Appendix D: Fisheries, Part 1

Note: References to Appendix 7A - 7G are included in Part 2 of this appendix

1. Fisheries

1.1 Introduction

Changes in Folsom Reservoir storage and Nimbus Dam flow release operations with the Folsom WCM alternatives could change the fisheries habitat conditions in the lower American River, relative to existing conditions and other baseline conditions. In addition, changes in Folsom Reservoir and Nimbus Dam release operations could alter the hydrologic and water temperature conditions in the Sacramento River below Keswick Dam and in the lower Feather River below the Fish Barrier Dam as a result of the coordinated State Water Project/Central Valley Project (SWP/CVP) operations between the Sacramento, Feather, and American Rivers. Further, changes in hydrologic conditions in the Sacramento River could alter the hydrologic and water quality conditions in the Sacramento–San Joaquin Delta and the Yolo Bypass.

The U.S. Army Corps of Engineers (USACE) evaluated the effects of the Folsom WCM alternatives on fish species and associated aquatic habitat by geographic region within the Project Area based on USACE's anticipated magnitude of changes in aquatic habitat conditions with the Folsom WCM alternatives and based on the types of modeling tools that were available for each geographic region. The geographic regions are the lower American River and the Far-Field study areas (Sacramento River, Feather River, Sacramento–San Joaquin Delta, and Yolo Bypass). Because the Folsom WCM alternatives are most likely to affect fisheries habitat conditions in the lower American River, USACE conducted more-detailed modeling and fisheries analyses for the lower American River than for other potentially affected areas within the Far-Field.

For each of the Folsom WCM study areas, USACE identified fish species of focused evaluation in potentially affected geographic regions in the study areas. Fish species of focused evaluation consist of special-status fish species (Federally and state listed threatened and endangered species, Federal candidate species and species of concern, and state species of special concern) as well as other recreationally important fish species.

Table 3-1 presents the special-status fish species that could occur in the Action Area and their Federal and state regulatory status, generally taken from CDFW (2014). Table 3-1 also presents non-special-status fish species of recreational or commercial importance. Table 3-2 indicates which species are evaluated in each waterbody in the Action Area.

Evaluating effects on fishery resources requires understanding fish species' life histories, spatial and temporal distributions, and lifestage-specific environmental requirements. Information regarding the legal status, life histories, spatial and temporal distributions, and habitat requirements of the fish species of focused evaluation is provided in the Fisheries Environmental Setting section (Appendix 7A).

Table 1-1. Special-status Fish Species and Species of Recreational or Commercial Importance in the Action Area.

Common Name	Status
• Sacramento River winter-run Chinook salmon evolutionarily significant unit (ESU)	Federally and state endangered
• Central Valley spring-run Chinook salmon ESU	Federally and state threatened
• Central Valley fall-/late fall-run Chinook salmon ESU	Federal species of concern State species of special concern
• Central Valley steelhead distinct population segment (DPS)	Federally threatened
• Southern DPS of North American green sturgeon	Federally threatened State species of special concern
• Delta smelt	Federally threatened State endangered
• Longfin smelt	Federal candidate[1] State threatened
• Hardhead	State species of special concern
• Pacific lamprey	Federal species of concern[2]
• River lamprey	State species of special concern
• Sacramento splittail	State species of special concern
• White sturgeon	Recreational and/or commercial importance
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

[1] Federal candidate status is for the San Francisco Bay-Delta DPS of longfin smelt.
[2] Although not referenced as a federal species of concern in CDFW (2014), the Oregon U.S. Fish and Wildlife Service (USFWS) office considers Pacific lamprey a species of concern. The Sacramento USFWS office does not maintain a species-of-concern list.

Table 1-2. Waterbodies and Fish Species of Focused Evaluation by Geographic Region.

	Lower American River	Sacramento River	Lower Feather River	Yolo Bypass	Delta
Sacramento River winter-run Chinook salmon ESU		✓		✓	✓
Central Valley spring-run Chinook salmon ESU	✓	✓	✓	✓	✓
Central Valley fall- and late fall-run Chinook salmon ESU	✓	✓	✓	✓	✓
Central Valley steelhead DPS	✓	✓	✓	✓	✓
North American green sturgeon (southern DPS)		✓	✓	✓	
Delta smelt*				✓	✓
Longfin smelt					✓
River lamprey	✓	✓	✓		
Pacific lamprey	✓	✓	✓		
Sacramento splittail				✓	
Hardhead	✓	✓	✓		
White sturgeon		✓	✓	✓	
American shad	✓	✓	✓		✓
Striped bass	✓	✓	✓		✓

1.2 Impact Assessment Methodology

This section summarizes the methodologies that USACE used to evaluate the effects of the Folsom WCM alternatives on fish species of focused evaluation and their habitats based on simulated changes in hydrology, water temperature, and fisheries habitat parameters relative to the California Environmental Quality Act (CEQA) Existing Condition and the National Environmental Protection Act (NEPA) No Action Alternative scenarios for regulatory compliance purposes.

The Fisheries Impact Assessment Methodology appendix (Appendix 7B) provides a detailed discussion of the fisheries impact assessment methodology, impact indicators, and significance criteria used to evaluate the effects of the Folsom WCM alternatives on fisheries resources, relative to basis of comparison.

1.2.1 Analytical Tools

The fisheries and aquatic habitat impact assessment relies on hydrologic modeling to provide a quantitative basis from which to assess the effects of the Folsom WCM alternatives on fish species of focused evaluation and aquatic habitats in the SWP/CVP system, relative to the basis of comparison. Specifically, hydrologic simulation results from CalSim II of mean monthly river flows provide a quantitative basis to assess the effects of operations on fish species for the Far-Field study area, while daily hydrologic output is used to assess effects of operations on fish species in the lower American River.

USACE used these simulated results as inputs to the U.S. Bureau of Reclamation's (Reclamation) Water Temperature Models (Reclamation 1997) for the Sacramento and Feather Rivers, which simulate mean monthly water temperature of the main river systems for the same simulation period. USACE used hydrologic simulation results for the lower American River as inputs to daily models to produce daily water temperature outputs.

USACE used simulated daily water temperatures for the lower American River as inputs to Reclamation's Mortality Model, as modified and updated by the Water Forum and USACE (2015), herein referred to as the LAR Mortality Model, to estimate annual mortality rates for the early lifestages (in-vivo eggs, incubating eggs, and pre-emergent fry) of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the lower American River. USACE also used simulated flows as inputs to other analytical tools to calculate salmonid spawning habitat (weighted usable area, or WUA) for the upper Sacramento, lower Feather and lower American rivers, and salmonid redd dewatering for the lower American River, to quantify specific effects on specific lifestages.

Detailed information about specific modeling tools and the modeling assumptions used to characterize Project operations is presented in Appendix A.

1.2.2 Model Uncertainty

The physical habitat models used in the analyses, although mathematically precise, should be viewed as having inherent uncertainty because of limitations in the theoretical basis of the model and the scope of the formulation and function for which each model is designed. Nonetheless, physical habitat models developed for planning and impact-assessment purposes represent the best available information with which to conduct evaluations of proposed changes in SWP and CVP operations. Therefore, USACE used physical habitat models as analytical tools to identify changes in aquatic habitat variables (e.g., flows and water temperatures) as well as inputs to species specific analytical tools (e.g., LAR Mortality Model).

1.2.3 Application of Model Output

USACE used computer simulation models and post-processing tools to assess changes in hydrology and water quality, and associated changes in species-specific habitat conditions, that could occur under the Folsom WCM alternatives, relative to the basis of comparison. USACE used model assumptions and results for comparative purposes, rather than for absolute predictions, and the focus of the analysis is on differences in the results among comparative scenarios. All of the assumptions are the same for both the with-project and without-project model runs, with the exception of assumptions associated with the action itself, and the focus of the analysis is the differences in the results.

1.2.4 General Analytical Approach

USACE assessed effects on fish species of focused evaluation by evaluating hydrologic and water temperature model outputs to identify changes in aquatic habitat that could affect fish species of focused evaluation. Specific types of model output used to assess changes in fisheries habitat conditions are summarized below. Refer to Appendix 7B for detailed descriptions of the types of model output and their application to the fisheries impact assessment.

1.2.4.1 Long-term Average Flow and Average Flow by Water Year Type

Post-processing tools use monthly output (Far-Field) and daily output (lower American River) to calculate the long term average flows, by month, that would occur over the respective simulation periods under the alternatives and the basis of comparison. USACE used monthly average simulated flows by water year type to compare differences between the basis of comparison and the alternatives. Presented in tabular format, the data tables for the long term average flows by month, and the monthly average flows by water year type, demonstrate the changes that USACE expects to occur with the Folsom WCM alternatives, relative to the basis of comparison.

1.2.4.2 Flow Exceedance Distributions

USACE developed monthly flow exceedance distributions (or curves) from monthly (Far-Field) and daily (lower American River) output for the entire simulation periods. These distributions illustrate the distribution of simulated flows with the Folsom WCM alternatives and the basis of comparison. Exceedance distributions generally represent the monthly flow output for a given month sorted by magnitude for the entire period of record. In general, flow exceedance distributions represent the probability, as a percentage of time, that modeled flow values would be met or exceeded at a specific location during a certain period. Therefore, exceedance distributions demonstrate the cumulative probabilistic distribution of flows for each month at a given river location under a given simulation. Exceedance distributions also allow a comparison of flow output among model scenarios without attributing unwarranted specificity to changes between particular model years.

Exceedance distributions are particularly useful for examining flow changes occurring at lower flow levels. Results from past instream flow studies indicate that salmonid spawning and rearing habitat is most sensitive to changes during lower-flow conditions (CDFG 1994; USFWS 1985). Given the sensitivity of various lifestages to lower-flow conditions, this impact assessment specifically evaluates flow differences during low-flow conditions.

1.2.4.3 Flow-Dependent Habitat Availability

1.2.4.3.1 Spawning WUA

Flow-dependent habitat availability refers to the quantity and quality of habitat available to individual species and lifestages for a particular instream flow. The physical habitat simulation (PHABSIM) system is a commonly used method to express indices of the quantity and quality of habitat associated with specific flows. PHABSIM is the combination of hydraulic and habitat models, the output of which is expressed as WUA. PHABSIM is used to predict the relationship between instream flow and the quantity and quality of habitat for various lifestages of one or more species of fish.

For the Chinook salmon and steelhead spawning lifestage, *flow-dependent habitat availability* refers to the amount of spawning habitat, characterized by the suitability of water depths, velocities, and substrate, for successful spawning that is, in part, contingent on stream flow. Salmonids typically deposit eggs within a range of depths and velocities that ensure adequate exchange of water between surface and substrate interstices to maintain high oxygen levels and remove metabolic wastes from the redd. Stream flow directly affects the availability of spawning habitat (SWRI 2002).

USACE applied spawning WUA-discharge relationships to simulated mean monthly flows (Far-Field) and to simulated mean daily flows (lower American River) for anadromous salmonids. Although USACE does not expect substantial flow changes in the Far-Field, because the relationships between flow and flow-dependent spawning habitat is not linear, USACE applied spawning WUA-discharge relationships to anadromous salmonids in the lower Feather River and the upper Sacramento River.

USACE used the resulting species-specific annual spawning WUA output to develop exceedance distributions, and calculate long-term average spawning WUA and average spawning WUA by water year type, which was used to evaluate changes in spawning habitat under the Folsom WCM alternatives, relative to the basis of comparison.

Appendix 7D provides a detailed discussion of the spawning WUA-discharge relationships used for winter-run, fall-run and late fall-run Chinook salmon and steelhead spawning in the upper Sacramento River and for steelhead and spring-run and fall-run Chinook salmon spawning in the lower feather River and their application. Appendix 7E provides a detailed discussion of the spawning WUA-discharge relationships used for fall-run Chinook salmon and steelhead in the lower American River and their application.

Because of the lack of habitat-discharge relationships for fry and juvenile Chinook salmon and steelhead rearing in the lower American River, the lower Feather River, and the upper Sacramento River, these lifestages are not evaluated using PHABSIM habitat-discharge relationships in this assessment. Rather, the evaluation of juvenile fall-run Chinook salmon and steelhead habitat suitabilities in the lower American River in this evaluation focuses on differences in flow and differences in water temperature, which is the primary stressor to these lifestages.

1.2.4.4 Water Temperature Exceedance Distributions

USACE developed monthly water temperature exceedance distributions (or curves) from Reclamation's monthly water temperature model output (Far-Field) and from the daily water temperature modeling (lower American River) for the entire simulation periods. These distributions illustrate the distribution of simulated water temperatures with the Folsom WCM alternatives and the basis of comparison. In general, water temperature exceedance distributions represent the probability, as a percentage of time, that modeled water temperature values would be met or exceeded at a specific location during a certain period. Monthly water temperature exceedance distributions are applied to species and lifestage-specific water temperature index (WTI) values with the Folsom WCM alternatives relative to the basis of comparison.

Water temperature evaluation guidelines have been developed more extensively for Chinook salmon and steelhead than for other fish species in the Central Valley. USACE used species and lifestage-specific WTI values developed by Bratovich et al. (2012) as a means to assess the effects of the Folsom WCM alternatives, relative to the basis of comparison, on Chinook salmon and steelhead in the Project Area. Bratovich et al. (2012) evaluated water temperature suitabilities associated with the reintroduction of spring-run Chinook salmon and steelhead into the upper Yuba River Basin and describe development of the upper optimum (UO) WTI values and upper tolerable (UT) WTI values used for this assessment (Table 7-3).

- **Upper Optimum Temperature (UO).** The upper optimum temperature represents the upper boundary of the optimum range and represents a temperature below which growth, reproduction, and/or behavior are not affected by temperature.
- **Upper Tolerable Temperature (UT).** The upper tolerable temperature represents a water temperature at which fish can survive indefinitely, without experiencing substantial detrimental effects to physiological and biological functions such that survival occurs, but growth and reproduction success are less than at optimum water temperature.

Table 1-3. Lifestage-specific Upper Optimum and Upper Tolerance WTI Values for Chinook Salmon and Steelhead.

Chinook Salmon			Steelhead		
Lifestage	**Upper Optimum WTI**	**Upper Tolerance WTI**	**Lifestage**	**Upper Optimum WTI**	**Upper Tolerance WTI**
Adult immigration	64°F	68°F	Adult immigration	64°F	68°F
Adult holding	61°F	65°F	Adult holding	61°F	65°F
Spawning	56°F	58°F	Spawning	54°F	57°F
Embryo incubation	56°F	58°F	Embryo incubation	54°F	57°F
Juv. rearing and outmigration	61°F	65°F	Juv. rearing and outmigration	65°F	68°F
Smolt emigration	63°F	68°F	Smolt emigration	52°F	55°F

Chinook salmon holding WTI values were applied only to the holding of winter-run and spring-run Chinook salmon, because fall-run Chinook salmon generally enter freshwater in a sexually mature state and reportedly spawn relatively soon after reaching freshwater spawning grounds. The Chinook salmon smolt emigration WTI values were applied only to spring-run Chinook salmon, because fall-run and winter-run Chinook salmon generally emigrate from Central Valley rivers as young-of-the-year (Kimmerer and Brown 2006).

Lifestage-specific WTI values were also applied for other fish species of focused evaluation, based on reported lifestage-specific water temperature tolerances and preferences. Appendix 7C describes WTI values for other fish species and the rationale for the selection of representative WTI values and ranges evaluated. WTI value ranges are typically used for a lifestage when insufficient information is available to identify specific WTI values.

The WTI values applied to simulated water temperatures in this assessment represent water temperature values above which the water temperature could be considered to be impactive, for evaluation purposes.

The WTI values are not meant to be significance thresholds but instead provide a mechanism by which to compare the resultant water temperatures associated with the Folsom WCM alternatives, relative to the basis of comparison.

1.2.4.5 Chinook Salmon Early Lifestage Mortality

USACE also used the water temperature results for the lower American River as inputs to the updated LAR Mortality Model (Water Forum and USACE 2015) to estimate thermally induced annual mortality rates for the embryonic lifestage of fall-run Chinook salmon in the lower American River. The LAR Mortality Model was initially developed by Reclamation in 1983 for the Sacramento River and was later applied to the lower American River in the 1990s. Because additional information has become available since the LAR Mortality Model was originally developed that could be incorporated into the model to improve its accuracy, the Water Forum and USACE (2015) updated the LAR Mortality Model during 2013 through 2015. The following LAR Mortality Model assumptions were refined based on new data and information that has become available:

1. The temporal distribution for the arrival of spawning fall-run Chinook salmon adults in the lower American River
2. The temporal distribution for fall-run Chinook salmon spawning in the lower American River
3. The spatial distribution of spawning fall-run Chinook salmon in the lower American River
4. The thermally induced Chinook salmon daily mortality rates for pre-spawn eggs, fertilized eggs, and pre-emergent fry
5. The Accumulated Thermal Unit (ATU) thresholds associated with the end of the fertilized-egg and pre-emergent fry lifestages

Appendix 7G provides a detailed description of the updates and modifications made to the original mortality model.

USACE generated simulated annual total early lifestage mortality of fall-run Chinook salmon in the lower American River for the entire simulation period for the Folsom WCM alternatives and the basis of comparison. The resulting series of annual values for early lifestage mortality were used to calculate and compare the corresponding early lifestage mortality exceedance distributions and long-term averages and averages by water year type for the Folsom WCM alternatives and the basis of comparison.

1.2.5 Overview of Evaluation Criteria

Evaluation criteria for evaluating impact indicators are described in detail in Appendix 7B. USACE's evaluation of impact indicators on fisheries resources included evaluating the net difference in habitat variables in relation to specific criteria for individual species and lifestages for each of the Folsom WCM alternatives, relative to a baseline condition. Depending on the lifestage and habitat variable (e.g., flow or water temperature), variables were evaluated over the entire modeled period of record (e.g., 82 years), by water year type (e.g., wet, above-normal, below-normal, dry and critical years), and/or during the driest 40 percent of years as defined by the exceedance probability distributions.

For the Far-Field, USACE's evaluations focused on comparisons of mean monthly flow and water temperature model output. The primarily purpose of the Far-Field fisheries evaluations was to determine whether additional, more-detailed modeling and/or analyses would be required to elucidate effects on fish species of focused evaluation. USACE's decision to conduct more-detailed impact evaluations was based on considering all flow and water temperature impact indicators for all lifestages for a particular species. Detailed evaluations were conducted for any given Folsom WCM alternative if the initial evaluation indicated that that alternative could adversely affect an individual species or run for its defined geographic area (e.g., upper Sacramento River, lower Feather River, etc.), in consideration of all evaluated impact indicators for all lifestages.

In general, USACE evaluated modeled flows and water temperatures at representative nodes for species of focused evaluation (i.e., net changes in mean monthly flow of 10 percent or more, and changes in the probability of exceeding lifestage-specific WTI values). Additional evaluation criteria were applied to habitat variables, as described in Appendix 7B.

In order to summarize and display comparative model results for flows and water temperatures in relation to evaluation criteria for key impact indicators with the Folsom WCM alternatives relative to the basis of comparison, USACE developed fisheries "summary tables" by species and waterbody. For flow, water temperature, and Delta parameters, the net change in the probability of exceedance under an alternative, relative to a baseline condition, was evaluated. The net change in the probability of exceedance was calculated by compiling the ranked and sorted model output data under a baseline condition and subtracting it from the analogous alternative data. This calculation represents the difference in the percentage of time that a specified value is exceeded under an alternative scenario, relative to a baseline scenario. In other words, the net change in the probability of exceedance represents the percentage of time that a criterion is exceeded more often or less often under an alternative scenario compared to a baseline scenario.

In the fisheries summary tables, shading helps elucidate more-suitable or less-suitable conditions. Specifically, blue shading indicates the potential for more-suitable habitat conditions under the alternative scenario, relative to the baseline scenario. Red shading indicates the potential for less-suitable habitat conditions. Net changes in exceedance are shaded in blue when the resulting difference values for the following parameters are positive and are shaded in red when they are negative: (1) riverine flow parameters; (2) Delta outflow; (3) water temperature ranges (i.e., frequency of occurring within the range); and (4) frequency of X2 occurring within a range or less than a specific criterion. Net changes in exceedance are shaded in red when the resulting difference values for the following parameters are positive and are shaded in blue when they are negative: (1) WTI values (i.e., exceedance of a specific WTI value); (2) general changes in X2; and (3) frequency of Old and Middle River (OMR) flows being more negative than a specified criterion.

These summary tables generally indicate simple absolute changes in the frequency of exceeding or being less than a specific value or occurring within a range of values; i.e., the difference in frequency of: (1) a WTI value or flow value being exceeded; (2) flow, water temperature, or X2 occurring within a specified range; (3) X2 or OMR flows less than a specific criterion; and (4) specified changes in X2. By contrast, based on the flow evaluation criteria applied in this analysis (see Appendix 7B), the resulting difference values displayed for riverine flow and Delta outflow actually show the "net change in 10 percent exceedance" under an alternative scenario, relative to a baseline scenario for that month.

The net change in 10 percent exceedance represents the percentage of time that flow is greater under the alternative scenario than the baseline scenario by 10 percent or more, minus the percentage of time that flow is greater under the baseline scenario than the alternative scenario by 10 percent or more. For example, a negative value for a given month indicates the net increase in the percentage of time that flows are reduced by 10 percent or more under an alternative scenario, relative to a baseline scenario, and would be shaded red. Likewise, a positive value indicates the net increase in the percentage of time that flows are increased by 10 percent or more under an alternative scenario, relative to a baseline scenario, and would be shaded blue.

Due to the complexity in interpreting fisheries habitat variables, including salmonid spawning WUA for the Far-Field and the lower American River and fall-run Chinook salmon early lifestage mortality in the lower American River, these parameters are not summarized in the fisheries summary tables. Results for these parameters are provided in separate appendices.

It should be emphasized that the fisheries summary tables are intended only to provide a comparative summary of some of the key flow and water temperature impact indicators under an alternative scenario relative to a baseline scenario, whereas conclusions drawn regarding overall changes in habitat suitability for each species are based on results shown in the fisheries summary tables, in addition to the suite of model output available, such as monthly probability of exceedance distributions and specific habitat variables, including spawning WUA and early lifestage mortality.

USACE relied on the following model output data for the fisheries impact assessment:

- Simulated riverine flows (GATAER Volume II Appendices)
- Simulated Delta hydrology and X2 location (GATAER Volume II Appendices)
- Simulated riverine water temperatures (GATAER Volume I Appendices)
- Summarized simulated hydrology and water temperature data (i.e., Fisheries Summary Tables – Appendix 7H through 7J)
- Simulated spawning WUA in the Sacramento River and Feather River (Appendix 7H)
- Simulated spawning WUA in the lower American River (Appendix 7I)
- Simulated fall-run Chinook salmon early lifestage mortality in the lower American River (Appendix 7J)

1.2.6 Impact Evaluation Synthesis

USACE determined expected changes in lifestage-specific and overall species suitabilities for each fish species of focused evaluation in each geographic region evaluated, under each alternative, relative to a baseline scenario.

USACE determined overall changes in lifestage-specific suitabilities for each fish species of focused evaluation for each geographic region evaluated (i.e., Sacramento River, Feather River, American River, and Delta) based on the flow, water temperature, and Delta-specific metrics presented in the fisheries summary tables, in addition to the suite of model output available, including monthly flow, water temperature, and Delta-specific output over the entire simulation period; spawning WUA for anadromous salmonids; and early lifestage mortality (for fall-run Chinook salmon in the lower American River).

USACE evaluated the aforementioned habitat variables and associated metrics in consideration of the specified spatial and temporal distributions for each lifestage as well as uncertainties associated with biological populations and modeling. When changes in physical habitat variables indicated different directional changes in suitability during different months of a particular lifestage period, reported peak lifestage timings based on fisheries surveys, and existing key stressors that affect a lifestage during particular months, were considered when determining the overall change in suitability for a lifestage.

Specifically, peak lifestage timings were used to emphasize changes in habitat variables during the peak months over other months in the lifestage period, and changes in habitat variables during months when a key stressor influences a lifestage (e.g., elevated water temperatures during the summer months of the steelhead juvenile rearing lifestage) were emphasized relative to other months of the lifestage period, to the extent that supporting information was available.

