 2015, a critical period just before hatching was found to provide the best fit (Anderson 2018). This analysis used a critical period of 5 days in length, following the implementation of the Anderson (2018) model on the SacPAS website (http://www.cbr.washington.edu/sacramento/fishmodel/).

Instead of using the Zeug et al. (2012) equation to estimate date of emergence, the Anderson (2018) model uses a different equation to estimate date of hatching. Like the Zeug et al. (2012) equation, daily temperatures are correlated to daily maturation and a cumulative sum of daily maturation is calculated until maturation crosses a known threshold. The date on which this occurs is the hatching date, and in this implementation of the Anderson (2018) model the 5 days before hatching are the days on which mortality is estimated.

The daily equation was calibrated as by Alderdice and Velsen (1978): ln(Daily development rate) = ln(k) + b * (ln(T - c)), where k = 0.08646, b = 1.23473, c = -2.26721, and temperature is measured in °C. The day on which the cumulative sum of daily development rate passes 100 is considered the redd hatching date.

Like the Martin et al. (2017) model, the Anderson (2018) model assumes a linear relationship between mortality and temperature, with zero mortality below a threshold. The threshold was set identical to the Martin et al. (2017) model at 11.9 C, while the slope is not 0.024 but 0.5. This is unsurprising; calibration to substantially the same dataset will naturally result in a much higher slope, or a much larger mortality impact per degree C above the threshold, for a model that only applies mortality to 5 days instead of the full lifespan of the redd. The same formulae for adding up daily survivals and finding a total mortality estimate were used as for the Martin et al. (2017) model, as described above in *Mortality Calculations*. The same spatiotemporal redd weighting was applied as the Martin et al. (2017) model; see description above in *Spatiotemporal Distribution of Simulated Winter-Run Chinook Salmon Eggs*.

11B.2 References

11B.2.1. Printed References

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11B.2.2. Personal Communications

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