Peak timings for applicable lifestages, such as adult immigration, spawning, and juvenile outmigration for anadromous salmonids, are summarized in Appendix 7B to the extent that they were available. Fisheries surveys that have been conducted in the Project Area focus primarily on anadromous salmonids. Therefore, more-detailed life history information, such as peak lifestage timings, is available for anadromous salmonid species than for other fish species of focused evaluation. There is also more information related to key stressors and limiting population factors for anadromous salmonids in the Project Area because of the availability of focused studies, regulatory compliance documents that focus on Endangered Species Act–listed fish species, and recovery planning documents for anadromous salmonids prepared by Federal and state agencies.

Therefore, consideration of key stressors and limiting factors is generally applicable only to anadromous salmonids. In addition, key stressors and limiting factors are considered for anadromous salmonids only in the lower American River, because of the increased potential for changes in habitat conditions in the lower American River relative to the Far-Field study areas. If a more detailed evaluation is necessary in a Far-Field study area, consideration of key stressors and limiting factors would be incorporated into the more-detailed evaluation.

USACE determined the change in suitability for each species for each geographic region based on the lifestage-specific suitability conclusions for each species, as well as known key stressors and limiting factors, to the extent supporting information is readily available. Expected changes in suitability identified for each species in each geographic region were then used to identify the expected change in suitability for each species for the entire Project Area.

1.2.7 References

Fisheries

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2. J602F3 ELD Relative to E504 ELD

2.1 Far-Field Fisheries

As described in detail in Appendix 7B, Fisheries Impact Assessment Methodology, the species and lifestage-specific interpretive comparisons below are based on numerous output provided in the appendices, including: (1) long-term average and average by water year type riverine flows on a monthly basis; (2) monthly riverine flow exceedance distributions; (3) monthly water temperature exceedance distributions in relation to specific water temperature index values; (4) long-term average and average by water year type annual spawning habitat availability for anadromous salmonids; (5) annual spawning habitat availability exceedance distributions for anadromous salmonids; (6) long-term average and average by water year type monthly Delta outflow, Old and Middle River flow, and Delta exports; (7) monthly exceedance distributions for Delta outflow, Old and Middle River flow, and Delta exports; (8) long-term average and average by water year type monthly X2 location; and (9) monthly X2 location exceedance distributions.

2.1.1 Sacramento River

For salmonid species, the U.S. Army Corps of Engineers (USACE) examined flow and water temperature model results for the Sacramento River below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, at Bend Bridge, at Red Bluff, at Verona, below the Feather River confluence, and at Freeport. In addition to flow and water temperature modeling, USACE examined model results for spawning habitat availability (weighted usable area, or WUA) for salmonid species. Modeling results for other fish species are described separately.

2.1.1.1 Winter-run Chinook Salmon

USACE examined flow model results for the Sacramento River below Keswick Dam, at Bend Bridge, at Red Bluff, at Verona, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, at Bend Bridge, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (November through July) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam, at Bend Bridge and at Verona, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency at Verona (6.1 percent); and (4) generally equivalent monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

- Similar adult holding (November through July) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 1.5 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Bend Bridge when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent at both locations; and (4) generally equivalent monthly probabilities of exceeding both UT and UO WTI values at both locations evaluated.

- Similar spawning (April through August) and embryo incubation (April through September) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 1.2 percent) and decreases (up to 1.5 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 10 percent of the distributions; (3) equivalent or similar net changes in flow of 10 percent or more during all months at both locations evaluated; (4) generally equivalent or similar long-term average spawning WUA and similar spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally equivalent or similar spawning WUA over most of the distribution, with slightly more spawning WUA over about 20 percent of the middle portion of the distribution and generally similar over the remainder of the distribution; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values most of the time at all locations, with slightly reduced exceedance probabilities at Jelly's Ferry during August, slightly increased exceedance probabilities at Bend Bridge during May and July, and slightly reduced exceedance probabilities at Bend Bridge during August and September.

- Similar juvenile rearing and downstream (July through March) movement conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam, at Bend Bridge and at Verona, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time at all locations, except during July when flows are lower by 6.1 percent at Verona; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values during all months at all locations.

In consideration of the general similarity of impact indicators to all life stages of winter-run Chinook salmon in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.2 Spring-run Chinook Salmon

USACE examined flow model results for the Sacramento River below Keswick Dam, at Bend Bridge, at Red Bluff, at Verona, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, at Bend Bridge, at Red Bluff, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (March through September) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam, at Bend Bridge and at Verona, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (6.1 percent) at Verona; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

- Similar adult holding (March through September) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 1.5 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Bend Bridge, when flows are somewhat lower over about the lowest 10 percent of the distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent at both locations; and (4) generally equivalent or similar monthly probabilities of exceeding both UT and UO WTI values at both locations evaluated.

- Similar spawning (September and October) and embryo incubation (September through January) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 1.2 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions during the evaluation period; (3) equivalent net changes in flow of 10 percent or more during both months at both locations; and (4) equivalent or similar probabilities of exceeding both UO and UT WTI values most of the time at all locations, but with slightly increased exceedance probabilities at Jelly's Ferry and Bend Bridge during October with respect to the UT WTI values.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 10 percent of the distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time at all locations, except during July when flows are lower by 10 percent or more with somewhat higher frequency (6.1 percent) at Verona; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values during all months at all locations during all months of the evaluation period.

- Generally equivalent smolt emigration (October through May) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions during the evaluation period; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values at all locations evaluated during all months of the evaluation period.

In consideration of the general similarity of impact indicators to all life stages of spring-run Chinook salmon in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.3 Fall-run Chinook Salmon

USACE examined flow model results for the Sacramento River below Keswick Dam, at Bend Bridge, at Red Bluff, at Verona, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, at Bend Bridge, at Red Bluff, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and staging (July through December) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 5–10 percent of the distributions below Keswick Dam, at Red Bluff, and at Verona; (3) during low-flow conditions, generally equivalent or similar net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 6.1 percent) at Verona; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated, except for a slightly increased probability of exceedance during July at Red Bluff.

- Similar spawning (October through December) and embryo incubation (October through March) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) equivalent net changes in flow of 10 percent or more during all months at both locations; (4) generally equivalent or similar long-term average spawning WUA and similar spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally equivalent or similar spawning WUA over the entire distribution; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values most of the time at all locations.

- Similar juvenile rearing and downstream movement (December through July) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower at Bend Bridge and Verona over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time at all locations, except during July when flows are lower by 10 percent or more with somewhat higher frequency (6.1 percent) at Verona; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values during all months at all locations, but with slightly decreased UO WTI value exceedance probabilities at Freeport in April.

In consideration of the general similarity of impact indicators to all life stages of fall-run Chinook salmon in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.4 Late Fall-run Chinook Salmon

USACE examined flow model results for the Sacramento River below Keswick Dam, at Bend Bridge, at Red Bluff, at Verona, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, at Bend Bridge, at Red Bluff, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and staging (October through April) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

- Similar spawning (January through April) and embryo incubation (January through June) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) equivalent net changes in flow of 10 percent or more during all months at both locations; (4) generally equivalent long-term average spawning WUA and equivalent or similar spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally equivalent or similar spawning WUA over the entire distribution; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values most of the time at all locations, except for a slightly increased probability of exceedance during May at Bend Bridge.

- Similar juvenile rearing and downstream movement (April through December) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 1.9 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Verona, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time at all locations, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 6.1 percent) at Verona; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values during all months at all locations, except for a slightly reduced probability of exceedance at Freeport during April.

In consideration of the general similarity of impact indicators to all life stages of late fall-run Chinook salmon in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.5 Steelhead

USACE examined flow model results for the Sacramento River below Keswick Dam, at Bend Bridge, at Red Bluff, at Verona, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, at Bend Bridge, at Red Bluff, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (August through March) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

- Similar adult holding (August through March) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent or similar net changes in flow of 10 percent or more during all months at both locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

- Similar spawning (December through April) and embryo incubation (December through May) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 2.1 percent) and decreases (2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) equivalent net changes in flow of 10 percent or more during both months at both locations; (4) generally equivalent long-term average spawning WUA and spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally equivalent spawning WUA over the entire distribution; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values most of the time at all locations, except for a slightly reduced probability of exceedance at Bend Bridge during May.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time at all locations, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 6.1 percent) at Verona; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values during all months at all locations.

- Similar smolt emigration (January through June) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values at all locations evaluated during all months of the evaluation period, except for a slightly decreased probability of exceedance during March at Freeport.

In consideration of the general similarity of impact indicators to all life stages of steelhead in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.6 Green Sturgeon

USACE examined flow model results for the Sacramento River below Keswick Dam, at Red Bluff, at Wilkins Slough, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Red Bluff, at Wilkins Slough, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and holding (February through July) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Red Bluff, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated, except for a slightly decreased probability of exceedance at Freeport during April.

- Similar spawning and embryo incubation (March through August) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.9 percent) and decreases (up to 5.3 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 10–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent) at Freeport during July; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated.

- Similar adult post-spawning holding and emigration (July through November) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.4 percent) and decreases (up to 1.7 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Red Bluff, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July at Red Bluff and Wilkins Slough, when flows are somewhat lower over about the lowest 10–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent) at Wilkins Slough; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated.

In consideration of the general similarity of impact indicators to all life stages of green sturgeon in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.7 White Sturgeon

USACE examined flow model results for the Sacramento River at Red Bluff, at Wilkins Slough, at Verona and at Freeport and examined water temperature model results for the Sacramento River at Red Bluff, at Wilkins Slough, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and holding (November through May) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (2.1 percent) and decreases (2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated.

- Similar spawning and embryo incubation (February through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated except for increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July at Wilkins Slough and Verona, when flows are somewhat lower over about the lowest 5–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency at Wilkins Slough (3.0 percent) and at Verona (6.1 percent); and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value at all locations evaluated.

In consideration of the general similarity of impact indicators to all life stages of white sturgeon in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.8 River Lamprey

USACE examined flow model results for the Sacramento River below Keswick Dam, at Red Bluff, at Wilkins Slough, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Red Bluff, at Wilkins Slough, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (September through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range at all locations evaluated, except for a slight increase in the probability of occurring within the specified range at Wilkins Slough in October and at Freeport during October and April.

- Similar spawning and embryo incubation (February through July) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.2 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 10–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July at Wilkins Slough when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent); and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified ranges at all locations evaluated, except for a slightly higher probability of occurring within the specified range during March below Keswick Dam, and a slightly lower probability of occurring within the specified range during July at Red Bluff.

- Similar ammocoete rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.6 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Wilkins Slough, when flows are somewhat lower over about the lowest 10–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent) at Wilkins Slough; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

In consideration of the general similarity of impact indicators to all life stages of river lamprey in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.9 Pacific Lamprey

USACE examined flow model results for the Sacramento River below Keswick Dam, at Red Bluff, at Wilkins Slough, and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Red Bluff, at Wilkins Slough, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (January through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range at all locations evaluated except for a slight increase in the probability of occurring within the range at Freeport in April.

- Similar spawning and embryo incubation (March through August) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.8 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July, when flows are somewhat lower over about the lowest 5–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent) at Wilkins Slough; and (4) generally equivalent or similar monthly probabilities water temperatures occurring within the specified range at all locations evaluated, except for a slightly higher probability of occurring within the specified range during March below Keswick Dam, and a slightly lower probability of occurring within the specified range during July at Red Bluff.

- Similar ammocoete rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Wilkins Slough, when flows are somewhat lower over about the lowest 10–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent) at Wilkins Slough; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values at all locations evaluated.

In consideration of the general similarity of impact indicators to all life stages Pacific lamprey in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.10 Hardhead

USACE examined flow model results for the Sacramento River below Keswick Dam, at Wilkins Slough, at Verona and at Freeport and examined water temperature model results for the Sacramento River below Keswick Dam, at Wilkins Slough, below the Feather River confluence, and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult and other lifestage (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July below Keswick Dam and at Verona, when flows are somewhat lower over about the lowest 5–10 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 6.1 percent) at Verona; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range at all locations evaluated, except during April at Freeport when water temperatures occur within the specified range slightly less often.

- Similar spawning (April through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough, slightly increased average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range at all locations evaluated.

In consideration of the general similarity of impact indicators to all life stages of hardhead in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.11 American Shad

USACE examined flow model results for the Sacramento River at Red Bluff, at Wilkins Slough, at Verona and at Freeport and examined water temperature model results for the Sacramento River at Red Bluff, at Wilkins Slough, below the Feather River confluence and at Freeport.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and spawning (April through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly increased average monthly flow during April at Freeport and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range at all locations evaluated, except during April when water temperatures occur within the specified range slightly more often at Freeport.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, except for slightly lower average monthly flow during July at Wilkins Slough, higher average monthly flow during April at Freeport, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 2.1 percent) and decreases (up to 2.0 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July at Wilkins Slough and Verona, when flows are somewhat lower over about the lowest 5–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows decrease by 10 percent or more with somewhat higher frequency (about 3–6.1 percent) at Wilkins Slough and Verona; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range at all locations evaluated, except for a slightly higher probability of occurring within the specified range during September at Wilkins Slough.

In consideration of the general similarity of impact indicators to all life stages of American shad in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.1.12 Striped Bass

USACE examined flow model results for the Sacramento River at Wilkins Slough and Verona and examined water temperature model results for the Sacramento River at Wilkins Slough and below the Feather River confluence.

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and spawning (April through June) conditions due to: (1) generally equivalent long-term average monthly flows at both locations evaluated, except for slightly reduced average monthly flow during July at Wilkins Slough and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.8 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at both locations evaluated; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range at both locations evaluated.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows at both locations evaluated, except for slightly lower average monthly flow during July at Wilkins Slough, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 1.8 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions, except during July at Wilkins Slough and Verona, when flows are somewhat lower over about the lowest 5–15 percent of the distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at both locations evaluated, except during July when flows decrease by 10 percent or more with somewhat higher frequency (about 3–6.1 percent) at both locations; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range at both locations evaluated, but with slightly decreased exceedance probabilities at Verona during June (1.3 percent).

In consideration of the general similarity of impact indicators to all life stages of striped bass in the Sacramento River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2 Feather River

USACE examined flow and water temperature model results for the Feather River below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River. In addition to flow and water temperature modeling, USACE examined model results for spawning habitat availability (WUA) for salmonid species.

Flows in the Low Flow Channel below the Fish Barrier Dam were modeled consistent with the terms of the California Department of Water Resources' agreement with the California Department of Fish and Wildlife. As shown in the appendices to this section, modeled results for long-term average flows, average flows by water year type, and flow exceedance probabilities during all years and during low-flow conditions were equivalent for the Folsom WCM alternatives relative to the Existing Condition and No Action scenarios. Although these results are not repeated for the discussions below, USACE considered the model results for the Low Flow Channel below the Fish Barrier Dam along with the information presented below and incorporated them into the impact determinations for spring-run Chinook salmon, fall-run Chinook salmon, steelhead, river lamprey, Pacific lamprey, and hardhead.

2.1.2.1 Spring-run Chinook Salmon

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar adult immigration (March through September) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows by water year type most of the time during all water year types, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with lower flows by 10 percent or more with somewhat higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and June at the mouth and with higher flows by 10 percent or more with slightly higher frequency during August (3 percent) at the mouth and higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet; and (4) generally equivalent monthly probabilities of exceeding both UO and UT WTI values, except for a slightly increased probability of exceedance of UO WTI values below the Thermalito Afterbay Outlet during September.

- Similar adult holding (March through September) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows by water year type most of the time during all water year types, but with some increases (up to 16.3 percent) and decreases (up to 2.8 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with lower flows by 10 percent or more with somewhat higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet, and with higher flows by 10 percent or more with slightly higher frequency during June and August below the Thermalito Afterbay Outlet; and (4) generally equivalent monthly probabilities of exceeding both UO and UT WTI values, except for a slightly increased probability of exceedance of UO WTI values below the Thermalito Afterbay Outlet during September.
- Similar spawning (September through October) and embryo incubation (September through February) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period, and generally equivalent or similar average monthly flows during all water year types, but with some increases (up to 1.5 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) generally equivalent net changes in flow of 10 percent or more at both locations; (4) generally equivalent long-term average spawning WUA, and equivalent or similar average spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally similar spawning WUA over the entire distribution, with spawning WUA always above 80 percent of maximum under both E504 ELD and J602F3 ELD; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values.
- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with lower flows by 10 percent or more with slightly higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and June at the mouth and with higher flows by 10 percent or more with slightly higher frequency during August (3 percent) at the mouth and with higher frequency (about 3 percent) during June and August below the Thermalito Afterbay Outlet; and (4) generally equivalent monthly probabilities of exceeding both UO and UT WTI values, except for a slightly increased probability of exceedance of UO WTI values below the Thermalito Afterbay Outlet during September.

- Similar smolt emigration (October through June) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time, but with lower flows by 10 percent or more with somewhat higher frequency (about 3 percent) during June at the mouth, and higher flows during June below the Thermalito Afterbay Outlet by 10 percent or more with higher frequency (3 percent); and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values during all months of the evaluation period.

In consideration of the general similarity of impact indicators to all life stages of spring-run Chinook salmon in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.2 Fall-run Chinook Salmon

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar adult immigration and staging (July through December) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 1.5 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with higher flows by 10 percent or more with higher frequency (3.0 percent) during August at both locations and slightly lower frequency (3.0 percent) below the Thermalito Afterbay Outlet during July; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values, except for a slightly higher probability (2.4 percent) of exceedance of UO WTI values in September.
- Similar spawning (October through December) and embryo incubation (October through March) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and equivalent or similar average monthly flows during all water year types, but with some decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with slightly lower frequency (3.0 percent) below the Thermalito Afterbay Outlet during November; (4) generally equivalent long-term average spawning WUA and average spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally equivalent or similar spawning WUA over the entire distribution, with spawning WUA always above 80 percent of maximum under both E504 ELD and J602F3 ELD; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values.
- Similar juvenile rearing and downstream movement (November through June) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally

equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with somewhat higher frequency (3 percent) during June at the mouth and higher flows by 10 percent or more with higher frequency (3 percent) during June below the Thermalito Afterbay Outlet; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values.

In consideration of the general similarity of impact indicators to all life stages of fall-run Chinook salmon in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.3 Steelhead

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar adult immigration (August through March) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 2.6 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with higher flows by 10 percent or more with higher frequency (3.0 percent) during August at both locations; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values, except for a slight increase in exceedance (2.4 percent) below the Thermalito Afterbay Outlet in September.
- Similar adult holding (August through March) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 2.6 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, generally equivalent net changes in flow of 10 percent or more most of the time, but with higher flows by 10 percent or more with higher frequency (3.0 percent) during August at both locations; and (4) generally equivalent or similar monthly probabilities of exceeding both UO and UT WTI values, except for a slight increase in exceedance (1.3 percent) below the Thermalito Afterbay Outlet in September.
- Similar spawning (January through April) and embryo incubation (January through May) conditions due to: (1) generally equivalent long-term average monthly flows during the evaluation period and generally equivalent or similar average monthly flows during all water year types; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) equivalent net changes in flow of 10 percent or more; (4) generally equivalent long-term average spawning WUA and equivalent or similar average spawning WUA by water year type; (5) over the annual spawning WUA exceedance distribution, generally equivalent or similar amounts of spawning WUA over the entire distribution; and (6) equivalent or similar probabilities of exceeding both UO and UT WTI values.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values, except for slightly reduced probabilities (1.3 percent) of exceedance during September below the Thermalito Afterbay Outlet.
- Similar smolt emigration (October through April) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period and generally equivalent or similar average monthly flows by water year type most of the time; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more; and (4) generally equivalent or similar probabilities of exceeding UO and UT WTI values.

In consideration of the general similarity of impact indicators to all life stages steelhead in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.4 Green Sturgeon

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and holding (February through November) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more most of the time, but with lower flows of 10 percent or more with somewhat higher frequency (about 3 percent) at the mouth during June and below the Thermalito Afterbay Outlet during July, and higher flows of 10 percent or more with higher frequency (3.0 percent) at both locations during August and below the Thermalito Afterbay Outlet during June; and (4) generally equivalent or similar monthly probabilities of exceeding both the specified WTI value.
- Similar spawning and embryo incubation (March through August) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with an increase of 16.3 percent in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (about 3 percent) and flows are higher by 10 percent or more with higher frequency (3 percent) below the Thermalito Afterbay Outlet during

June and August; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet and during August at the mouth; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value.

In consideration of the general similarity of impact indicators to all life stages green sturgeon in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.5 White Sturgeon

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and holding (November through May) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with some slight increases (up to 16.3 percent) and decreases (up to 2 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at both locations evaluated; and (4) generally equivalent monthly probabilities of exceeding the specified WTI value at both locations evaluated.
- Similar spawning and embryo incubation (February through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with an increase of 16.3 percent in average monthly flow during May of below-normal water years; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months evaluated, except during June when flows are higher by 10 percent or more with higher frequency (3 percent); and (4) generally equivalent monthly probabilities of exceeding the specified WTI value.
- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more

most of the time but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet and during August at the mouth; and (4) generally equivalent or similar monthly probabilities of exceeding the specified WTI value.

In consideration of the general similarity of impact indicators to all life stages of white sturgeon in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.6 River Lamprey

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (September through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated, and generally equivalent or similar average monthly flows most of the time during all water year types, but with some increases (up to 16.3 percent) and some decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more most of the time, but with lower flows of 10 percent or more with somewhat higher frequency (3 percent) at the mouth during June, and higher flows of 10 percent or more with higher frequency (3.0 percent) below the Thermalito Afterbay Outlet during June; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range, except for a slight increase in the probability of occurring within the specified range below the Thermalito Afterbay Outlet in May.
- Similar spawning and embryo incubation (February through July) conditions due to: (1) generally equivalent long-term average monthly flows and generally equivalent or similar average monthly flows most of the time during all water year types, but with increases of 16.3 percent in average monthly flow during May in below-normal water years; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (3 percent) below the Thermalito Afterbay Outlet and during June when flows are higher by 10 percent or more with higher frequency (3 percent) below the Thermalito Afterbay Outlet; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range.
- Similar ammocoete rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with slightly higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and

during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet and during August at the mouth; and (4) generally equivalent monthly probabilities of exceeding the specified WTI value at both locations evaluated, except for a slight increase (1.3 percent) in the probability of exceedance during August at the mouth.

In consideration of the general similarity of impact indicators to all life stages of river lamprey in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.7 Pacific Lamprey

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration (January through June) conditions due to: (1) generally equivalent long-term average monthly flows at all locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with an increase of 16.3 percent and some decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more most of the time, but with lower flows of 10 percent or more with somewhat higher frequency (3 percent) at the mouth during June and higher flows of 10 percent or more with higher frequency (3 percent) below the Thermalito Afterbay Outlet during June; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range.
- Similar spawning and embryo incubation (March through August) conditions due to: (1) generally equivalent long-term average monthly flows and generally equivalent or similar average monthly flows most of the time during all water year types, but with a slight increase of 16.3 percent in average monthly flow during below-normal water year types; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more during all months at all locations evaluated, except during July when flows are lower by 10 percent or more with somewhat higher frequency (3 percent) below the Thermalito Afterbay Outlet and during June and August when flows are higher by 10 percent or more with higher frequency (3 percent) below the Thermalito Afterbay Outlet; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range.
- Similar ammocoete rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time, but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet and during August at the mouth;

and (4) generally equivalent monthly probabilities of exceeding the specified WTI value at both locations evaluated, except a slight increase (1.3 percent) in the probability of exceedance in August at the mouth.

In consideration of the general similarity of impact indicators to all life stages of Pacific lamprey in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.8 Hardhead

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult and other lifestage (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet and during August at the mouth; and (4) generally equivalent monthly probabilities of exceeding the specified WTI value at both locations evaluated.
- Similar spawning (April through June) conditions due to: (1) generally equivalent long-term average monthly flows at both locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with an increase of 16.3 percent in average monthly during below-normal water year types; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more most of the time, except for an increase in flow by 10 percent or more with higher frequency (3 percent) during June below the Thermalito Afterbay Outlet; and (4) generally equivalent or similar monthly probabilities of water temperatures occurring within the specified range.

In consideration of the general similarity of impact indicators to all life stages of hardhead in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.9 American Shad

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult immigration and spawning (April through June) conditions due to: (1) generally equivalent long-term average monthly flows at both locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with an increase of 16.3 percent in average monthly flow during below-normal water year types; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more most of the time, except for a reduction in flow by 10 percent or more with somewhat higher frequency (3 percent) during June at the mouth and an increase in flow by 10 percent or more with higher frequency (3 percent) during June below the Thermalito Afterbay Outlet; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range.

- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during June and August below the Thermalito Afterbay Outlet and during August at the mouth; and (4) generally equivalent monthly probabilities of exceeding the specified WTI value at both locations evaluated.

In consideration of the general similarity of impact indicators to all life stages of American shad in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.2.10 Striped Bass

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar adult immigration and spawning (April through June) conditions due to: (1) generally equivalent long-term average monthly flows at both locations evaluated and generally equivalent or similar average monthly flows most of the time during all water year types, but with an increase of 16.3 percent in average monthly flow during below-normal water year types; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent net changes in flow of 10 percent or more most of the time, except for a reduction in flow by 10 percent or more with slightly higher frequency (3 percent) during June at the mouth and an increase in flow by 10 percent or more with higher frequency (3 percent) during June below the Thermalito Afterbay Outlet; and (4) generally equivalent monthly probabilities of water temperatures occurring within the specified range.

- Generally similar juvenile rearing and downstream movement (year-round) conditions due to: (1) generally equivalent long-term average monthly flows over the evaluation period, and generally equivalent or similar average monthly flows by water year type most of the time, but with some increases (up to 16.3 percent) and decreases (up to 2.9 percent) in average monthly flow; (2) generally equivalent or similar flows most of the time over the monthly flow exceedance distributions; (3) during low-flow conditions, equivalent or similar net changes in flow of 10 percent or more most of the time but with lower flows by 10 percent or more with higher frequency (about 3 percent) during July below the Thermalito Afterbay Outlet and during June at the mouth, and with higher flows by 10 percent or more with higher frequency (3 percent) during September and June and August below the Thermalito Afterbay Outlet and during August at the mouth; and (4) generally equivalent monthly probabilities of exceeding the specified WTI value at both locations evaluated, except a slight decrease (1.3 percent) in the probability of exceedance in May below the Thermalito Afterbay Outlet.

In consideration of the general similarity of impact indicators to all life stages of striped bass in the Feather River under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3 Sacramento–San Joaquin Delta and Yolo Bypass

USACE examined model results for Old and Middle River (OMR) flows and X2 location for delta smelt and longfin smelt. USACE also examined Delta outflow and water temperatures in the Sacramento River at Freeport for delta smelt.

USACE examined model results for Sacramento River flows at Rio Vista, Yolo Bypass outflow, Delta outflow, and OMR flows for all runs of Central Valley Chinook salmon and Central Valley steelhead. USACE also examined OMR flows for adult San Joaquin River fall- and late fall-run Chinook salmon.

In addition, USACE examined Yolo Bypass outflow for delta smelt, splittail, green sturgeon, and white sturgeon and examined X2 location for American shad and striped bass.

USACE examined model results for exports at the State Water Project (SWP) and Central Valley Project (CVP) export facilities year-round. The model results showed that: (1) long-term average monthly total SWP and CVP Delta exports are generally equivalent year-round; (2) average total Delta exports by water year type are generally equivalent, except for some slight increases (up to 1.0 percent) during some months of above-normal water years and decreases (up to 0.5 percent) during some months of dry water years; and (3) monthly exceedance distributions are generally similar year-round, with the exception of September when exports increase somewhat over about 20 percent of the distribution. Therefore, no further evaluations were conducted to evaluate fish salvage at the SWP and CVP export facilities.

2.1.3.1 Delta Smelt in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult conditions due to: (1) equivalent or similar monthly probabilities of water temperatures at Freeport occurring within the specified water temperature range (December through May); (2) similar or reduced probabilities of X2 occurring between 74 and 81 RKm during wet and above-normal water years (September through November); and (3) generally equivalent monthly probabilities of OMR flows being more negative than –5,000 cfs (December through February).
- Similar adult spawning conditions in the Yolo Bypass (December through May) due to: (1) generally equivalent net changes in Yolo Bypass outflow of 10 percent or more during the evaluation period, with the exception of January when flows are reduced by 10 percent or more with a higher (8.5 percent) frequency. However, all of the 10 percent or greater reductions in flow over the exceedance distribution occur when Yolo Bypass outflow is less than 40 cfs, therefore, these reductions are not expected to affect inundation extent or frequency in the Yolo Bypass.

- Similar egg and embryo conditions (February through May) due to: (1) equivalent or similar monthly probabilities of water temperatures at Freeport occurring within the specified water temperature range.
- Similar larvae conditions (March through June) due to: (1) similar monthly probabilities of water temperatures at Freeport occurring within the specified water temperature range; (2) during March through June of dry and critical water years, generally equivalent probabilities of mean monthly OMR flows being more negative than –1,500 cfs except for a slight decrease in probability of 3.3 percent during June; and (3) and generally equivalent net changes of 10 percent or more in mean monthly Delta outflow.
- Similar juvenile conditions (May through July) due to: (1) generally equivalent monthly probabilities of water temperatures at Freeport occurring within the specified water temperature range; and (2) between RKm 65 and 80, X2 location moves upstream by 0.5RKm or more with generally similar or lower frequency (up to 8.5 percent more often).

In consideration of the general similarity of impact indicators to all life stages of delta smelt in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.2 Longfin Smelt in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult conditions (December through March) due to: (1) generally equivalent monthly probabilities of OMR flows being more negative than –5,000 cfs.
- Generally similar larvae and juvenile conditions due to: (1) during April and May of dry and critical water years, the probabilities of mean monthly OMR flows being more negative than –1,500 cfs are generally equivalent, and the probabilities of mean monthly OMR flows being less than 0 are generally equivalent; (2) for all water years during January through June, mean monthly X2 location occurs downstream of 75 RKm with generally similar frequency during all months evaluated; and (3) for dry and critical water years only during January through June, mean monthly X2 location occurs downstream of 75 RKm with generally equivalent frequencies during all months evaluated.

In consideration of the general similarity of impact indicators to all life stages of longfin smelt in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.3 Winter-run Chinook Salmon in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar juvenile and emigration conditions (November through May) due to: (1) generally equivalent net changes in mean monthly Rio Vista flows of 10 percent or more; (2) generally equivalent or similar net changes in mean monthly Yolo Bypass outflow of 10 percent or more, except during January and November when flows are lower by 10 percent or more with higher frequency (see previous discussion for delta smelt); (3) generally equivalent or similar net changes in mean monthly Delta outflow of 10 percent or more; and (4) generally equivalent probabilities of OMR flows being more negative than –2,500 cfs.

In consideration of the general similarity of impact indicators to all life stages of winter-run Chinook salmon in the Delta under the J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.4 Spring-run Chinook Salmon in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar juvenile and emigration conditions (November through June) due to: (1) generally equivalent net changes in mean monthly Rio Vista flows of 10 percent or more; (2) generally equivalent or similar net changes in mean monthly Yolo Bypass outflow of 10 percent or more, except during January when flows are lower by 10 percent or more with higher frequency (see previous discussion for delta smelt); (3) generally equivalent or similar net changes in mean monthly Delta outflow of 10 percent or more; and (4) generally equivalent probabilities of OMR flows being more negative than –2,500 cfs.

In consideration of the general similarity of impact indicators to all life stages of spring-run Chinook salmon in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.5 Fall-run and Late Fall-run Chinook Salmon in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar juvenile and emigration conditions (November through June) due to: (1) generally equivalent net changes in mean monthly Rio Vista flows of 10 percent or more; (2) generally equivalent or similar net changes in mean monthly Yolo Bypass outflow of 10 percent or more, except during January and November when flows are lower by 10 percent or more with higher frequency (8.5 percent; see previous discussion for delta smelt); (3) generally equivalent or similar net changes in mean monthly Delta outflow of 10 percent or more; and (4) generally equivalent probabilities of OMR flows being more negative than –2,500 cfs.
- Generally similar San Joaquin River adult fall-run Chinook salmon conditions (December through February) due to generally similar probabilities of OMR flows being more negative than –5000 cfs.

In consideration of the general similarity of impact indicators to all life stages of fall-run and late fall-run Chinook salmon in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.6 Steelhead in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar juvenile and emigration conditions (October through July) due to: (1) generally equivalent net changes in mean monthly Rio Vista flows of 10 percent or more; (2) generally equivalent or similar net changes in mean monthly Yolo Bypass outflow of 10 percent or more, except during January and November when flows are lower by 10 percent or more with higher frequency (8.5 percent; see previous discussion for delta smelt); (3) generally equivalent or similar net changes in mean monthly Delta outflow of 10 percent or more; and (4) generally equivalent probabilities of OMR flows being more negative than –2,500 cfs.

In consideration of the general similarity of impact indicators to all life stages of steelhead in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.7 Green Sturgeon in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar juvenile rearing and emigration conditions (year-round) due to generally equivalent or similar net changes in mean monthly Yolo Bypass outflow of 10 percent or more, except during January and November when flows are lower by 10 percent or more with higher frequency (8.5 percent; see previous discussion for delta smelt) and during September when flows are higher by 10 percent or more with a slightly higher frequency (3.7 percent).

In consideration of the general similarity of impact indicators to all life stages of green sturgeon in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.8 White Sturgeon in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar juvenile rearing and emigration conditions (April through June) due to generally equivalent net changes in mean monthly Yolo Bypass outflow of 10 percent or more.

In consideration of the general similarity of impact indicators to all life stages of white sturgeon in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.9 Splittail in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Similar adult spawning and embryo incubation conditions (February through May) due to generally equivalent net changes in mean monthly Yolo Bypass outflow of 10 percent or more.
- Similar juvenile rearing and emigration conditions (April through July) due to generally equivalent net changes in mean monthly Yolo Bypass outflow of 10 percent or more.

In consideration of the general similarity of impact indicators to all life stages of splittail in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.10 American Shad in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar egg and larval conditions (April through June) due to generally equivalent or similar net changes, except during June with a lower frequency (3.7 percent) of 1RKm or more in X2 location.

In consideration of the general similarity of impact indicators to all life stages of American shad in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

2.1.3.11 Striped Bass in the Delta Region

Relative to E504 ELD, USACE expects J602F3 ELD to provide:

- Generally similar egg and larval conditions (April through June) due to generally equivalent or similar net changes, except during June with a lower frequency (3.7 percent) of 1RKm or more in X2 location.

In consideration of the general similarity of impact indicators to all life stages of striped bass in the Delta under J602F3 ELD relative to E504 ELD, no further evaluations are necessary.

3 J602F3 ELD Relative to E504 ELD

3.1 Lower American River

For salmonid and other fish species, daily flow and water temperature model results on a monthly basis were examined for the lower American River below Nimbus Dam, at Watt Avenue, and near the mouth of the lower American River (i.e., RM 1). In addition to flow and water temperature modeling, model results for spawning habitat availability (WUA) and an index for redd dewatering were examined for steelhead and fall-run Chinook salmon. For fall-run Chinook salmon, an updated lower American River early lifestage mortality model also was used to compare thermally influenced early lifestage mortality.

A discussion of general changes in simulated water temperatures in the lower American River under J602F3 ELD relative to E504 is provided in the Water Temperature section (Chapter 4), and is summarized below. Monthly water temperature exceedance distributions demonstrate that water temperatures are generally similar most of the time during all months, but are slightly higher over portions of the distributions during March and April (while water temperatures under both scenarios are below 56°F), are slightly lower over portions of the monthly distributions during May, June, August, September, and October, and are slightly lower and higher with similar frequencies during July.

A summary of general changes in flows in the lower American River below Nimbus Dam under J602F3 ELD relative to E504 is provided below, and is based on changes in long-term average monthly flow and average monthly flow by water year type, and monthly cumulative probability of exceedance distributions over the entire simulation period.

Generally, flows are higher more often during March through June, September, October, and December, lower more often during through January, February, July, and August, and higher and lower with similar frequency during November, as described in more detail for below Nimbus Dam, at Watt Avenue, and near the mouth.

Long-term average monthly flows below Nimbus Dam under J602F3 ELD relative to E504 are generally slightly lower during November through February and August, and slightly higher during March through June, September, and October (Table 3.1-1). Average monthly flows exhibit similar trends during wet and above-normal water years. Average monthly flows during below-normal water years are generally slightly lower during February and March, and are slightly higher during April through June and September. During dry water years, average monthly flows are slightly lower during February, April, and August and substantially lower during March, and are generally slightly higher during May through July and September through November. During critical water years, average monthly flows are generally slightly higher during November through January, March, July, and August, and are lower during February and April. Long-term average monthly flows and average monthly flow by water year type at Watt Avenue and at the mouth of the lower American River exhibit trends similar to those described for below Nimbus Dam (see Appendix 7A).

Table 3.1-1. Average Monthly Flows below Nimbus Dam under J602F3 ELD and E504

Long-term and Water Year Type Average Lower American River Flow below Nimbus Dam Under E504 ELD and J602F3 ELD Conditions

Analysis Period	Flow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Long-term												
Full Simulation Period[2]												
E504 ELD	2,119	3,162	3,597	4,867	5,394	3,963	3,273	3,609	3,555	3,451	2,462	2,552
J602F3 ELD	2,154	3,106	3,497	4,610	4,976	4,242	3,524	3,680	3,698	3,471	2,380	2,611
Difference	35	-56	-100	-257	-418	279	251	71	143	20	-82	59
Percent Difference[3]	1.7	-1.8	-2.8	-5.3	-7.7	7.0	7.7	2.0	4.0	0.6	-3.3	2.3
Water Year Types[1]												
Wet												
E504 ELD	2,299	4,008	6,097	9,088	9,212	6,264	5,114	6,134	6,048	3,558	3,439	3,815
J602F3 ELD	2,335	3,864	5,892	8,509	8,328	7,200	5,737	6,153	6,211	3,529	3,233	3,875
Difference	36	-144	-205	-579	-884	936	623	19	163	-29	-206	60
Percent Difference[3]	1.6	-3.6	-3.4	-6.4	-9.6	14.9	12.2	0.3	2.7	-0.8	-6.0	1.6
Above Normal												
E504 ELD	2,085	3,885	3,561	6,254	7,224	5,457	3,280	3,368	2,728	4,169	2,252	3,728
J602F3 ELD	2,094	3,734	3,252	5,752	6,955	5,991	3,730	3,556	2,987	3,978	2,162	3,890
Difference	9	-151	-309	-502	-269	534	450	188	259	-191	-90	162
Percent Difference[3]	0.4	-3.9	-8.7	-8.0	-3.7	9.8	13.7	5.6	9.5	-4.6	-4.0	4.3
Below Normal												
E504 ELD	2,013	2,588	2,402	2,376	4,315	2,753	3,105	3,079	2,641	4,352	1,978	1,776
J602F3 ELD	2,028	2,573	2,423	2,388	3,933	2,687	3,203	3,152	2,811	4,393	1,965	1,834
Difference	15	-15	21	12	-382	-66	98	73	170	41	-13	58
Percent Difference[3]	0.7	-0.6	0.9	0.5	-8.9	-2.4	3.2	2.4	6.4	0.9	-0.7	3.3
Dry												
E504 ELD	2,174	2,584	1,956	1,774	1,860	2,299	1,867	1,690	2,124	3,161	2,088	1,511
J602F3 ELD	2,256	2,633	1,958	1,764	1,815	1,805	1,763	1,818	2,241	3,331	2,059	1,544
Difference	82	49	2	-10	-45	-494	-104	128	117	170	-29	33
Percent Difference[3]	3.8	1.9	0.1	-0.6	-2.4	-21.5	-5.6	7.6	5.5	5.4	-1.4	2.2
Critical												
E504 ELD	1,751	2,066	1,557	1,251	1,257	1,106	1,130	1,270	1,546	1,826	1,438	1,014
J602F3 ELD	1,758	2,100	1,587	1,281	1,226	1,194	1,039	1,271	1,538	1,895	1,497	1,018
Difference	7	34	30	30	-31	88	-91	1	-8	69	59	4
Percent Difference[3]	0.4	1.6	1.9	2.4	-2.5	8.0	-8.1	0.1	-0.5	3.8	4.1	0.4

1 As defined by the Sacramento Valley 40-30-30 Index Water Year Hydrologic Classification (SWRCB 1995)

2 Based on the entire simulation period

3 Relative difference of the monthly average

Monthly flow exceedance distributions for J602F3 ELD and E504 demonstrate that flows are generally similar most of the time during most months, but are lower substantially more often during February, and are higher substantially more often during March and April under J602F3 ELD (Figure 7.1-1 through Figure 7.1-12). In addition, flows generally decrease during a portion of the lowest-flow conditions (i.e., lowest 25 percent of the monthly distribution) during April. By contrast, flows increase during the lowest-flow conditions during July.

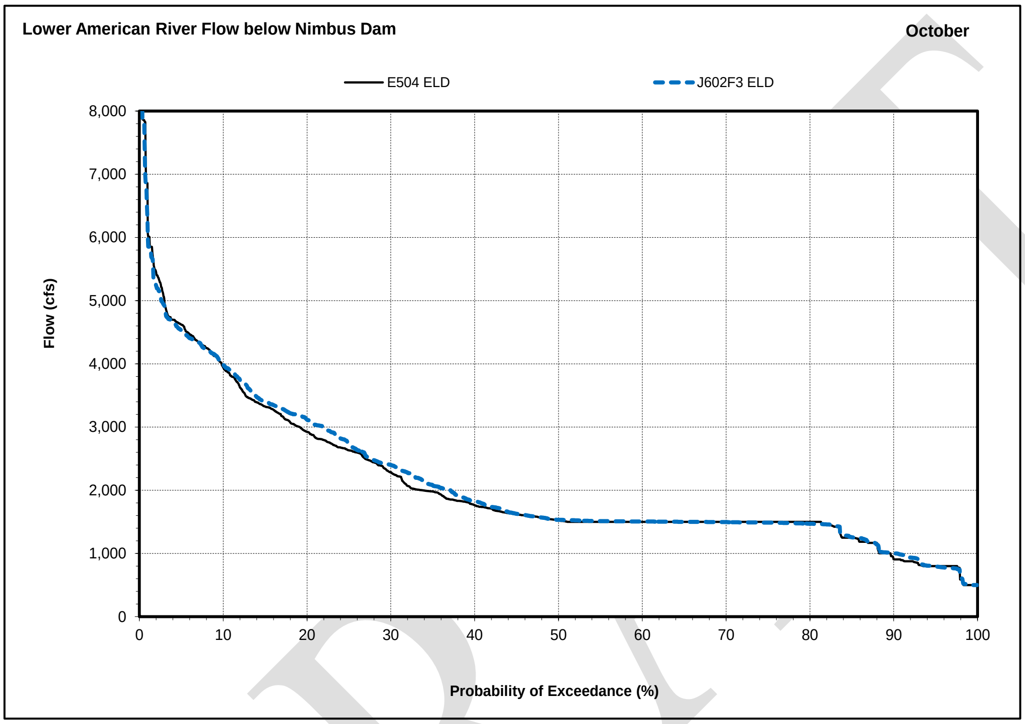

Figure 7.1-1. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for October under J602F3 ELD and E504 ELD

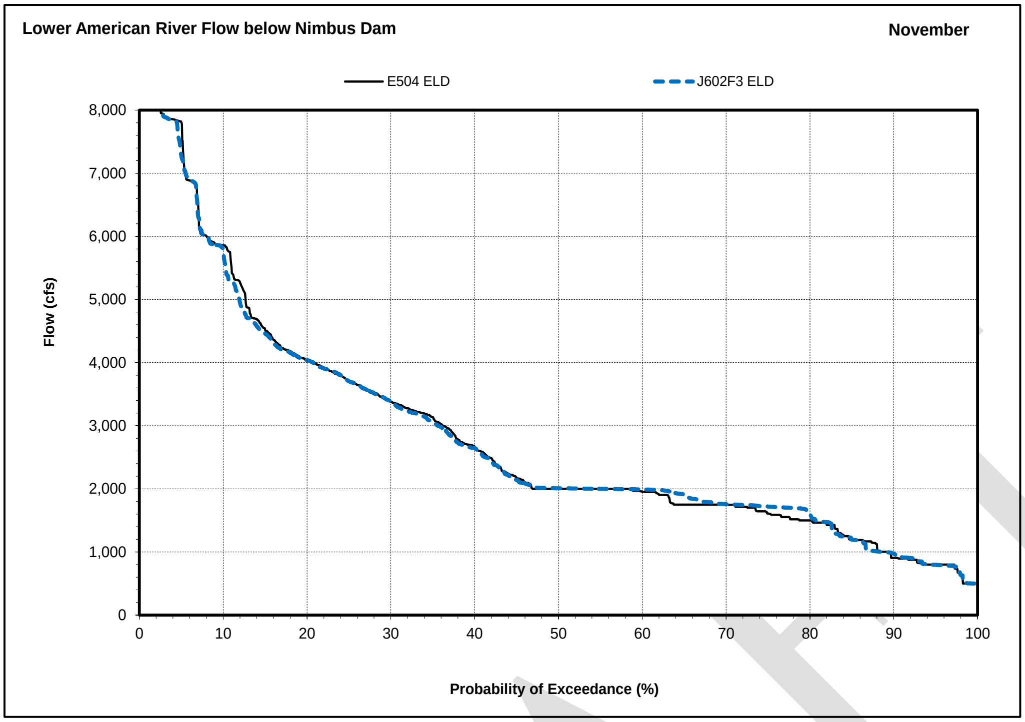

Figure 7.1-2. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for November under J602F3 ELD and E504 ELD

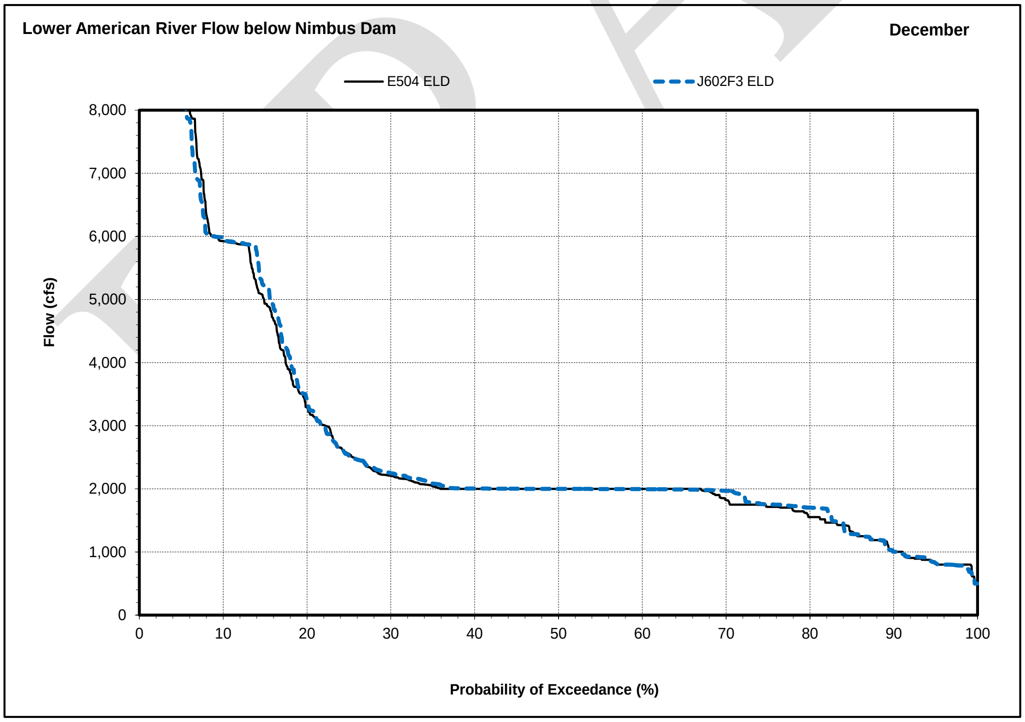

Figure 7.1-3. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for December under J602F3 ELD and E504 ELD

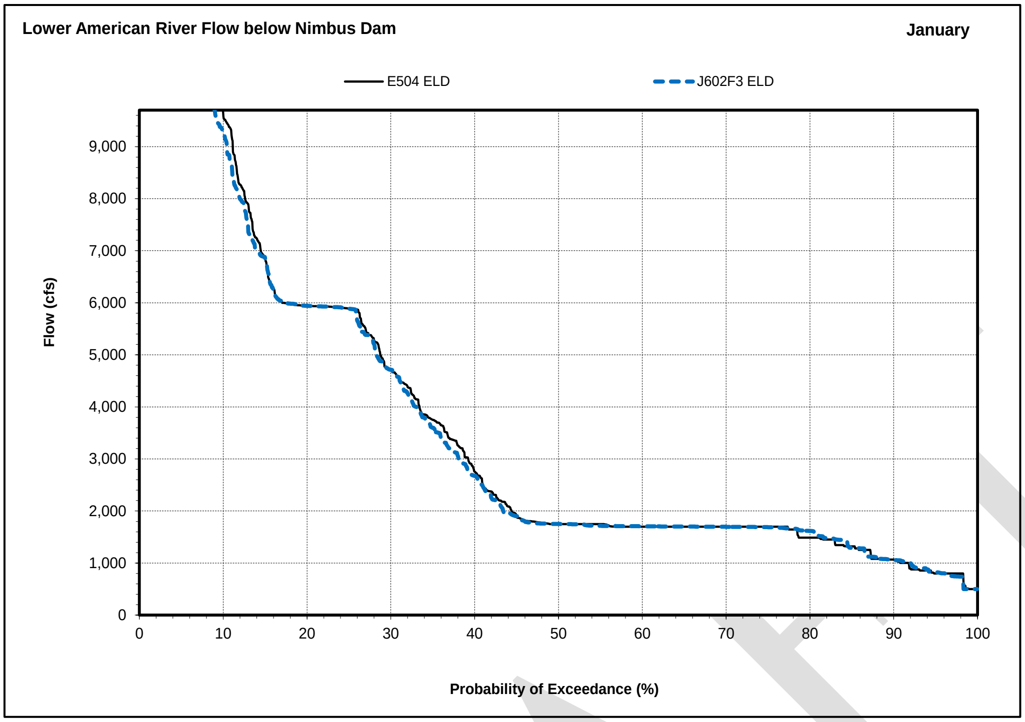

Figure 7.1-4. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for January under J602F3 ELD and E504 ELD

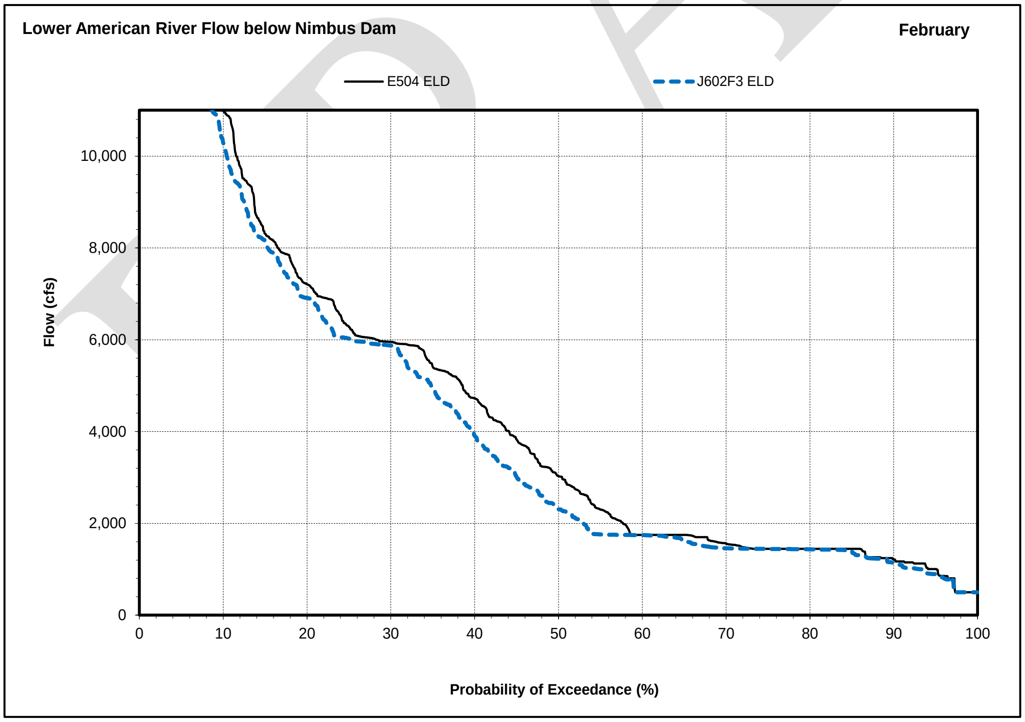

Figure 7.1-5. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for February under J602F3 ELD and E504 ELD

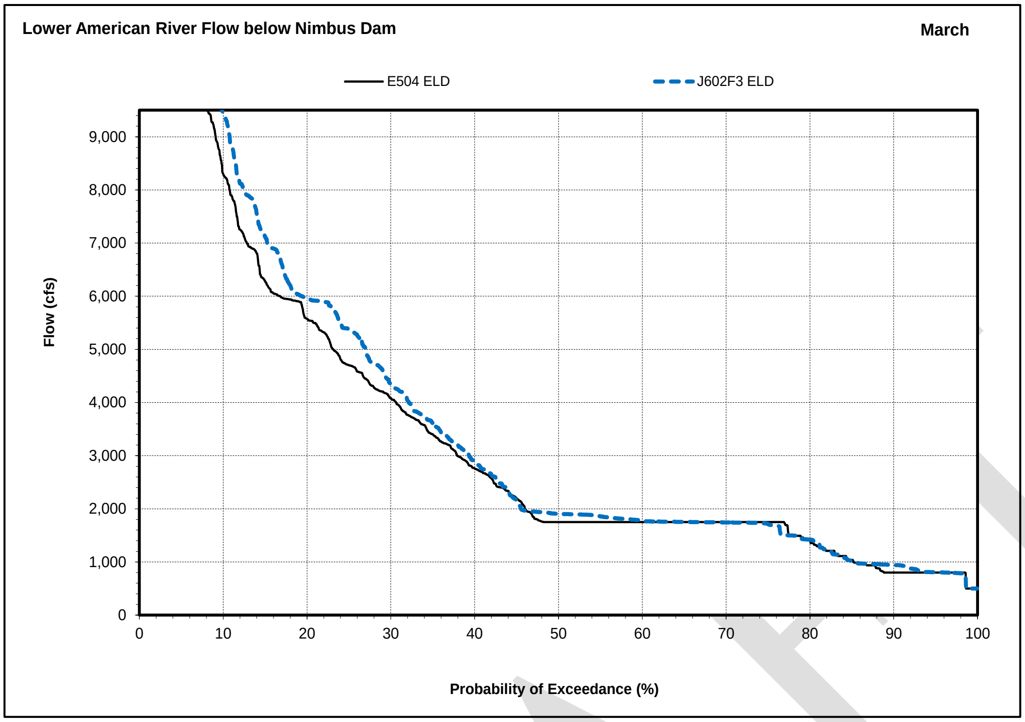

Figure 7.1-6. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for March under J602F3 ELD and E504 ELD

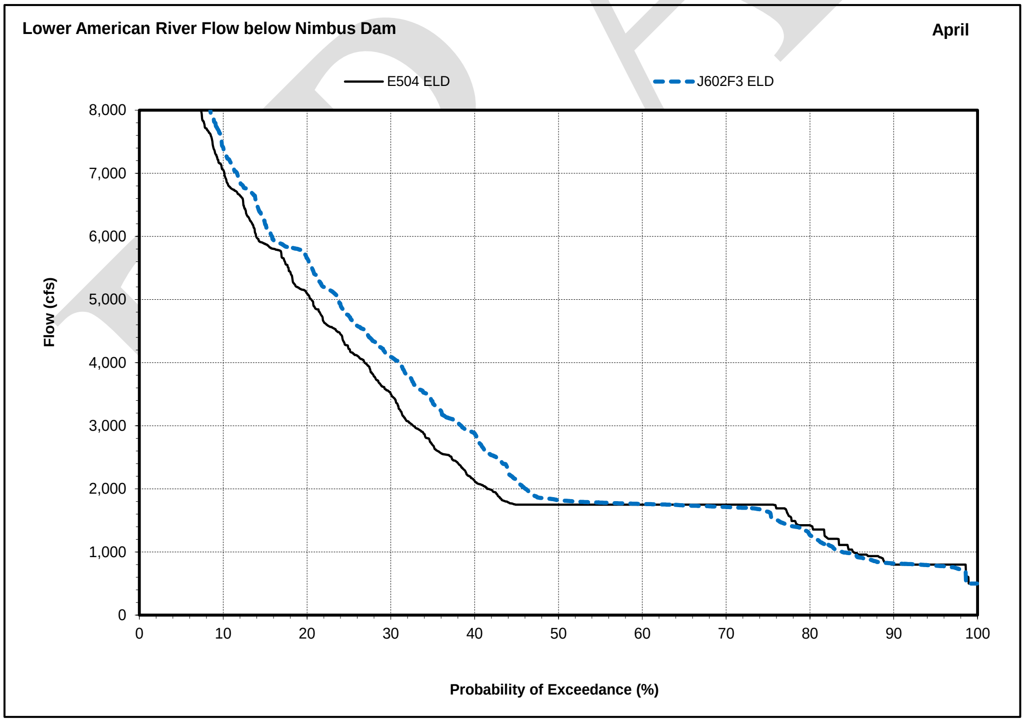

Figure 7.1-7. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for April under J602F3 ELD and E504 ELD

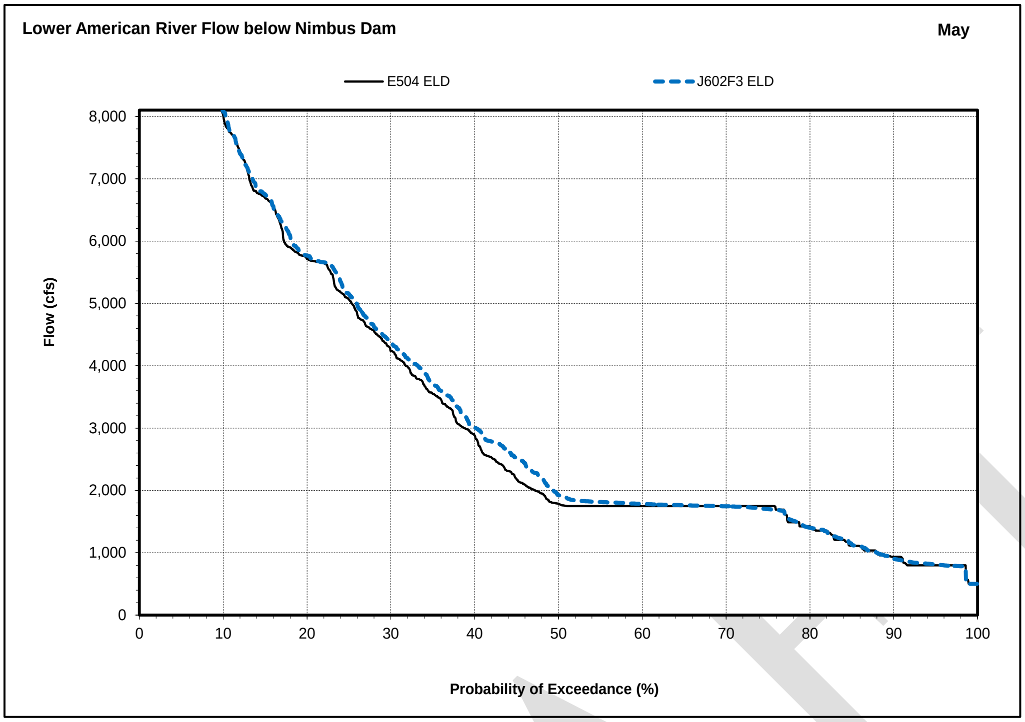

Figure 7.1-8. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for May under J602F3 ELD and E504 ELD

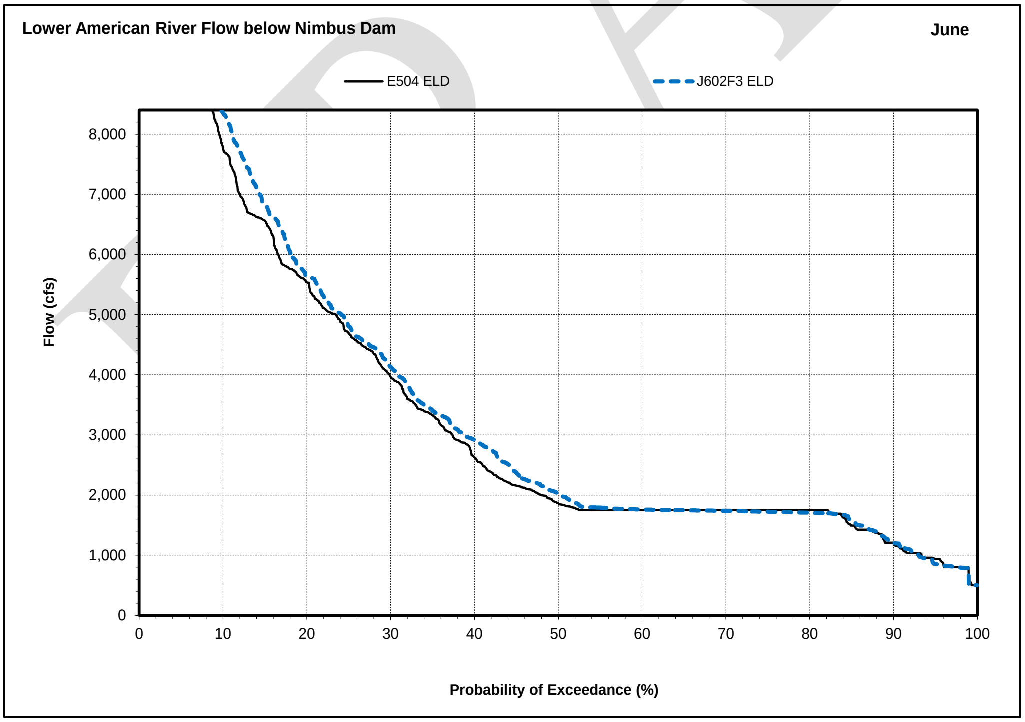

Figure 7.1-9. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for June under J602F3 ELD and E504 ELD

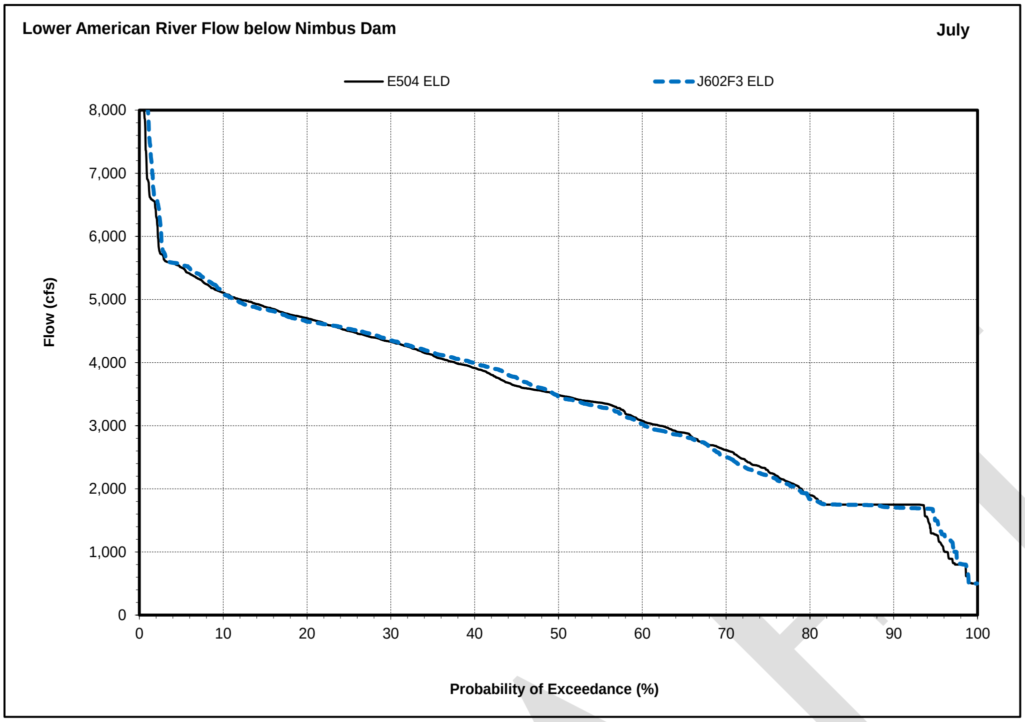

Figure 7.1-10. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for July under J602F3 ELD and E504 ELD

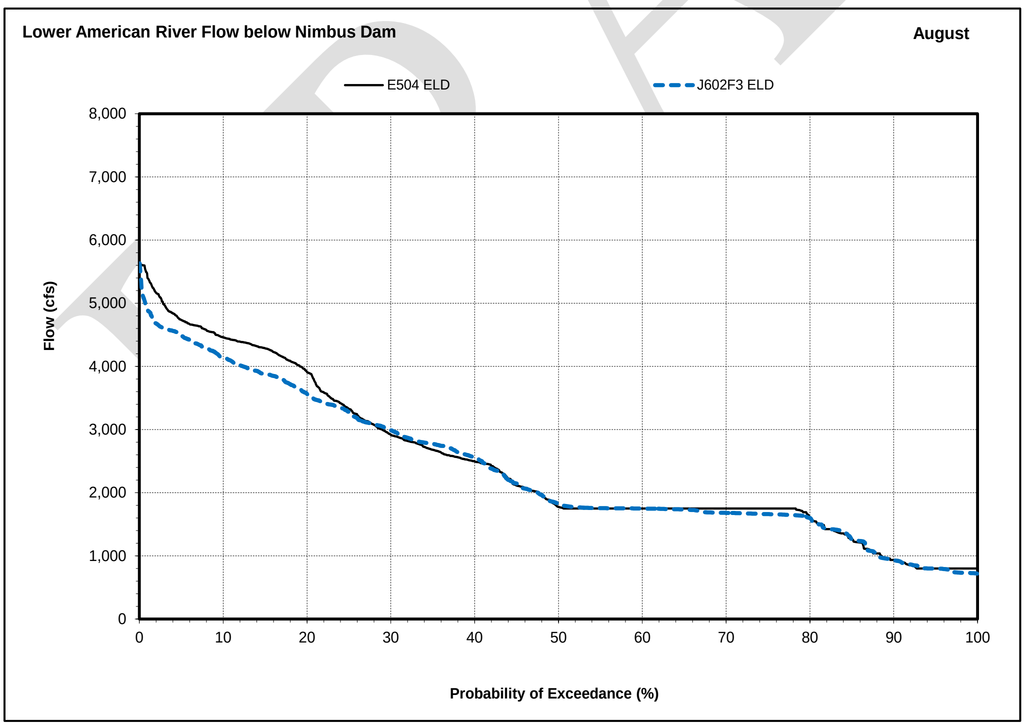

Figure 7.1-11. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for August under J602F3 ELD and E504 ELD

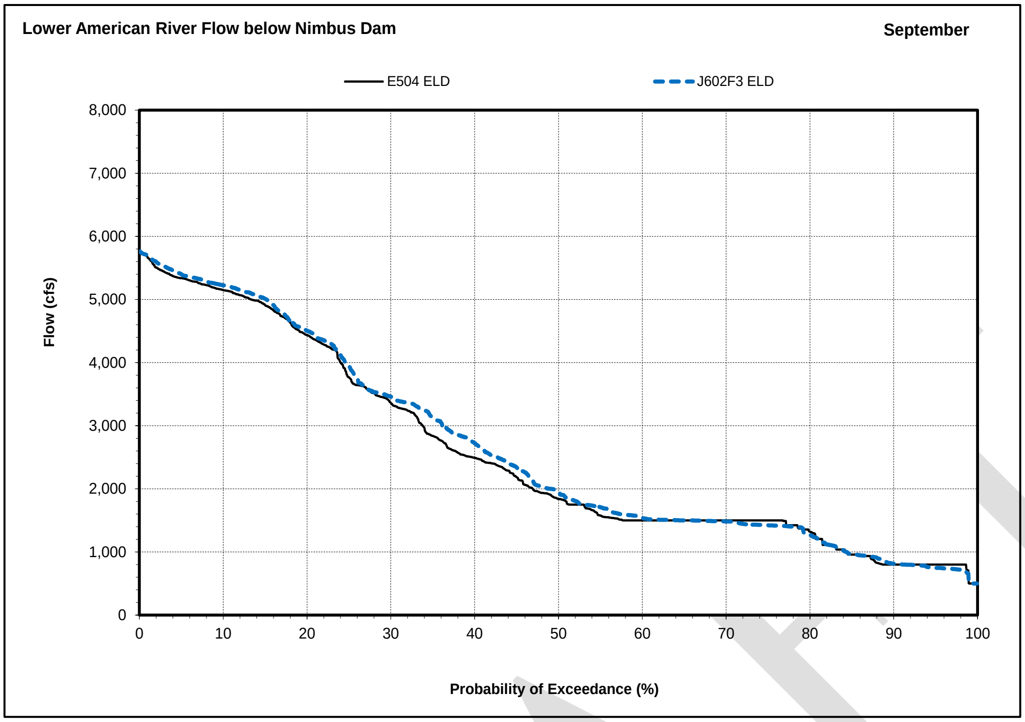

Figure 7.1-12. Lower American River Flow Probability of Exceedance Distributions below Nimbus Dam for September under J602F3 ELD and E504 ELD

Monthly flow exceedance distributions at Watt Avenue and at the mouth of the lower American River exhibit similar trends as described for below Nimbus Dam (see Appendix 7A).

In addition to evaluating general changes in the monthly flow exceedance distributions, net changes in flow of 10 percent or more are calculated based on the monthly exceedance distributions to determine whether flow increases by 10 percent or more with higher frequency, or whether flow decreases by 10 percent or more with higher frequency (i.e., the percentage of the time that flow increases by 10 percent or more minus the percentage of time that flow decreases by 10 percent or more) (refer to the Fisheries Impact Assessment Methodology, Appendix 7B). The net change in flow of 10 percent or more is evaluated on a monthly basis for below Nimbus Dam, at Watt Avenue and at the mouth of the lower American River for the entire distribution of flows, and/or for the lowest 40 percent of the distribution of flows, depending on the species and lifestage being evaluated.

Under J602F3 ELD relative to E504, net changes in flow at all three locations of 10 percent or more over the entire monthly distributions are generally similar (i.e., less than 5 percent) during July through December (Table 3.1-2). Flows decrease by 10 percent or more with higher frequency during January and August, and with substantially higher frequency (i.e., 10 percent or more) during February. In contrast, flows increase by 10 percent or more with higher frequency during May through July, and with substantially higher frequency during March and April.

Net changes in flow of 10 percent or more during low-flow conditions are generally similar (i.e., less than 5 percent) during most months of the year, including May, June, and August through January (Table 3.1-3). Net reductions in flow of 10 percent or more occur substantially more often during February and April, while a net increase in flow of 10 percent or more occurs substantially more often during July (at Nimbus Dam and Watt Avenue) under J602F3 ELD relative to E504.

Table 3.1-2. Monthly Net Changes in Flow of 10 Percent or More below Nimbus Dam, at Watt Avenue, and at the Mouth of the Lower American River

Indicator of Potential Impact	Location	Metric	Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
	Description	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean Daily Flow (cfs)	American River below Nimbus Dam	10	All Years	2	0	0	-7	-34	21	22	8	7	5	0	4
	American River at Watt Avenue	10	All Years	2	-1	-1	-7	-32	21	23	8	5	5	-4	2
	Mouth of the American River (RM 1)	10	All Years	2	-1	-1	-5	-29	19	24	9	4	5	-5	1

Table 3.1-3. Monthly Net Changes in Flow of 10 Percent or More during Low-Flow Conditions below Nimbus Dam, at Watt Avenue, and at the Mouth of the Lower American River

Indicator of Potential Impact	Location	Metric	Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
	Description	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean Daily Flow (cfs)	American River below Nimbus Dam	10	Lower 40%	2	5	6	-1	-13	7	-16	0	-1	10	0	-2
	American River at Watt Avenue	10	Lower 40%	3	2	5	0	-11	6	-16	0	-1	10	0	-2
	Mouth of the American River (RM 1)	10	Lower 40%	3	2	3	-1	-9	9	-13	0	0	9	0	-1

Based on the general changes in flows (described above) and water temperatures (see the Water Temperature section), as well as fish species and lifestage-specific flow and water temperature–related impact indicators presented below, potential changes in species and lifestage-specific suitabilities under J602F3 ELD relative to E504 are described in the following sections.

3.1.1 Steelhead

Flow and water temperature model results were examined for the lower American River below Nimbus Dam, at Watt Avenue, and near the mouth of the lower American River (i.e., RM 1) (Table 3.1-4). Additional flow and water temperature nodes were used to simulate potential redd dewatering (i.e., daily water temperatures by river mile).

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult immigration (November through March [peaking during January]) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher and lower flows with similar monthly frequency over the evaluation period; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency at both locations during February, and are higher by 10 percent or more with substantially higher frequency during March; (3) during low-flow conditions, flows are higher with slightly higher frequency during most months of the evaluation period, but are lower by 10 percent or more with higher or substantially higher frequency at both locations during February; (4) over the monthly water temperature exceedance distributions, similar water temperatures most of the time during all months of the evaluation period; and

(5) equivalent monthly probabilities of exceeding both UO and UT WTI values at both locations evaluated.

- Similar adult holding (November through March [peaking during January]) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher and lower flows with similar monthly frequency over the evaluation period; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with substantially higher frequency during March; (3) during low-flow conditions, flows are higher with slightly higher frequency during most months of the evaluation period, but are lower by 10 percent or more with substantially higher frequency at both locations during February; (4) over the monthly water temperature exceedance distributions, similar water temperatures most of the time during all months of the evaluation period; and (5) equivalent monthly probabilities of exceeding both UO and UT WTI values at both locations evaluated.
- More suitable spawning (January through mid-April [peaking during February]) conditions due to: (1) slightly higher long-term average spawning WUA and similar or slightly higher average spawning WUA during all water year types (Table 3.1-5); (2) over the annual spawning WUA exceedance distribution, similar probability of spawning WUA equal to or greater than 80 percent of maximum spawning WUA, and generally slightly higher spawning WUA over the distribution when spawning WUA is less than 80 percent of maximum under both scenarios (Figure 7.1-13); (3) over the monthly water temperature exceedance distributions, similar water temperatures most of the time during all months of the evaluation period; and (4) similar probabilities of exceeding WTI values at both locations during all months, except for an increase in the probability of exceedance of the UT WTI value during the first half of April. Although there is an increase in the probability of exceedance during the first half of April, less than 1 percent of steelhead spawning is expected to occur during April (see Appendix 7E, Analysis of Weighted Usable Area for Lower American River Salmonids). Therefore, water temperature conditions are expected to be generally similar overall for steelhead spawning.
- More suitable embryo incubation (January through May [peaking during March]) conditions due to: (1) lower long-term average annual redd dewatering index and slightly lower or similar average redd dewatering index during all water year types (Table 3.1-6); (2) lower annual redd dewatering index over most of the exceedance distribution (Figure 7.1-14); (3) over the monthly water temperature exceedance distributions, similar water temperatures most of the time during all months of the evaluation period, but with slightly lower temperatures over the entirety of the distribution during May; and (4) similar most of the time but with a slight increase in exceedance of the UO WTI value during April below Nimbus Dam, and a slight decrease in exceedance of the UT WTI value during April and May below Nimbus Dam and during May at Watt Avenue.
- Similar juvenile rearing and downstream movement (year-round) conditions due to: (1) over the monthly flow exceedance distributions, similar flows during most months of the evaluation period, but with higher flows more often during April and May, and lower flows more often during February; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during

February, and are higher by 10 percent or more with higher frequency during May through July and with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March and July; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures over most of the distributions during most months of the evaluation period; and (5) generally similar probabilities of exceeding UO and UT WTI values at all locations during most months, but with some slight increases in exceedance probabilities during July and August at the mouth, and slight decreases in exceedance during June through September below Nimbus Dam, during May and June at Watt Avenue, and during May, June, August, and September at the mouth.

- Slightly less suitable smolt emigration (December through April [peaking during January]) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows more often during most months of the evaluation period, but with lower flows more often during February; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with similar or higher frequency during January, and with substantially higher frequency during February, and are higher by 10 percent or more with substantially higher frequency during March and April (no net difference in flow changes of 10 percent or more occur during December); (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March and December (no net differences in flow changes of 10 percent or more occur during January); (4) over the monthly water temperature exceedance distributions, generally similar water temperatures during all months of the evaluation period; and (5) similar probabilities of exceeding UO and UT WTI values during all months at both locations, with the exception of a slight increase in the probability of exceeding the UO WTI value during April at Watt Avenue.

- Overall, in consideration of all flow and water temperature–related impact indicators, as well as peak lifestage-specific temporal considerations, and limiting factors and key stressors for steelhead in the lower American River, habitat conditions are expected to be slightly more suitable for steelhead under J602F3 ELD relative to E504. Although conditions may be slightly less suitable for smolt emigration, the probability of redd dewatering is reduced, spawning habitat availability increases slightly, and water temperatures are reduced more often during some spring and summer months. Therefore, key stressors to steelhead in the lower American River identified by NMFS (2014), including flow fluctuations and elevated water temperatures, may be less impactful to steelhead under J602F3 ELD relative to E504.

Table 3.1-4. Net Difference in Water Temperature Index Value Exceedance Probabilities for Steelhead

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value (°F)	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Immigration	November through March	Mean Daily Water Temperature (°F)	American River at Watt Avenue	64		All Years		0	0	0	0	0						
				68		All Years		0	0	0	0	0						
			Mouth of the American River (RM 1)	64		All Years		0	0	0	0	0						
				68		All Years		0	0	0	0	0						
Adult Holding	November through March	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	61		All Years		0	0	0	0	0						
				65		All Years		0	0	0	0	0						
			American River at Watt Avenue	61		All Years		0	0	0	0	0						
				65		All Years		0	0	0	0	0						
Adult Spawning	January through mid-April	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	54		All Years				0	0	1	8					
				57		All Years				0	0	0	0					
			American River at Watt Avenue	54		All Years				0	0	1	8					
				57		All Years				0	0	0	0					
Embryo Incubation	January through May	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	54		All Years				0	0	1	3	-1				
				57		All Years				0	0	0	-3	-3				
			American River at Watt Avenue	54		All Years				0	0	1	-1	0				
				57		All Years				0	0	0	1	-3				
Juvenile Rearing and Downstream Movement	Year-round	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	65		All Years	-2	0	0	0	0	0	0	0	-5	-2	-2	-3
				68		All Years	0	0	0	0	0	0	0	0	0	-2	0	0
			American River at Watt Avenue	65		All Years	-1	0	0	0	0	0	0	-3	-1	1	-1	0
				68		All Years	-1	0	0	0	0	0	0	-1	-4	0	-1	-1
			Mouth of the American River (RM 1)	65		All Years	-1	0	0	0	0	0	1	-2	-2	-1	3	0
				68		All Years	0	0	0	0	0	0	0	-3	-2	2	-2	-2
Smolt Emigration	December through April	Mean Daily Water Temperature (°F)	American River at Watt Avenue	52		All Years			0	0	0	0	2					
				55		All Years			0	0	0	1	-1					
			Mouth of the American River (RM 1)	52		All Years			0	0	1	0	1					
				55		All Years			0	0	0	0	-1					

Table 3.1-5. Long-term Average and Average by Water Year Type Steelhead Spawning WUA

Lower American River Steelhead Annual Spawning WUA Averages (% of Maximum WUA)			
Water Year Type Category	**J602F3 ELD**	**E504**	**Difference**
All Water Years	72.4%	71.6%	0.8%
Wet	53.3%	51.7%	1.6%
Above Normal	65.9%	64.4%	1.5%
Below Normal	82.5%	81.8%	0.7%
Dry	89.6%	89.4%	0.2%
Critical	82.0%	82.5%	–0.5%

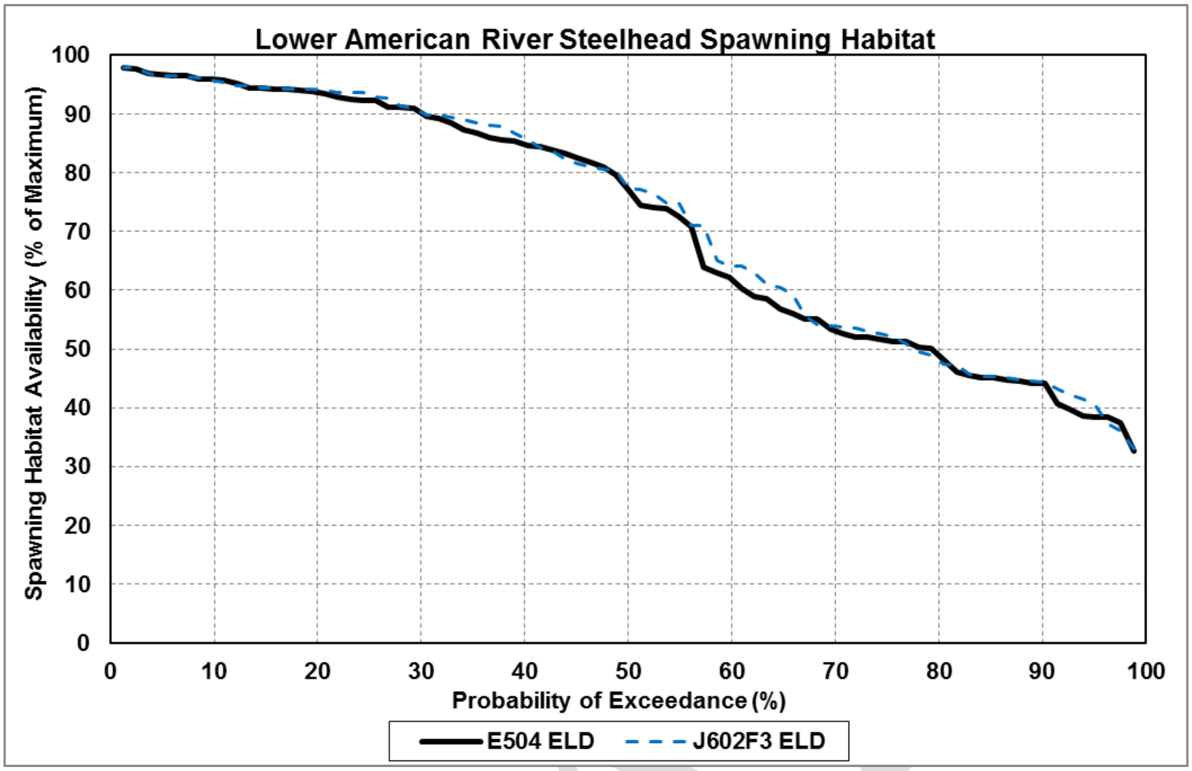

Figure 7.1-13. Steelhead Spawning WUA Exceedance Distribution

Table 3.1-6. Long-term Average and Average by Water Year Type Steelhead Redd Dewatering Index

Lower American River Steelhead Annual Redd Dewatering Index Averages (%)			
Water Year Type Category	**J602F3 ELD**	**E504**	**Difference**
All Water Years	25.2%	27.3%	–2.1%
Wet	45.2%	49.2%	–4.0%
Above Normal	43.6%	45.6%	–2.0%
Below Normal	15.1%	17.5%	–2.4%
Dry	4.8%	5.1%	–0.3%
Critical	2.6%	2.5%	0.1%

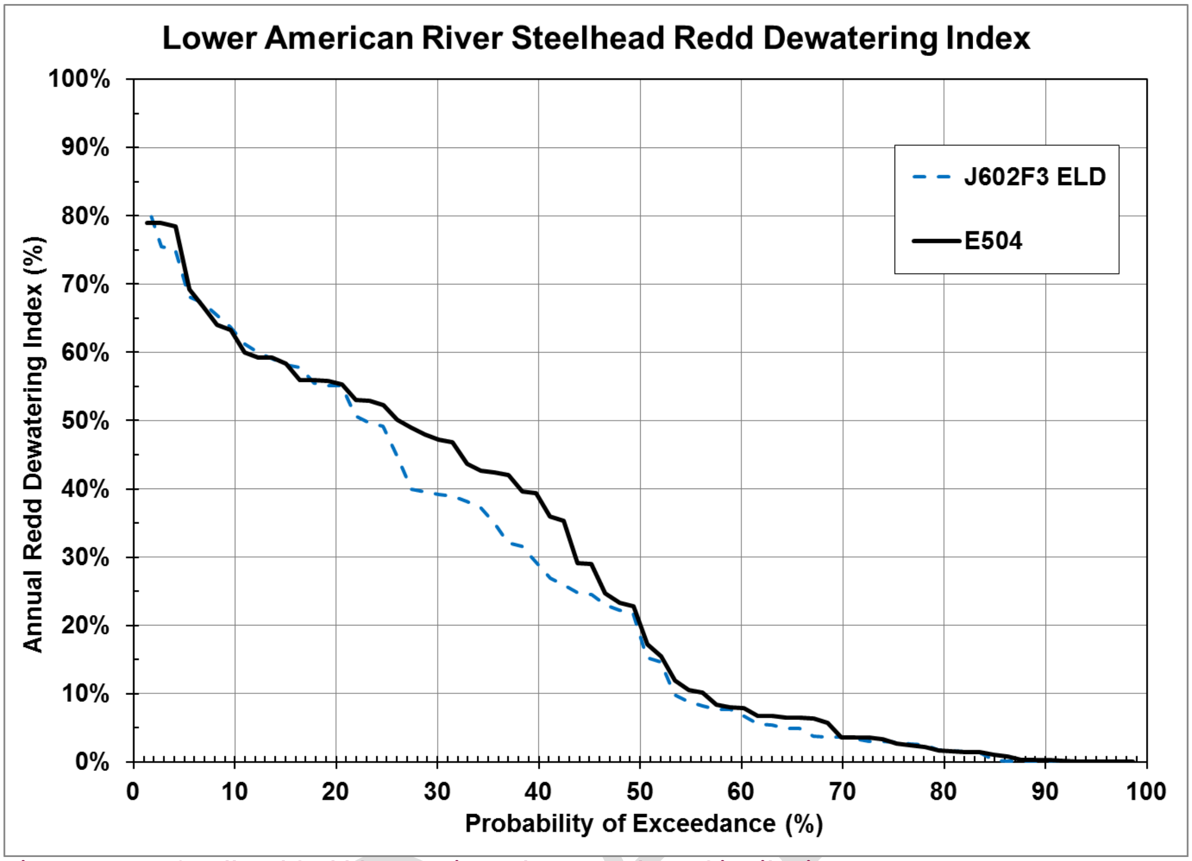

Figure 7.1-14. Steelhead Redd Dewatering Index Exceedance Distribution

3.1.2 Fall-run Chinook Salmon

Flow and water temperature model results were examined for the lower American River below Nimbus Dam, at Watt Avenue, and near the mouth of the lower American River (i.e., RM 1) (Table 3.1-7). Additional flow and water temperature nodes were used to simulate potential redd dewatering (i.e., daily water temperatures by river mile).

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult immigration and staging (August through December [peaking during November]) conditions due to: (1) over the monthly flow exceedance distributions, similar flows most of the time over the evaluation period; (2) over the entire flow exceedance distributions, minor net differences in flow changes of 10 percent or more during all months at most locations; (3) during low-flow conditions, flows are higher by 10% or more with higher frequency during December below Nimbus Dam but with minor net differences in flow changes of 10 percent or more during the remaining months at all locations; (4) over the monthly water temperature exceedance distributions, generally similar or slightly lower temperatures over the evaluation period; and (5) similar monthly probabilities of exceeding both UO and UT WTI values at all locations, but with some slight reductions in exceedance of the UO WTI value during October at all three locations, the UO WTI value during August below Nimbus Dam, and the UT WTI value at the mouth during August and September, and a slight increase in exceedance of the UO WTI value during August at the mouth.

- Similar spawning (mid-October through December [peaking during November]) conditions due to: (1) generally equivalent long-term average spawning WUA and average spawning WUA by water year type (Table 3.1-8); (2) over the annual spawning WUA exceedance distribution, similar probability of spawning WUA equal to or greater than 80 percent of maximum spawning WUA, and generally similar spawning WUA when spawning WUA is less than 80 percent of maximum (Figure 7.1-15); (3) over the monthly water temperature exceedance distributions, similar water temperatures during all months, including during relatively warm water temperature conditions (e.g., above 60°F); and (4) similar probabilities of exceeding both UO and UT WTI values during all months evaluated at both locations.
- Similar embryo incubation conditions (mid-October through March) due to: (1) generally equivalent long-term average annual redd dewatering index and similar average redd dewatering index during most water year types, except for a slight (1.6-percent) increase during critical water years (Table 3.1-9); (2) similar annual redd dewatering index over most of the exceedance distribution (Figure 7.1-16); (3) over the monthly water temperature exceedance distributions, similar water temperature over most of the monthly distributions, but with slightly lower temperatures more often during October at all locations, and slightly higher temperatures during March below Nimbus Dam; and (4) similar probabilities of exceeding both UO and UT WTI values during all months evaluated at both locations.
- Similar early lifestage mortality due to: (1) generally equivalent annual long-term average early lifestage mortality and average annual early lifestage mortality by water year type (Table 3.1-10); and (2) similar early lifestage annual mortality over the entire exceedance distribution (Figure 7.1-17).
- Similar juvenile rearing and downstream movement (January through May [peaking during February]) conditions due to: (1) over the monthly flow exceedance distributions, lower flows during February, but higher or similar flows more often during the remainder of the evaluation period; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with higher frequency during May and with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures more often over the evaluation period; and (5) similar probabilities of exceeding UO and UT WTI values most of the time at all locations, but with slightly lower probabilities of exceedance during May at all locations.
- Overall, in consideration of all flow and water temperature–related impact indicators, as well as peak lifestage-specific temporal considerations, and limiting factors and key stressors for

salmonids in the lower American River, habitat conditions are expected to be generally similar for fall-run Chinook salmon under J602F3 ELD relative to E504. Although flows decrease during some months of the rearing and emigration lifestage, spawning habitat availability, the probability of redd dewatering, and early lifestage mortality are similar under both scenarios. In addition, there are some slight reductions in water temperatures during the warmest periods of some lifestages, such as during October of the adult immigration lifestage and during May of the juvenile rearing and emigration lifestage under J602F3 ELD.

Table 3.1-7. Net Difference in Water Temperature Index Value Exceedance Probabilities for Fall-run Chinook Salmon

Lifestage	Evaluation Period	Indicator of Potential Impact	Location Description	Metric Value (°F)	Metric %	Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
							Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Immigration and Staging	August through December	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	64		All Years	-3	0	0								-2	0
				68		All Years	0	0	0								0	0
			American River at Watt Avenue	64		All Years	-3	0	0								1	0
				68		All Years	-1	0	0								-1	-1
			Mouth of the American River (RM 1)	64		All Years	-2	0	0								2	0
				68		All Years	0	0	0								-2	-2
Adult Spawning	Mid-October through December	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	56		All Years	0	0	0									
				58		All Years	0	1	0									
			American River at Watt Avenue	56		All Years	0	1	0									
				58		All Years	0	1	0									
Embryo Incubation	Mid-October through March	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	56		All Years	0	0	0	0	0	0						
				58		All Years	0	1	0	0	0	0						
			American River at Watt Avenue	56		All Years	0	1	0	0	0	1						
				58		All Years	0	1	0	0	0	0						
Juvenile Rearing and Emigration	January through May	Mean Daily Water Temperature (°F)	American River below Nimbus Dam	61		All Years				0	0	0	0	-5				
				65		All Years				0	0	0	0	0				
			American River at Watt Avenue	61		All Years				0	0	0	0	-3				
				65		All Years				0	0	0	0	-3				
			Mouth of the American River (RM 1)	61		All Years				0	0	0	1	-3				
				65		All Years				0	0	0	1	-2				

Table 3.1-8. Long-term Average and Average by Water Year Type Fall-run Chinook Salmon Spawning WUA

Lower American River Fall-run Chinook Salmon Annual Weighted WUA Averages (%)			
Water Year Type Category	**J602F3 ELD**	**E504**	**Difference**
All Water Years	84.4%	84.2%	0.2%
Wet	81.3%	80.7%	0.6%
Above Normal	81.1%	80.8%	0.3%
Below Normal	88.1%	88.5%	–0.4%
Dry	85.3%	85.1%	0.2%
Critical	88.3%	88.4%	–0.1%

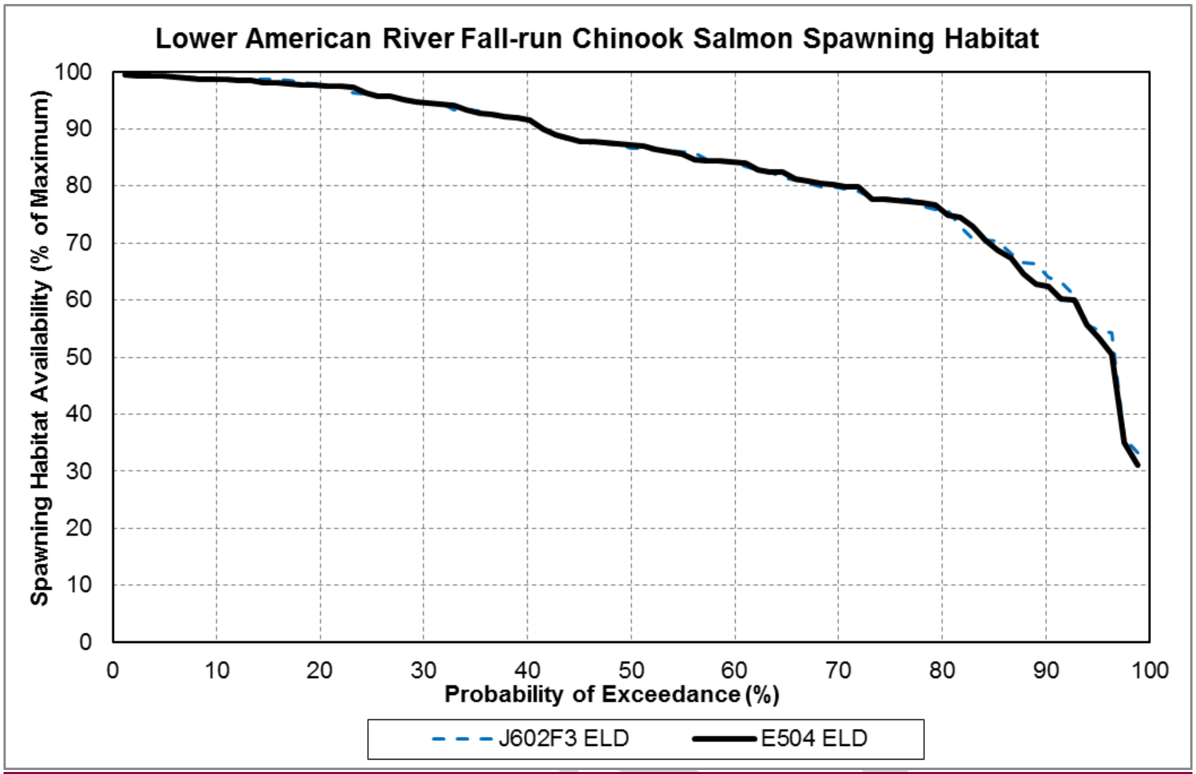

Figure 7.1-15. Fall-run Chinook Salmon Spawning WUA Exceedance Distribution

Table 3.1-9. Long-term Average and Average by Water Year Type Fall-run Chinook Salmon Redd Dewatering Index

Lower American River Chinook Salmon Annual Redd Dewatering Index Averages (%)			
Water Year Type Category	**J602F3 ELD**	**E504**	**Difference**
All Water Years	10.0%	10.1%	0.0%
Wet	12.4%	13.0%	–0.6%
Above Normal	6.6%	7.6%	–0.9%
Below Normal	6.2%	5.8%	0.4%
Dry	7.5%	7.5%	0.0%
Critical	15.8%	14.2%	1.6%

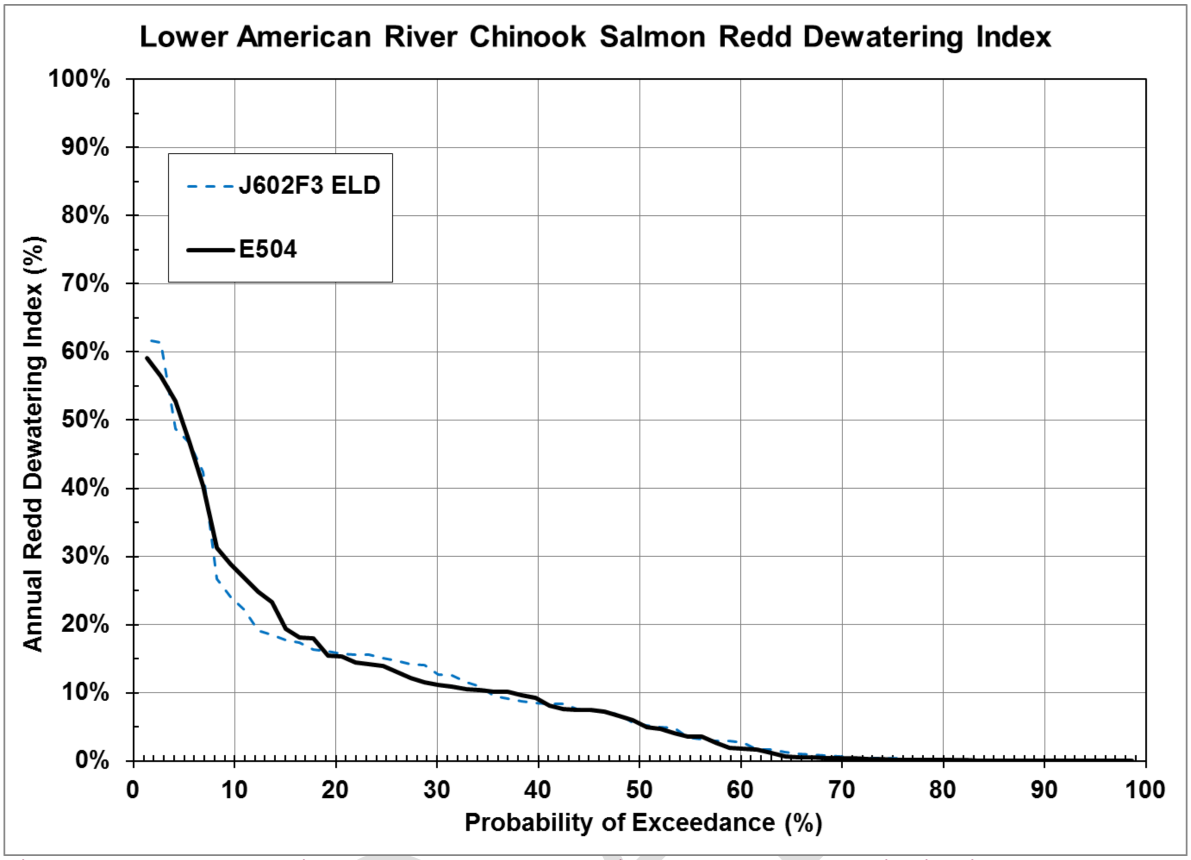

Figure 7.1-16. Fall-run Chinook Salmon Redd Dewatering Index Exceedance Distribution

Table 3.1-10. Long-term Average and Average by Water Year Type Fall-run Chinook Salmon Early Lifestage Mortality

Lower American River Fall-run Chinook Salmon Annual Early Lifestage Mortality Averages (%)			
Water Year Type Category	**J602F3 ELD**	**E504**	**Difference**
All Water Years	7.5%	7.7%	–0.2%
Wet	4.6%	4.6%	0.0%
Above Normal	4.1%	4.1%	–0.1%
Below Normal	4.9%	5.1%	–0.2%
Dry	10.9%	11.6%	–0.6%
Critical	14.9%	14.8%	0.1%

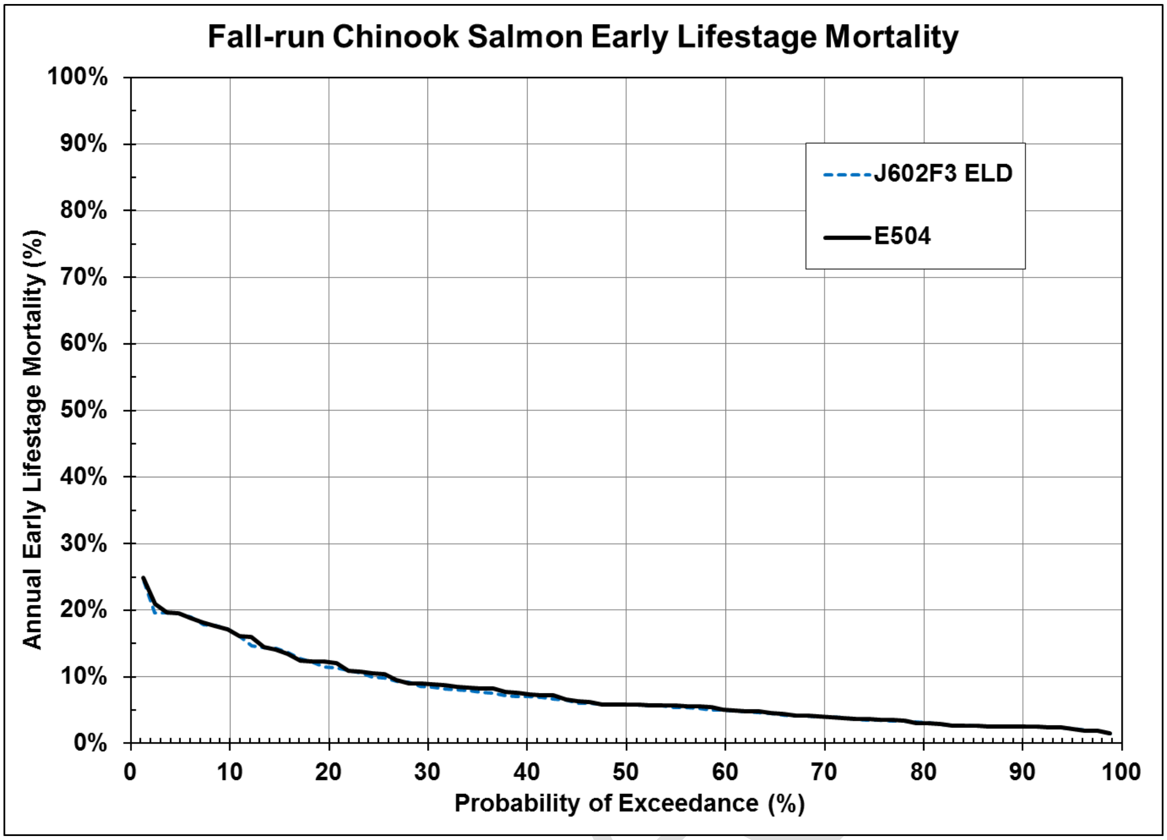

Figure 7.1-17. Fall-run Chinook Salmon Annual Early Lifestage Mortality Exceedance Distribution

3.1.3 Spring-run Chinook Salmon (Non-natal Juvenile Rearing)

Flow and water temperature model results were examined for the lower American River near the mouth of the lower American River (i.e., RM 1) for non-natal juvenile rearing (Table 3.1-11).

Relative to E504, J602F3 ELD would be expected to provide:

- Similar non-natal juvenile rearing (November through April) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows more often during most months of the evaluation period, but with lower flows during February; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March; (4) over the monthly water temperature exceedance distributions, similar temperatures over most of the evaluation period; and (5) similar probabilities of exceeding UO and UT WTI values during all months evaluated.

- Overall, in consideration of all flow and water temperature–related impact indicators, habitat conditions are expected to be similar for spring-run Chinook salmon under J602F3 ELD relative to E504. Although flows decrease during a portion of the evaluation period, water temperature index values are exceeded with similar frequency. In addition, flow reductions are not expected to substantially affect the incidental rearing of non-natal juvenile spring-run Chinook salmon in the lower American River when seeking refuge from high winter flows in the Sacramento River.

Table 3.1-11. Net Difference in Water Temperature Index Value Exceedance Probabilities for Spring-run Chinook Salmon

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value (°F)	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Non-Natal Juvenile Rearing	November through April	Mean Daily Water Temperature (°F)	Mouth of the American River (RM 1)	61		All Years		0	0	0	0	0	1					
				65		All Years		0	0	0	0	0	1					

3.1.4 River Lamprey

Flow and water temperature model results were examined for the lower American River at Watt Avenue and near the mouth of the lower American River (i.e., RM 1) (Table 3.1-12).

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult immigration (September through June) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows more often over most of the evaluation period; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher or substantially higher frequency during January and February, and are higher by 10 percent or more with higher or substantially higher frequency during March through June, with minor net changes of 10 percent or more during the remainder of the evaluation period; (3) during low-flow conditions, flows are lower by 10 percent or more with higher or substantially higher frequency during February and April, and are higher by 10 percent or more with substantially higher frequency during March, with minor net changes of 10 percent or more during most months of the evaluation period; (4) over the monthly water temperature exceedance distributions, similar water temperatures over most the evaluation period; and (5) similar probabilities of water temperatures occurring within the specified range during all months evaluated at both locations, but with a slighter higher probability of occurring within the range during May.
- Similar spawning and embryo incubation (February through July) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows most of the time over the evaluation period; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with substantially higher frequency during February, and are higher by 10 percent or more with higher or substantially higher frequency during March through June, with minor net changes of 10 percent or more during July; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March, with minor net changes of 10 percent or more during May and June; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures during most months;

and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months evaluated, but with a slightly higher probability of occurring within the range during May.

- Similar ammocoete rearing and downstream movement (year-round) conditions due to: (1) over the monthly flow exceedance distributions, similar flows during most months of the evaluation period, but with higher flows more often during April and May, and lower flows more often during February; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with higher frequency during May through July and with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March and July; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures over most of the distributions during most months, but with higher water temperatures during August at the mouth; and (5) similar monthly probabilities of exceeding the WTI value during all months evaluated at both locations, but with slightly lower probabilities of exceedance during June and July.
- Overall, in consideration of all flow and water temperature–related impact indicators, as well as peak lifestage-specific temporal considerations, habitat conditions are expected to be similar for river lamprey under J602F3 ELD relative to E504.

Table 3.1-12. Net Difference in Water Temperature Index Value Exceedance Probabilities for River Lamprey

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Immigration	September through June	Mean Daily Water Temperature (°F)	American River at Watt Avenue	42-60[1]		All Years	1	0	0	0	0	0	0	2	1			0
			Mouth of the American River (RM 1)	42-60		All Years	0	0	0	0	0	1	0	2	1			0
Spawning and Embryo Incubation	February through July	Mean Daily Water Temperature (°F)	American River at Watt Avenue	50-64		All Years					1	-1	1	4	1	0		
Ammocoete Rearing and Downstream Movement	Year-round	Mean Daily Water Temperature (°F)	American River at Watt Avenue	72		All Years	0	0	0	0	0	0	0	0	-1	-2	0	0
			Mouth of the American River (RM 1)	72		All Years	0	0	0	0	0	0	0	-1	-2	0	-1	1

[1]Water temperature ranges are evaluated by calculating the net change in the probability of water temperatures occurring within the specified range.

3.1.5 Pacific Lamprey

Flow and water temperature model results were examined for the lower American River at Watt Avenue and near the mouth of the lower American River (i.e., RM 1) (Table 3.1-13).

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult immigration (January through June) conditions due to: (1) over the monthly flow exceedance distributions, higher flows more often during April and May, and lower flows more often during February, with similar flows most of the time during the remainder of the evaluation period; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with higher frequency during May and June, and with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures over most of the distributions during most months, but with higher water temperatures during March below Nimbus Dam (when water temperatures are below 55°F); and (5) similar probabilities of water temperatures occurring within the specified range at both locations during all months evaluated, but with slight increases in the probability of occurring within the range during May.

- Similar spawning and embryo incubation (March through August) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows over the evaluation period; (2) over the entire flow exceedance distributions, flows are higher by 10 percent or more with higher frequency during May and June, and with substantially higher frequency during March and April, with minor net changes of 10 percent or more during July and August; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during April, and are higher by 10 percent or more with substantially higher frequency during March and July, with minor net changes of 10 percent or more during May, June, and August; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures over the evaluation period; (5) similar probabilities of water temperatures occurring within the specified range at both locations during all months evaluated, but with a slight increase in the probability of occurring within the range during May.
- Similar ammocoete rearing and downstream movement (year-round) conditions due to: (1) over the monthly flow exceedance distributions, similar flows during most months of the evaluation period, but with higher flows more often during April and May, and lower flows more often during February; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with higher frequency during May through July and with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March and July; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures over most of the distributions during most months, but with higher water temperatures during August at the mouth; and (5) similar monthly probabilities of exceeding the WTI value at both locations during all months, but with slight reductions in exceedance during June and July.
- Overall, in consideration of all flow and water temperature–related impact indicators, habitat conditions are expected to be similar for Pacific lamprey under J602F3 ELD relative to E504.

Table 3.1-13. Net Difference in Water Temperature Index Value Exceedance Probabilities for Pacific Lamprey

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Immigration	January through June	Mean Daily Water Temperature (°F)	American River at Watt Avenue	42-60[1]		All Years				0	0	0	0	2	1			
			Mouth of the American River (RM 1)	42-60		All Years				0	0	1	0	2	1			
Spawning and Embryo Incubation	January through August	Mean Daily Water Temperature (°F)	American River at Watt Avenue	50-64		All Years				0	1	-1	1	4	1	0	-1	
Ammocoete Rearing and Downstream Movement	Year-round	Mean Daily Water Temperature (°F)	American River at Watt Avenue	72		All Years	0	0	0	0	0	0	0	0	-1	-2	0	0
			Mouth of the American River (RM 1)	72		All Years	0	0	0	0	0	0	0	-1	-2	0	-1	1

[1]Water temperature ranges are evaluated by calculating the net change in the probability of water temperatures occurring within the specified range.

3.1.6 Hardhead

Flow and water temperature model results were examined for the lower American River at Watt Avenue (Table 3.1-14).

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult and other lifestage (year-round) conditions due to: (1) over the monthly flow exceedance distributions, similar flows during most months of the evaluation period, but with higher flows more often during April and May, and lower flows more often during February; (2) over the entire flow exceedance distributions, flows are lower by 10 percent or more with higher frequency during January and with substantially higher frequency during February, and are higher by 10 percent or more with higher frequency during May through July and with substantially higher frequency during March and April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during February and April, and are higher by 10 percent or more with higher or substantially higher frequency during March and July; (4) over the monthly water temperature exceedance distributions, similar or lower water temperatures over most of the monthly distributions; and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months, but with a slight reduction in the probability of occurring within the range during May (due to a reduction in water temperatures under J602F3 ELD).
- Similar spawning (April through June) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows more often during April through June; (2) over the entire flow exceedance distributions, flows are higher by 10 percent or more with higher frequency during May and June, and with substantially higher frequency during April; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during April, with minor net changes in flow of 10 percent or more during May and June; (4) over the monthly water temperature exceedance distributions, similar or lower temperatures over the monthly distributions; and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months evaluated, but with a slight increase in the probability of occurring within the range during May.
- Overall, in consideration of all flow and water temperature–related impact indicators, habitat conditions are expected to be similar for hardhead under J602F3 ELD relative to E504.

Table 3.1-14. Net Difference in Water Temperature Index Value Exceedance Probabilities for Hardhead

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adults and Other Lifestages	Year-round	Mean Daily Water Temperature (°F)	American River at Watt Avenue	61-77[1]		All Years	0	0	0	0	0	0	0	-3	-1	0	1	0
Spawning	April through June	Mean Daily Water Temperature (°F)	American River at Watt Avenue	59-64		All Years							1	2	0			

[1]Water temperature ranges are evaluated by calculating the net change in the probability of water temperatures occurring within the specified range.

3.1.7 American Shad

Flow and water temperature model results were examined for the lower American River at Watt Avenue (Table 3.1-15). In addition, flows near the mouth of the lower American River (i.e., RM 1) were evaluated for adult attraction into the lower American River.

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult attraction (May and June) conditions due to: (1) similar probability of flows at the mouth exceeding 2,000 cfs; (2) similar probability of flows at the mouth occurring between 3,000 and 4,000 cfs; and (3) similar probabilities that mean monthly flows at the mouth are equivalent to or greater than 10 percent of simulated mean monthly flow in the Sacramento River.
- Similar adult immigration and spawning (April through June) conditions due to: (1) over the monthly flow exceedance distributions, higher flows more often during April and May, and lower flows more often during June; (2) over the entire flow exceedance distributions, flows are higher by 10 percent or more with substantially higher frequency during April, with minor net changes of 10 percent or more during May and June; (3) during low-flow conditions, minor net changes in flow of 10 percent or more occur during April through June; (4) over the monthly water temperature exceedance distributions, similar or lower temperatures over the monthly distributions; and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months evaluated.
- Similar juvenile rearing and downstream movement (April through December) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows over the monthly distributions; (2) over the entire flow exceedance distributions, flows are higher by 10 percent or more with higher or substantially higher frequency during April through June, with minor net changes of 10 percent or more during July through December; (3) during low-flow conditions, flows are lower by 10 percent or more with substantially higher frequency during April, and are higher by 10 percent or more with substantially higher frequency during July, with minor net changes of 10 percent or more during May, June, and August through December; (4) over the monthly water temperature exceedance distributions, similar or lower temperatures most of the time; and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months evaluated, but with a slight increase in the probability of occurring within the range during August, and slight decreases in the probability of occurring within the range during October and May (due to reduced water temperatures under J602F3 ELD).
- Overall, in consideration of all flow and water temperature–related impact indicators, habitat conditions are expected to be similar for American shad under J602F3 ELD relative to E504.

Table 3.1-15. Net Difference in Flow and Water Temperature Index Value Exceedance Probabilities for American Shad

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Attraction	May and June	Mean Daily Flow (cfs)	Mouth of the American River (RM 1)	>2,000 cfs		All Years								2	2			
				3,000 - 4,000 cfs		All Years								0	0			
		Mean Monthly Flow (cfs)	Mouth of the American River (RM 1)	≥10% of Sac R. Flow		All Years								0	1			
Adult Immigration and Spawning	April through June	Mean Daily Water Temperature (°F)	American River at Watt Avenue	60-70[1]		All Years							0	-2	2			
Juvenile Rearing and Downstream Movement	April through December	Mean Daily Water Temperature (°F)	American River at Watt Avenue	63-77		All Years	-2	0	0				0	-4	-1	0	2	0

[1]Water temperature ranges are evaluated by calculating the net change in the probability of water temperatures occurring within the specified range.

3.1.8 Striped Bass

Flow and water temperature model results were examined for the lower American River at Watt Avenue (Table 3.1-16). In addition, flows near the mouth of the lower American River (i.e., RM 1) were evaluated for adult attraction into the lower American River.

Relative to E504, J602F3 ELD would be expected to provide:

- Similar adult attraction (May and June) conditions due to similar probabilities of flows at the mouth exceeding 1,500 cfs.
- Similar adult immigration and spawning (April through June) conditions due to: (1) over the monthly flow exceedance distributions, higher flows more often during April and May, and lower flows more often during June; (2) over the entire flow exceedance distributions, flows are higher by 10 percent or more with substantially higher frequency during April, with minor net changes of 10 percent or more during May and June; (3) during low-flow conditions, minor net changes in flow of 10 percent or more occur during April through June; (4) over the monthly water temperature exceedance distributions, similar or lower temperatures over the monthly distributions; and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months evaluated, but with a slight increase in the probability of occurring within the range during June.
- Similar juvenile rearing (May through October) conditions due to: (1) over the monthly flow exceedance distributions, similar or higher flows over the monthly distributions; (2) over the entire flow exceedance distributions, flows are higher by 10 percent or more with higher frequency during May and June, with minor net changes of 10 percent or more during July through October; (3) during low-flow conditions, flows are higher by 10 percent or more with substantially higher frequency during July, with minor net changes of 10 percent or more during May, June, and August through October; (4) over the monthly water temperature exceedance distributions, similar or lower temperatures most of the time; and (5) similar monthly probabilities of water temperatures occurring within the specified range during all months evaluated, but with a slight increase in the probability of occurring within the range during May (due to reduced water temperatures under J602F3 ELD).
- Overall, in consideration of all flow and water temperature–related impact indicators, habitat conditions are expected to be similar for striped bass under J602F3 ELD relative to E504.

Table 3.1-16. Net Difference in Flow and Water Temperature Index Value Exceedance Probabilities for Striped Bass

Lifestage	Evaluation Period	Indicator of Potential Impact	Location	Metric		Range	Net Change in Probability of Exceedance under J602F3 ELD relative to E504 ELD											
			Description	Value	%		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Attraction	May and June	Mean Daily Flow (cfs)	Mouth of the American River (RM 1)	>1500 cfs		All Years								1	1			
Adult Immigration and Spawning	April through June	Mean Daily Water Temperature (°F)	American River at Watt Avenue	59-68[1]		All Years							0	-1	3			
Juvenile Rearing	May through October	Mean Daily Water Temperature (°F)	American River at Watt Avenue	61-71		All Years	0							-3	0	1	1	0

[1]Water temperature ranges are evaluated by calculating the net change in the probability of water temperatures occurring within the specified range.

Appendix D: Fisheries, Part 2

Model Appendices

Appendix 7A

1.1 Environmental Setting

This section describes the environmental setting related to fisheries and aquatic ecosystems in waterbodies that could be influenced by implementation of the proposed Folsom Dam Water Control Manual (WCM) Update that is being analyzed in this document by the U.S. Army Corps of Engineers (USACE). The following sections describe the aquatic habitats and fish populations in the Action Area, which includes the Primary Study Area of the lower American River as well as the “Far-Field” areas, including the Sacramento River, the Feather River, and the Sacramento–San Joaquin Delta (Delta) and the Yolo Bypass.

1.1.1 Fisheries Resources in the Action Area

This section describes specific conditions (e.g., species composition, spatial distribution, and temporal distribution) for each of the affected major waterbodies with special-status fish species in the Action Area. Life histories and lifestage-specific environmental considerations for several species can differ slightly among the waterbodies. Any differences are noted in the discussions of the individual waterbodies. If there are not any noted differences, USACE has assumed that the species’ life history and environmental considerations are generally similar to the general discussions in the following Section 1.1.1.1, *Overview of Fish Species*.

1.1.1.1 Overview of Fish Species

Special-status fish species considered in this document are those that are Federally or state listed as threatened or endangered, species that are proposed for Federal or state listing as threatened or endangered, species classified as candidates for future Federal or state listing, Federal species of concern, or state species of special concern. USACE identified special-status fish species potentially occurring in the Action Area using U.S. Fish and Wildlife Service (USFWS) species lists for the Action Area and by reviewing environmental documents for other projects in the region. **Table 1** presents the special-status fish species that could occur within the Action Area and their Federal and state regulatory status, generally taken from the California Department of Fish and Wildlife (CDFW 2014). Table 1 also presents non-special-status fish species of recreational or commercial importance. **Table 2** indicates which species are evaluated in each waterbody in the Action Area.

Fish species of focused evaluation include those that are:

1. Federally and/or state-listed species and species proposed for Federal or state listing within the area; specifically:

   - Sacramento River winter-run Chinook salmon (Oncorhynchus tshawytscha) evolutionarily significant unit (ESU);
   - Central Valley spring-run Chinook salmon ESU;
   - Central Valley steelhead (*Oncorhynchus mykiss*) distinct population segment (DPS);
   - Delta smelt (Hypomesus transpacificus);

- Longfin smelt (Spirinchus thaleichthys); and
- Southern DPS of North American green sturgeon (*Acipenser medirostris*);

2. Federal species of concern and state species of special concern, specifically:
   - Central Valley fall-/late fall-run Chinook salmon ESU;
   - Green sturgeon;
   - Hardhead (Mylopharodon conocephalus);
   - River lamprey (*Lamptera ayresi*);
   - Pacific lamprey (*Entosphenus tridentatus*); and
   - Sacramento splittail (Pogonichthys macrolepidotus);
3. Federal or state candidate species for listing (longfin smelt); and
4. Species that are recreationally or commercially important, specifically:
   - Fall-run Chinook salmon;
   - Steelhead;
   - White sturgeon (Acipenser transmontanus);
   - American shad (*Alosa sapidissima*); and
   - Striped bass (*Morone saxatilis*).

Table 1. Special-Status Fish Species and Species of Recreational or Commercial Importance in the Action Area.

Common Name	Status
• Sacramento River winter-run Chinook salmon ESU	Federally and state endangered
• Central Valley spring-run Chinook salmon ESU	Federally and state threatened
• Central Valley fall-/late fall-run Chinook salmon ESU	Federal species of concern State species of special concern
• Central Valley steelhead DPS	Federally threatened
• Southern DPS of North American green sturgeon	Federally threatened State species of special concern
• Delta smelt	Federally threatened State endangered
• Longfin smelt	Federal candidate[1] State threatened
• Hardhead	State species of special concern
• Pacific lamprey	Federal species of concern[2]
• River lamprey	State species of special concern
• Sacramento splittail	State species of special concern
• White sturgeon	Recreational and/or commercial importance
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

[1] Federal candidate status is for the San Francisco Bay-Delta DPS of longfin smelt.

[2] Although not referenced as a federal species of concern in CDFW (2014), the Oregon USFWS office considers Pacific lamprey a species of concern. The Sacramento USFWS office does not maintain a species of concern list.

Table 2. Waterbodies and Fish Species of Focused Evaluation in the Lower American River and Far-Field Areas.

	Lower American River	Sacramento River	Feather River	Yolo Bypass	Delta
Sacramento River winter-run Chinook salmon ESU		✓		✓	✓
Central Valley spring-run Chinook salmon ESU	✓	✓	✓	✓	✓
Central Valley fall- and late fall-run Chinook salmon ESU	✓	✓	✓	✓	✓
Central Valley steelhead DPS	✓	✓	✓	✓	✓
North American green sturgeon (southern DPS)		✓	✓	✓	✓
Delta smelt*				✓	✓
Longfin smelt					✓
River lamprey	✓	✓	✓		✓
Pacific lamprey	✓	✓	✓		✓
Sacramento splittail				✓	
Hardhead	✓	✓	✓		
White sturgeon		✓	✓	✓	✓
American shad	✓	✓	✓		✓
Striped bass	✓	✓	✓		✓

USACE has placed special emphasis on these fish species of focused evaluation to facilitate compliance with applicable laws, particularly the Federal and state Endangered Species Acts (ESA), and to be consistent with Federal and state restoration/recovery plans and National Marine Fisheries Service (NMFS) and USFWS Biological Opinions (BO). This focus is consistent with:

1. The NMFS (2009) *Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project*;
2. The NMFS (2014) Central Valley salmon and steelhead recovery plan;
3. CALFED's (2000) Ecosystem Restoration Program Plan and Multi-Species Conservation Strategy;

4. The programmatic determinations for the CALFED Bay-Delta Program, which include the California Department of Fish and Game's (CDFG) Natural Community Conservation Planning Act (NCCPA) approval and the programmatic BOs issued by NMFS and USFWS;
5. USFWS's 1997 Draft Anadromous Fish Restoration Program (AFRP), which identifies specific actions to protect anadromous salmonids;
6. CDFG's 1996 Steelhead Restoration and Management Plan for California, which identifies specific actions to protect steelhead;
7. Sacramento County's American River Parkway Plan (Sacramento County 2008); and
8. CDFG's Restoring Central Valley Streams: A Plan for Action (CDFG 1993), which identifies specific actions to protect salmonids. Improvement of habitat conditions for these fish species of focused evaluation could protect or enhance conditions for other fish resources, including native resident species.

Evaluating impacts on fishery resources requires understanding fish species' life histories, spatial and temporal distributions, and lifestage-specific environmental requirements. General information is provided below regarding legal status and life histories of fish species of focused evaluation in the Action Area.

1.1.1.1.1 Chinook Salmon

Chinook salmon is the most important commercial species of anadromous fish in California. Chinook salmon have evolved a broad array of life history patterns that allow them to take advantage of diverse riverine conditions throughout the year. Chinook salmon exhibit two generalized freshwater life history types (M.C. Healey 1991).

- Adult "stream-type" Chinook salmon enter freshwater months before spawning, while juveniles reside in freshwater for a year or more prior to emigrating.
- "Ocean-type" Chinook salmon spawn soon after entering freshwater and migrate to the ocean as fry or parr within their first year.

Both winter-run and spring-run Chinook salmon tend to enter freshwater in a sexually immature state and delay spawning for weeks or months while holding in freshwater. Fall-run Chinook salmon enter freshwater at an advanced stage of maturity, and generally spawn within a few days or weeks of freshwater entry (M.C. Healey 1991).

Four principal life history variants are recognized in the Central Valley and are named for the timing of their adult spawning runs: fall-run, late fall-run, winter-run, and spring-run. The Sacramento River supports all four runs of Chinook salmon. The larger tributaries to the Sacramento River (American, Feather, and Yuba Rivers) and rivers in the San Joaquin Basin also provide habitat for one or more of these runs. Discussions of each of these runs are provided below.

SACRAMENTO RIVER WINTER-RUN CHINOOK SALMON ESU

Winter-run Chinook salmon occur only in the Sacramento River; therefore, this species account is specific to the Sacramento River. The Sacramento River winter-run Chinook salmon ESU is listed as endangered under both the Federal and state ESAs. In 1993, critical habitat for winter-run Chinook salmon was designated to include:

1. The Sacramento River from Keswick Dam (river mile [RM] 302) to Chipps Island (RM 0) at the westward margin of the Sacramento–San Joaquin Delta;
2. All waters from Chipps Island westward to Carquinez Bridge, including Honker Bay, Grizzly Bay, Suisun Bay, and Carquinez Strait;
3. All waters of San Pablo Bay westward of the Carquinez Bridge; and
4. All waters of San Francisco Bay north of the San Francisco–Oakland Bay Bridge (NMFS 2014).

On August 15, 2011, after a second 5-year status review (76 Federal Register [FR] 50447), NMFS determined that the ESU had continued to decline since 2005, with a negative point estimate for the 10-year trend. However, the current population size reportedly still falls within the low-risk criterion, and the 10-year average rate of hatchery fish spawning in the river (about 8 percent) remains below the low-risk threshold for hatchery influence (Williams et al. 2011).

Winter-run Chinook salmon are unique because they spawn during the summer when air temperatures usually approach their yearly maximum (NMFS 2014). Hence, primary spawning and rearing habitats for winter-run Chinook salmon are now confined to the coldwater areas between Keswick Dam (RM 302) and Red Bluff Diversion Dam (RBDD) (RM 243) (NMFS 2014). The lower reaches of the Sacramento River, Sacramento–San Joaquin River Delta (Delta), and San Francisco Bay serve as migration corridors for the upstream migration of adult and downstream migration of juvenile winter-run Chinook salmon.

According to NMFS (2009, 2014), adult winter-run Chinook salmon immigration (upstream spawning migration) in the Sacramento River occurs from November through July. The majority of the run passes RBDD from January through May, with the peak passage occurring in mid-March (Hallock and Fisher 1985 as cited in NMFS 2009), although the timing of migration can vary somewhat as a result of changes in river flows, dam operations, and water year type (Yoshiyama et al. 1998 and Moyle 2002, both as cited in NMFS 2009). Winter-run Chinook salmon spawn primarily between mid-April and mid-August, with the peak spawning generally occurring during June (Vogel and Marine 1991). Winter-run Chinook salmon embryo incubation in the Sacramento River can extend into September during wet water years (Vogel and Marine 1991).

During the Chinook salmon juvenile rearing and downstream movement lifestage, salmonids prefer stream margin habitats with sufficient depths and velocities to provide suitable cover and foraging opportunities. Juvenile Chinook salmon reportedly use river channel depths ranging from 0.9 foot to 2.0 feet, and most frequently use water velocities ranging from 0 feet per second (ft/s) to 1.3 ft/s (Raleigh et al. 1986). The water temperature reported for maximum growth of juvenile Central Valley Chinook salmon is 66.2 degrees Fahrenheit (°F) (Cech and Myrick 1999).

Winter-run Chinook salmon fry rearing in the upper Sacramento River exhibit peak abundance during September, with fry and juvenile emigration past RBDD occurring as early as mid-July and sometimes continuing through March in dry water years (NMFS 1997 and Vogel and Marine 1991, both as cited in NMFS 2014). From 1995 to 1999, all winter-run Chinook salmon outmigrating as fry passed RBDD by October, and all outmigrating pre-smolts and smolts passed RBDD by March (Martin et al. 2001 as cited in NMFS 2014). Juvenile emigration past Knights Landing occurs primarily between November and March, peaking in December, with some emigration continuing through May in some years (Snider and Titus 2000a). The numbers of juvenile winter-run Chinook salmon caught in rotary screw traps at the Knights Landing sampling location were reportedly dependent on the magnitude of flows during the emigration period (Snider and Titus 2000a). Additional information on the life history and habitat requirements of winter-run Chinook salmon is available in NMFS (2009, 2014).

According to NMFS (2014), juvenile winter-run Chinook salmon can occur in the Delta primarily from November through early May, based on size-at-date criteria from trawl data in the Sacramento River at West Sacramento (RM 57) (USFWS 2001). Juveniles reportedly remain in the Delta until they reach a fork length (FL) of about 118 millimeters (mm) and are from 5 to 10 months of age. Emigration to the ocean begins as early as November and continues through May (Fisher 1994 and Myers et al. 1998, both as cited in NMFS 2014).

CENTRAL VALLEY SPRING-RUN CHINOOK SALMON ESU

Because of the significantly reduced range and small size of remaining spring-run Chinook salmon populations, the Central Valley spring-run Chinook salmon ESU was listed as a threatened species under both the Federal and state ESAs (64 FR 50393, September 16, 1999). Critical habitat was designated on September 2, 2005 (70 FR 52488) and includes the mainstem Sacramento River from Chipps Island (RM 0) to downstream of Keswick Dam, and stream reaches such as those of the Feather and Yuba Rivers; Big Chico, Butte, Deer, Mill, Battle, Antelope, and Clear Creeks; and portions of the northern Delta.

Sacramento River spring-run Chinook salmon are known to use the Sacramento River as a migratory corridor to spawning areas in upstream tributaries. Historically, spring-run Chinook salmon did not use the mainstem Sacramento River downstream of the Shasta Dam site except as a migratory corridor to and from headwater streams (CDFG 1998).

As reported by NMFS (2014), adult spring-run Chinook salmon leave the ocean to begin their upstream migration in late January and early February (CDFG 1998) and enter the Sacramento River between March and September, primarily in May and June (Moyle 2002; Yoshiyama et al. 1998). Lindley et al. (2007) state that adult spring-run Chinook salmon migrate from the Sacramento River into spawning tributaries primarily between mid-April and mid-June (NMFS 2009). Butte Creek spring-run Chinook salmon adults migrate from February through June, with the peak occurring in mid-April (SJRRP 2010).

The primary characteristic distinguishing spring-run Chinook salmon from the other runs of Chinook salmon is that adult spring-run Chinook salmon hold in areas proximal to spawning grounds during the summer until their eggs fully develop and become ready for spawning. Adult spring-run Chinook salmon immigration and holding in the Central Valley occurs from mid-February through September (CDFG

1998; Lindley et al. 2004). The entire potential spring-run Chinook salmon holding and spawning habitat in the mainstem Sacramento River is located between Keswick Dam and RBDD (CDFG 1998).

Spring-run Chinook salmon spawning occurs during September and October depending on water temperatures (NMFS 2009). Spawning and embryo incubation has been reported to occur primarily during September through mid-February, with spawning peaking in mid-September (DWR 2004b; Moyle 2002; Vogel and Marine 1991). Survival of Chinook salmon eggs and alevins is believed to decrease rapidly when incubation temperatures exceed about 56°F for much or all of the incubation period (Reclamation 1991). The upper optimum water temperature for Chinook salmon egg development is reported to be 56°F (NMFS 1993). For maximum survival of Chinook salmon eggs and yolk-sac larvae in the Central Valley, USFWS (1995) suggested an upper water temperature value of 56.0°F. Water temperatures above 56°F reportedly result in significantly higher Chinook salmon alevin mortality in the Sacramento River (USFWS 1999). Consistently higher egg losses resulted at water temperatures above 60.0°F than at lower temperatures (Johnson and Brice 1953).

Boles et al. (1988) found that eggs incubated at constant water temperatures greater than 60°F or less than 38°F have suffered high mortalities. Survival increases, however, for eggs taken at high water temperatures but incubated at temperatures that gradually decline to the mid-40°F-to-mid-50°F range. Mortalities in fry were reduced to low levels when eggs were incubated at constant temperatures of from 50°F to 55°F, or under declining temperatures from initial incubation temperatures up to 60°F.

Spring-run Chinook salmon fry emerge from the gravel from November to March (Moyle 2002) and have highly variable emigration timing (NMFS 2009). Some juveniles begin emigrating soon after emergence from the gravel, whereas others over-summer and emigrate as yearlings with the onset of intense fall storms (CDFG 1998). The emigration period for spring-run Chinook salmon generally extends from November to early May, with up to 69 percent of the young-of-the-year (YOY) fish outmigrating through the lower Sacramento River and Delta during this period (CDFG 1998 as cited in NMFS 2009). As described in NMFS (2009), juvenile spring-run Chinook salmon emigration at RBDD occurs primarily from November through January and can extend into mid-May. Peak movement of yearling spring-run Chinook salmon in the Sacramento River at Knights Landing occurs in December, and again in March and April for YOY juveniles (NMFS 2009). However, juveniles also have been observed between November and the end of May (Snider and Titus 2000a).

Water temperature is generally considered to be the most limiting factor for the juvenile rearing lifestage, particularly during late spring. Water temperatures reported to be optimal for rearing Chinook salmon fry and juveniles are between 45°F and 65°F (NMFS 2002; Rich 1987; Seymour 1956). Raleigh et al. (1986) reviewed the available literature on Chinook salmon thermal requirements and suggested an upper limit of 75°F and a range of suitable water temperatures of about 53.6°F to 64.4°F. The smoltification process can become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997).

Additional information on the life history and habitat requirements of spring-run Chinook salmon can be found in NMFS (2009, 2011, 2014).

CENTRAL VALLEY FALL-/LATE FALL-RUN CHINOOK SALMON ESU

Central Valley fall-run and late fall-run Chinook salmon are considered by NMFS to be the same ESU (64 FR 50394). NMFS determined that listing this ESU as threatened was not warranted (64 FR 50394) but subsequently classified it as a species of concern because of specific risk factors, including population size and hatchery influence (69 FR 19975). The Central Valley fall-run and late fall-run Chinook salmon ESU also is listed as a state species of special concern (CDFW 2014). The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin River basins and their tributaries east of Carquinez Strait, California. The Central Valley fall-run and late fall-run Chinook salmon ESU is not listed as threatened or endangered, so critical habitat has not been designated.

Annual run sizes of fall-run and late fall-run Chinook salmon are reported in GrandTab, a database administered by CDFW for the Central Valley that includes reported run size estimates from 1952 through 2013 for fall-run Chinook salmon and from 1970 through 2013 for late fall-run Chinook salmon (CDFW 2014). The Central Valley fall-/late fall-run Chinook salmon ESU has displayed broad fluctuations in adult abundance. Between 1959 and 1970, escapement of fall-run Chinook salmon in the mainstem Sacramento River exceeded 100,000 fish every year except for one year (1967). Since 1970, escapement in the mainstem Sacramento River generally has not exceeded 100,000 (Reclamation 2008a).

More recent estimates of fall-run Chinook salmon in the Sacramento River and its tributaries have ranged from 28,669 in 2009 to 738,652 in 2002. (This number does not include the lower Yuba and Feather Rivers because GrandTab does not distinguish between fall-run and spring-run Chinook salmon in-river spawners and does not include the Feather River Fish Hatchery [FRFH]). Since 2009, fall-run Chinook salmon escapement in the Sacramento River and its tributaries increased to over 100,000 spawners during 2010 through 2012, and over 300,000 spawners during 2013 (CDFW 2014). Hatchery escapement of fall-run Chinook salmon also has increased in recent years, from about 20,000 during 2007 through 2009 to over 100,000 during 2012 and 2013 (CDFW 2014).

As a result of very low returns of fall-run Chinook salmon to the Central Valley in 2007 and 2008, there was a complete closure of the commercial and recreational ocean Chinook salmon fishery in 2008 and 2009 (Lindley et al. 2009). In April 2009, the Pacific Fishery Management Council (PFMC) and NMFS adopted a closure of all commercial ocean salmon fishing through April 30, 2010, and placed restrictions on inland salmon fisheries (CDFG 2009). Fishing in 2010 was also constrained for the same reasons as in the previous two years. In 2011, both CDFW and PFMC approved reopening the commercial and recreational fishing season.

Although Central Valley fall-run and late fall-run Chinook salmon are considered to be the same ESU, because they differ in lifestage-specific timing, they are discussed and considered separately in this evaluation.

Fall-run Chinook Salmon

In the Central Valley, fall-run Chinook salmon are the most numerous of the four salmon runs and continue to support commercial and recreational fisheries of significant economic importance. Fall-run Chinook salmon is currently the largest run of Chinook salmon using the Sacramento River system.

Adult fall-run Chinook salmon enter the Sacramento and San Joaquin Rivers from July through December (Reclamation 2008a). Migration of adult fall-run Chinook salmon into the Sacramento River Basin reportedly begins in July, peaks in October, and ends in December (Vogel 2011). Unlike spring-run Chinook salmon, adult fall-run Chinook salmon do not exhibit an extended over-summer holding period, based on studies conducted in the lower Yuba River (RMT 2010, 2013). Rather, they stage for a relatively short period of time prior to spawning. Fall-run Chinook salmon generally spawn from October through December (Reclamation 2008a; Vogel 2011). Fall-run Chinook salmon spawning in the mainstem Sacramento River generally occurs between Keswick Dam and Princeton (CDFW 2013).

In general, the fall-run Chinook salmon spawning and embryo incubation period extends from October through March (NMFS 2004; Vogel and Marine 1991).

In the Sacramento River Basin, fall-run Chinook salmon juvenile emigration occurs from January through June (Moyle 2002; Vogel 2011; Vogel and Marine 1991). Juvenile fall-run Chinook salmon emigration at RBDD begins as early as December, peaks in January and February during winter flow events, decreases through the spring, and extends to as late as June or July (Gaines and Martin 2001 as cited in USFWS and CDFG 2012).

Late Fall-run Chinook Salmon

Central Valley late fall-run Chinook salmon escapement is dominated by spawners in the Sacramento River above RBDD and hatchery production at Coleman National Fish Hatchery on Battle Creek, with varying numbers of spawners in the Sacramento River downstream of RBDD and relatively few spawners in Battle Creek (CDFW 2014).

Adult immigration of late fall-run Chinook salmon in the Sacramento River generally begins in late October and extends through March (USFWS and CDFG 2012). Spawning has been suggested to occur in tributaries to the upper Sacramento River (e.g., Battle, Cottonwood, Clear, Big Chico, Butte and Mill Creeks) and the Feather and Yuba Rivers, although these fish do not make up a large proportion of the late fall-run Chinook population (USFWS 1995). Late fall-run Chinook salmon spawning generally occurs from January through April in the mainstem Sacramento River, primarily from Keswick Dam to RBDD (Moyle 2002; NMFS 2004; Vogel and Marine 1991).

Late fall-run Chinook salmon embryo incubation can extend from January through June (USFWS and CDFG 2012; Vogel and Marine 1991). Post-emergent fry and juveniles rear and disperse from their spawning and rearing grounds in the upper Sacramento River and its tributaries during the April through December period, with low rates of emigration occurring from July into the fall, although fall and winter freshets can increase emigration rates (Vogel 2011; Vogel and Marine 1991). According to USFWS and CDFG (2012), juvenile late-fall run Chinook salmon rear in the upper Sacramento River from late April through the following winter before emigrating to the estuary. Late fall-run Chinook salmon yearlings can use flow events as migration cues during the late-fall and winter, and some individuals could continue to emigrate for up to 5 months (Reclamation 2008a).

1.1.1.1.2 Central Valley Steelhead DPS

NMFS listed the Central Valley steelhead DPS as threatened under the Federal ESA on March 19, 1998, and reaffirmed its threatened status on January 5, 2006 (71 FR 834). On February 16, 2000, NMFS published a final rule designating critical habitat for Central Valley steelhead (65 FR 7764). Critical habitat was designated to include all river reaches accessible to listed steelhead in the Sacramento and San Joaquin Rivers and their tributaries in California. NMFS proposed new critical habitat for spring-run Chinook salmon and Central Valley steelhead on December 10, 2004 (69 FR 71880) and published a final rule designating critical habitat for these species on September 2, 2005. This critical habitat designation includes the Action Area.

Historical information on Central Valley steelhead populations is limited. Steelhead ranged throughout accessible tributaries and headwaters of the Sacramento and San Joaquin Rivers before major dam construction, water development, and other watershed disturbances. Many of the freshwater habitat factors cited for declines in spring-run Chinook salmon runs generally apply to steelhead as well, because of their need for tributaries and headwater streams where cool, well-oxygenated water is available year-round. Historical declines in steelhead abundance have been attributed largely to dams that eliminated access to most of their historic spawning and rearing habitat and restricted steelhead to unsuitable habitat below the dams. Other factors that have contributed to the decline of steelhead and other salmonids include habitat modification, over-fishing, disease and predation, inadequate regulatory mechanisms, climate variation, and artificial propagation (NMFS 1996).

Adult steelhead immigration into Central Valley streams typically begins in August, continues into March or April (McEwan 2001; NMFS 2014), and generally peaks during January and February (Moyle 2002). Adult steelhead immigration can occur during all months of the year at RBDD, with upstream migration occurring primarily during September and October (NMFS 2009). In Mill and Deer Creeks, adult steelhead immigration has been represented to not occur from July through September, with peak migration occurring from October through mid-March (NMFS 2009).

Water temperatures can affect the timing of adult spawning and migrations and can affect the egg viability of holding females. Few studies have been published that examine the effects of water temperature on either immigration or holding, and none have been recent (Bruin and Waldsdorf 1975; McCullough et al. 2001). The available studies suggest that adverse effects could occur to immigrating and holding steelhead at water temperatures that exceed the mid-50°F range and that immigration could be delayed if water temperatures approach about 70°F (Bruin and Waldsdorf 1975; McCullough et al. 2001).

Steelhead reportedly spawn from December through April, with peaks from January though March, in small streams and tributaries (NMFS 2009). Steelhead spawning in the mainstem Sacramento River is probably limited to the area upstream of RBDD, although specific information regarding steelhead spawning within the mainstem Sacramento River is limited because of lack of monitoring (NMFS 2004, 2009). Water depth range preference for spawning steelhead has been most frequently observed between 0.3 foot and 4.9 feet (Moyle 2002). The reported preferred water velocity for steelhead spawning is 1.5 ft/s to 2.0 ft/s (USFWS 1995).

Optimal steelhead spawning temperatures have been reported to range from 39°F to 52°F (CDFG 1991). The upper water temperature value for optimal egg incubation has been reported as 52°F (Humpesch 1985; NMFS 2001, 2002; Reclamation 1997; USFWS 1995). In the lower American River, fish surveys that identified newly emerged steelhead through May indicated that incubating steelhead embryos do survive at water temperatures above the reported preferred range (NMFS 2007). Most of the studies of *O. mykiss* embryo incubation conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), and some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F could represent an inflection point between properly functioning water temperature conditions and the conditions that cause negative effects on steelhead spawning and embryo incubation.

Embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57.0°F (Rombough 1988; Velsen 1987). Thus, from the available literature, water temperatures in the low-50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high-50°F range and above. McEwan (2001) reports that steelhead fry and fingerlings rear and move downstream in the Sacramento River year-round, although most steelhead smolts reportedly emigrate from January through June.

Based on CDFW sampling at Knights Landing, juvenile steelhead emigration occurs primarily from January through May with peaks during March and April (Snider and Titus 2000a). Juvenile steelhead emigration at Knights Landing has been variously reported as not occurring from mid-May through mid-December, or June through October (NMFS 2009). Although the reported preferred water temperatures for fry and juvenile steelhead rearing range from 45°F to 65°F, most of the literature on steelhead smolting suggests that water temperatures of 52°F (Adams et al. 1975; Myrick and Cech 2001; Rich 1987) or less than 55°F (EPA 2003; McCullough et al. 2001; Wedemeyer et al. 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur.

1.1.1.1.3 Green Sturgeon

After completion of NMFS's North American green sturgeon status review (Adams et al. 2002), NMFS determined that green sturgeon consists of a northern DPS and southern DPS but that neither warranted listing under the ESA. However, because of uncertainties in the structure and status of both DPSs, NMFS added both the northern and southern DPSs to NMFS's species of concern list in 2004 (69 FR 19975). After a legal challenge to NMFS's determination that neither DPS warranted listing under the ESA, NMFS produced an updated status review in 2005, proposed the southern DPS to be listed as threatened under the ESA, and made a final rule to list the southern DPS as threatened in 2006 (71 FR 17757).

Within the Action Area, southern DPS green sturgeon occur only in the Sacramento and Feather Rivers and in the Delta region. On April 7, 2006, a final rule was issued and adopted to list the southern DPS as threatened under the ESA. The final rule became effective June 6, 2006 (71 FR 17757). NMFS (2005) states that the main factor for the decline of the southern DPS of green sturgeon is the reduction of spawning habitat in the Sacramento and Feather Rivers. On October 9, 2009, NMFS (74 FR 52300) designated critical habitat for the southern DPS of North American green sturgeon. In the Central Valley, critical habitat for green sturgeon includes the Sacramento River, lower Feather River, lower Yuba River, the Sacramento–San Joaquin Delta, and the San Francisco Estuary.

Green sturgeon adults in the Sacramento River are reported to begin their upstream spawning migrations into freshwater during late February, prior to spawning between March and July, with peak spawning believed to occur between April and June (Adams et al. 2002). NMFS (2009) reports that, based on recent data gathered from acoustically tagged adult green sturgeon, they migrate upstream during May as far as the mouth of Cow Creek near Bend Bridge on the Sacramento River. Heublein et al. (2009) observed that green sturgeon enter San Francisco Bay in March and April and migrate rapidly up the Sacramento River to the region between Glenn Colusa Irrigation District (GCID) and Cow Creek. The fish lingered at these regions at the apex of their migration for 14 to 51 days and presumably engaged in spawning behavior before moving back downriver (Heublein et al. 2009). Brown (2007) suggested that spawning in the Sacramento River can occur from April to June and that the potential spawning period can extend from late April through July, as indicated by the rotary screw trap data at RBDD from 1994 to 2000.

Since 2008 and including 2011 data, green sturgeon spawning habitat has been confirmed within a 58-mile reach of the Sacramento River extending from about RM 207 to RM 265 (Poytress et al. 2012). After spawning, the adults hold over in the upper Sacramento River between RBDD and GCID until November (Klimley et al. 2007). Some adult North American green sturgeon rapidly leave the system following their suspected spawning activity and re-enter the ocean in early summer (Heublein 2006).

Larvae and juvenile green sturgeon appear to be nocturnal (Cech et al. 2000), which could protect them from downstream displacement (LCFRB 2004). Green sturgeon larvae and juveniles (up to day 84) forage day and night, but activity is reported to peak at night. At days 110 to 118, juvenile green sturgeon are reported to move downstream at night, and habitat preference suggests that juveniles prefer deep pools with low light and some rock structure (Kynard et al. 2005). Wintering juveniles forage actively at night between dusk and dawn and are inactive during the day, seeking the darkest available habitat (Kynard et al. 2005).

Juvenile green sturgeon migrate downstream and feed mainly at night. Juvenile green sturgeon are taken in traps at RBDD and the GCID diversion in Hamilton City, primarily in May through August, with peak counts reported for June and July (68 FR 4433). Juvenile emigration can reportedly extend through September (Environmental Protection Information Center et al. 2001).

1.1.1.1.4 Delta Smelt

USFWS listed delta smelt as a threatened species under the ESA in March 1993 (58 Code of Federal Regulations [CFR] 12854), and critical habitat for delta smelt has been designated within the area. Critical habitat for delta smelt is defined as follows:

> *Areas and all water and all submerged lands below ordinary high water and the entire water column bounded by and contained in Suisun Bay (including the contiguous Grizzly and Honker Bays); the length of Goodyear, Suisun, Cutoff, First Mallard (Spring Branch), and Montezuma Sloughs; and the existing contiguous waters contained within the Delta.* (USFWS 1994)

Delta smelt also is listed as threatened under the California Endangered Species Act (CESA).

Delta smelt is a euryhaline fish that is native to the Sacramento–San Joaquin Estuary. As a euryhaline species, delta smelt tolerate wide-ranging salinities but rarely occur in waters with salinities greater than 10 parts per thousand (ppt) to 14 ppt (Baxter et al. 1999). Similarly, delta smelt tolerate a wide range of water temperatures, as shown by their being found at water temperatures from 42.8°F to 82.4°F (Moyle 2002). Delta smelt are typically found within Suisun Bay and the lower reaches of the Sacramento and San Joaquin Rivers, although they are occasionally collected within the Carquinez Strait and San Pablo Bay.

The delta smelt is a small, slender-bodied fish with a typical adult size of 2 to 3 inches, although some individuals can reach lengths of 5 inches.

During the late winter and spring, delta smelt migrate upstream to spawn. Shortly before spawning, adults migrate upstream from the brackish-water estuarine areas into river channels and tidally influenced backwater sloughs.

In the Sacramento–San Joaquin River system, delta smelt spawning reportedly occurs from February through May, with embryo incubation extending through June (Wang 1986). Delta smelt are thought to spawn in shallow fresh or slightly brackish waters in tidally influenced backwater sloughs and channel edgewaters (Wang 1986). Although most delta smelt spawning seems to take place at 44.6°F to 59°F, gravid delta smelt and recently hatched larvae have been collected at 59°F to 71.6°F. Thus, it is likely that spawning can take place over the entire range of 44.6°F to 71.6°F (Moyle 2002).

Females generally produce between 1,000 and 2,600 eggs (Bennett 2005), which adhere to vegetation and other hard substrates. Larvae hatch in between 10 and 14 days (Wang 1986) and are planktonic (float with water currents) as they are transported and dispersed downstream into the low-salinity areas within the western Delta and Suisun Bay (Moyle 2002).

Delta smelt grow rapidly, with the majority of smelt living only 1 year. Most adult smelt die after spawning in the early spring, although they might be capable of spawning twice during a season (Bennett 2005; Brown and Kimmerer 2001; Moyle 2002). Delta smelt feed entirely on zooplankton. For the majority of their 1-year lifespan, delta smelt inhabit areas within the western Delta and Suisun Bay characterized by salinities of about 2 ppt. Historically, they have been abundant in low (around 2-ppt) salinity habitats. Delta smelt occur in open surface waters and shoal areas (USFWS 1994).

Because delta smelt typically have a 1-year lifespan, their abundance and distribution have been observed to fluctuate substantially within and among years. Delta smelt abundance appears to be reduced during years characterized by either unusually dry years with exceptionally low outflows (e.g., 1987 through 1991) or unusually wet years with exceptionally high outflows (e.g., 1982 and 1986). Other factors thought to affect the abundance and distribution of delta smelt within the Bay-Delta estuary include entrainment in water diversions, changes in the zooplankton community resulting from introductions of non-native species, and potential effects of toxins.

1.1.1.1.5 Longfin Smelt

Longfin smelt were listed as threatened under the CESA in 2009, and the San Francisco Bay-Delta DPS (Bay-Delta DPS) of longfin smelt was designated as a Federal candidate species by USFWS in 2012.

In response to a 2007 petition to list the Bay-Delta DPS of longfin smelt as endangered or threatened under the ESA, USFWS determined in 2009 that the Bay-Delta population of longfin smelt did not meet the discreteness element of USFWS's DPS policy and, therefore, was not a valid DPS and was not a listable entity under the ESA. In response to a legal complaint regarding USFWS's 2009 determination, USFWS conducted a more comprehensive rangewide status review of longfin smelt and further evaluated whether the Bay-Delta population of longfin smelt constitutes a DPS. In 2012, USFWS determined that listing the Bay-Delta DPS of longfin smelt was warranted, but the listing was precluded by higher-priority actions to amend the List of Endangered and Threatened Wildlife and Plants. Therefore, USFWS added the Bay-Delta DPS of longfin smelt to the USFWS candidate species list.

Longfin smelt is a euryhaline species. This is particularly evident in the Delta, where longfin smelt are found in areas ranging from almost pure seawater upstream to areas of pure freshwater. In this system, they are most abundant in San Pablo and Suisun Bays (Moyle 2002). They tend to inhabit the middle to lower portion of the water column. Longfin smelt spend the early summer in San Pablo and San Francisco Bays, generally moving into Suisun Bay in August. Most spawning is from February to April at water temperatures of 44.6°F to 58.1°F (Moyle 2002). The majority of adults perish following spawning.

Longfin smelt eggs have adhesive properties and are probably deposited on rocks or aquatic plants upon fertilization. Newly hatched longfin smelt are swept downstream into more brackish parts of the estuary. Strong Delta outflow is thought to correspond with longfin smelt survival, as higher flows transport longfin smelt young to more-suitable rearing habitat in Suisun and San Pablo Bays (Moyle 2002). Longfin smelt are rarely observed upstream of Rio Vista in the Delta (Moyle et al. 1995).

1.1.1.1.6 River Lamprey

River lamprey is not listed under the Federal ESA or the CESA, although it is identified as a California species of special concern.

River lampreys have generally not been studied in California (Moyle 2002). Most of the available information on their life history is based on studies in British Columbia (UC Davis 2012). Adult river lampreys are reportedly fish parasites in California rivers (Hart 1973, Kimsey and Fisk 1964, and Withler 1955, all as cited in Wang 1986). Their most common prey species are believed to be herring and salmon (UC Davis 2012).

Adult river lampreys migrate into freshwater in the fall and spawn during the winter or spring in small tributary streams, although the timing and extent of their migration in California is poorly known (UC Davis 2012). Wang (1986) reports that adult river lampreys spawn from April to June in small tributary streams, while Moyle (2002) reports that river lampreys spawn during February through May. Adults create saucer-shaped depressions in gravelly riffles for spawning by moving rocks with their mouths (UC Davis 2012).

Larval river lampreys (ammocoetes) burrow into sandy or muddy substrates near banks (Hart 1973 and Scott and Crossman 1973, both as cited in Wang 1986) and remain in silt-sand backwaters and eddies (UC Davis 2012). The ammocoete lifestage has been reported to last several years (Hart 1973 as cited in Wang 1986) and is believed be about 3 to 5 years (Moyle 2002). During the final stages of metamorphosis, ammocoetes congregate immediately upriver from saltwater and enter the ocean during late spring (Moyle et al. 1995), which indicates that downstream migration of juveniles in the Sacramento River can occur during the winter through spring.

River lampreys are reported to spawn at water temperatures ranging from 55.4°F to 56.3°F (Wang 1986), after which the adults die. Studies addressing the thermal requirements of early lifestages of Pacific and river lampreys have been conducted for the Columbia River Basin (Meeuwig et al. 2005). However, because of river lampreys' scarcity and the consequent inability to evaluate their early lifestage thermal requirements, river lampreys were not assessed. Laboratory studies and analyses did suggest, however, that consistently high survival and low occurrence of embryonic developmental abnormalities occur in Pacific lampreys at water temperatures ranging from 50°F to 64.4°F, with a significant decrease in survival and increase in developmental abnormalities at 71.6°F. Presumably, the adults need clean, gravelly riffles in permanent streams for spawning, while the ammocoetes (i.e., larvae) require sandy backwaters or stream edges in which to bury themselves, where water quality is continuously good and water temperatures do not exceed 77°F.

Ammocoetes begin their transformation into adults when they are about 12 centimeters (cm) (4.7 inches) total length (TL) during the summer. The process of metamorphosis can take 9 to 10 months, the longest known for any lamprey species. Lampreys in the final stages of metamorphosis congregate immediately upriver from saltwater and enter the ocean in late spring. Adults apparently spend only 3 to 4 months in saltwater, where they grow rapidly, reaching 25 to 31 cm (9.8 to 12.2 inches) TL (Moyle 2002).

1.1.1.1.7 Pacific Lamprey

Pacific lamprey is not listed under the Federal or California ESAs, although it is identified as a species of concern by the USFWS Portland office. Pacific lamprey was petitioned for protection under the ESA in 2003, but USFWS determined that insufficient population information existed to warrant its listing. Pacific lamprey is also considered a covered species in the Bay-Delta Conservation Plan (BDCP) (ICF 2013).

Adult Pacific lampreys typically migrate into freshwater streams between March and June (Moyle 2002), but upstream migrations have been observed during January and February (Entrix 1996 and Trihey and Associates 1996a, both as cited in Moyle 2002). Most upstream movement is reported to occur at night (Chase 2001 as cited in USFWS 2010; Moyle 2002).

Spawning reportedly generally occurs between March and July (USFWS 2010). The spawning habitat requirements of Pacific lampreys have not been well studied, but it is believed that adults need clean, gravelly riffles in permanent streams to spawn successfully and that these requirements are similar to those of salmonids (Moyle 2002; USFWS 2010). Moyle (2002) reported that, although historic spawning locations of Pacific lampreys are not known, they have been observed spawning in Deer Creek and likely could have migrated over 300 miles to spawn. Typically, spawning habitat is located near suitable ammocoete habitat, and low-to-moderate-gradient stream reaches with a mix of silt and cobble substrate are reported to potentially offer optimal spawning and rearing habitat (USFWS 2010).

Moyle (2002) reported that Pacific lamprey embryos hatch in about 19 days at 15 degrees Celsius (°C) (59°F). Eggs hatch into ammocoetes, spend a short time in the nest, and then drift downstream to suitable areas in sand, silt, or mud substrates (Moyle 2002; USFWS 2010).

Typical ammocoete habitat includes areas of low velocity with muddy or sandy substrate into which they burrow and remain in freshwater for about 3 to 7 years. Although mostly sedentary during their freshwater residence, ammocoetes are reported to have the ability to move downstream when disturbed or during high-flow events (USFWS 2010).

Ammocoetes begin metamorphosis into macropthalmia (juveniles) when they reach 14 to 16 cm TL. Juveniles reportedly drift and swim downstream between late fall and spring (USFWS 2010), but others report that downstream migration is associated with increased streamflows during the winter and spring (see USFWS 2010 and the references therein). Juvenile lifestages of lamprey (ammocoetes and macropthalmia), as well as adult lampreys, are reported to stay close to the stream bottom during their migration periods. Juveniles also are reported to prefer low light conditions and migrate mostly during the night (Moursund et al. 2003 as cited in Chelan County Public Utility District 2006).

1.1.1.1.8 Sacramento Splittail

USFWS removed Sacramento splittail from the list of threatened species on September 22, 2003, and did not identify it as a candidate for listing under the ESA. However, Sacramento splittail is identified as a California species of special concern (CDFW 2014). Splittail are believed to occur in the Sacramento River and its major tributaries, including the lower Feather and American Rivers.

Sacramento splittail spawning can occur anytime between late February and early July, but peak spawning occurs in March and April (Moyle 2002). DWR (2004a) reported that Sacramento splitttail spawning, egg incubation, and initial rearing in the Feather River occurs primarily during February through May. A gradual upstream migration begins in the winter to forage and spawn, although some spawning activity has been observed in Suisun Marsh (Moyle 2002). During wet years, upstream migration is much more directed, and fish tend to swim farther upstream (Moyle 2002). Attraction flows are necessary to initiate migration onto floodplains where spawning occurs (Moyle et al. 2004). Spawning generally occurs in water with depths of 3 to 6 feet over submerged vegetation where eggs adhere to vegetation or debris until hatching (Moyle 2002; Wang 1986). Caywood (1974) reports older fish are generally the first to spawn. Based on field observations and a review of splittail thermal tolerance literature, DWR (2004a) concluded that water temperatures from 45°F to 75°F are suitable for splittail spawning.

Eggs normally incubate for 3 to 7 days depending on water temperature (Moyle 2002). After hatching, splittail larvae remain in shallow weedy areas until water recedes, and then they migrate downstream (Meng and Moyle 1995). The largest catches of Sacramento splittail larvae occurred in 1995, a wet year when outflow from inundated areas peaked during March and April (Meng and Matern 2001).

Juvenile Sacramento splittail prefer shallow-water habitat with emergent vegetation during rearing (Meng and Moyle 1995). Sommer et al. (2002) report juvenile splittail are more abundant in the Yolo Bypass floodplain in the shallowest areas of the wetland with emergent vegetation. Juvenile splittail are classified as benthic foragers (USFWS 1995). Downstream movement of juvenile splittail appears to coincide with drainage from the floodplains between May and July (Caywood 1974; Meng and Moyle 1995; Sommer et al. 1997).

Sacramento splittail attain sexual maturity by the end of their second winter at a length of 180 to 200 mm (Daniels and Moyle 1983). The normal lifespan of Sacramento splittail ranges from 5 to 7 years (Caywood 1974; Meng and Moyle 1995). Adults can attain a length of over 300 mm (USFWS 1995). Adults are normally found in relatively shallow (<12 feet) water in brackish tidal sloughs, such as Suisun Marsh, but can also occur in freshwater areas with either tidal or riverine flows (Moyle et al. 2004). Splittail are also known to withstand very low dissolved oxygen (O_2) levels (<1 milligram O_2), a wide range of water temperatures (41.0°F to 75.2°F), and salinities of 6 to 10 ppt (Moyle et al. 2004).

Floodplain inundation during March and April appears to be the primary factor contributing to splittail abundance. Moyle et al. (2004) report that moderate-to-strong year classes of splittail develop when floodplains are inundated for 6 to 10 weeks between late February and late April. Reportedly, when floodplains are inundated for less than a month, strong year classes are not produced (Sommer et al. 1997).

Sommer et al. (1997) discuss the resiliency of splittail populations and suggest that, because of their relatively long lifespan, high reproductive capacity, and broad environmental tolerances, splittail populations can recover rapidly even after several years of drought conditions. This suggests that frequent floodplain inundations are not necessary to support a healthy population. Moyle et al. (2004) report that the ability of at least a few splittail to reproduce under even the worst flow conditions ensures that the population will persist indefinitely, despite downward trends in total population size during periods of drought.

Historically, Sacramento splittail were found as far up the Sacramento River as Redding, yet today are largely absent from the upper parts of their distribution range (Moyle 2002). It has been suggested that, during wet years, Sacramento splittail might migrate up the Sacramento River as far as RBDD (Moyle 2002). However, the extent of successful spawning in these upstream areas is unclear given that spawning reportedly occurs in inundated, vegetated floodplains.

1.1.1.1.9 Hardhead

Hardhead, a California species of special concern, is a large, native cyprinid (minnow) species that is widely distributed throughout the Sacramento–San Joaquin River system, although it is absent from the valley reaches of the San Joaquin River (Moyle 2002).

Hardheads generally occur in large, undisturbed low-to-mid-elevation rivers and streams of the region (Moyle 2002). Hardheads mature during their third year and often make spawning migrations, which occur in the spring, into smaller tributary streams (Moyle 2002). Most hardhead spawning is reportedly restricted to foothill streams (Wang and Reyes 2007). Hardheads reportedly spawn primarily during April and May (Grant and Maslin 1999; Reeves 1964) but might spawn into July in Sacramento River tributaries and into August in San Joaquin River tributaries (Wang and Reyes 2007). Estimates based on juvenile recruitment suggest that hardheads spawn by May and June in Central Valley streams (Wang 1986). Spawning behavior has not been documented, but hardheads are believed to elicit mass spawning in gravel riffles (Moyle 2002). Suitable temperatures for spawning hardhead can range from 59°F to 64.4°F (Wang 1986). Hardheads forage the bottoms of deep pools for aquatic insects, occasionally taking drifting insects on the surface (Moyle 2002).

Little is known about lifestage-specific temperature requirements of hardheads. However, temperatures ranging from about 65°F to 75°F are believed to be suitable (Cech et al. 1990), although most streams in which hardheads occur have summer water temperatures higher than 20°C (about 68°F). A recent laboratory study conducted on adult and juvenile hardheads indicated that they appear to be particularly well-suited to water temperatures below 25°C (77.0°F) and clearly avoid water temperatures above 26°C (78.8°F) (Thompson et al. 2012).

1.1.1.1.10 White Sturgeon

White sturgeon is not listed as threatened or endangered under the Federal or state ESAs, nor is it a Federal species of concern or a state species of special concern. However, white sturgeon is a recreationally important species in the Central Valley and is regulated by CDFW.

The number of adults fluctuates annually and appears to be the result of highly variable juvenile production; the population is dominated by a few strong year classes associated with high spring outflows (Moyle 2002).

Apparently triggered by photoperiod (Doroshov et al. 1997) and increases in river flow (Schaffter 1997), adult white sturgeons initiate their upstream migration into the lower Sacramento River from the Delta during late fall and winter (Kohlhorst and Cech 2001). Some mature adult white sturgeons move up the Sacramento River until they are concentrated near Colusa from March through May (Kohlhorst et al. 1991 as cited in Kohlhorst and Cech 2001).

White sturgeon spawning typically occurs between February and June when water temperatures are 46°F to 66°F (Moyle 2002). It is thought that adults broadcast spawn in the water column in areas with swift current. Fertilized eggs sink and attach to the gravel bottom, where they hatch. Eggs reportedly hatch after 4 days at 61°F (Beer 1981) but can take up to 2 weeks at lower water temperatures (PSMFC 1992). Although exact spawning locations are unknown, white sturgeons are reported to likely spawn between Knights Landing (RM 90) and Colusa (RM 143) (CDFG 2002 and Shafter 1997, both as cited in Beamesderfer et al. 2004; Kohlhorst 1976 as cited in Wang 1986; Moyle 2002), or several kilometers upstream of Colusa (Miller 1972, Kohlhorst 1976, and Schaffter 1997, all as cited in Israel et al. 2011). Vogel (2008) sampled adult sturgeons for a telemetry study near GCID between 2003 and 2006 and sampled white sturgeons as far upstream as RM 165. Juvenile rearing and downstream movement can occur year-round.

1.1.1.1.11 American Shad

American shad occur in the Sacramento River, its major tributaries, the San Joaquin River, and the Delta. Because of its importance as a sport fish, American shad has been the subject of investigations by CDFW. American shad are native to the Atlantic coast and were planted in the Sacramento River in 1871 and 1881 (Moyle 2002).

Adult American shad typically enter Central Valley rivers from April through early July (CDFG 1986), with the majority of immigration and spawning occurring from mid-May through June (Urquhart 1987). Spawning takes place mostly in the main channels of rivers, and generally about 70 percent of the spawning run is made up of first-time spawners (Moyle 2002).When suitable spawning conditions are found, American shad school and broadcast their eggs throughout the water column.

Water temperature is an important factor influencing the timing of spawning. American shad are reported to spawn at water temperatures ranging from about 46°F to 79°F (USFWS 1967), although optimal spawning temperatures are reported to range from about 60ºF to 70°F (Bell 1986; CDFG 1980; Leggett and Whitney 1972; Painter et al. 1979; Rich 1987). Eggs hatch in 6 to 8 days at 62°F; at temperatures near 75°F, eggs reportedly hatch in 3 days (MacKenzie et al. 1985). Egg development and hatching, therefore, are coincident with the spawning period.

Some young shad move downstream into brackish water soon after hatching, but large numbers reportedly remain in freshwater through November when they are 5 to 6 months old (CDFG 2010). Some juvenile American shad rear in estuaries for 1 to 2 years before migrating to the ocean, but the majority of American shad migrate directly to the ocean after transforming from larvae to juveniles, which occurs about 4 weeks after hatching (UC Davis 2015). Juvenile American shad can occur in the Sacramento River year-round (Moyle 2002).

1.1.1.1.12 Striped Bass

Striped bass occur in the Sacramento River, its major tributaries, and the Delta, spending most of their lives in the San Francisco Estuary. Because of its importance as a sport fish, striped bass has been the subject of investigations by CDFW. Substantial striped bass spawning and rearing occurs in the Sacramento River and Delta, although striped bass can typically be found upstream as far as barrier dams (Moyle 2002). Striped bass are native to the Atlantic coast and were first introduced to the Pacific coast in 1879, when they were planted in the San Francisco Estuary (Moyle 2002).

Adult striped bass are present in Central Valley rivers throughout the year, with peak abundance occurring during spring (CDFG 1971; DeHaven 1977, 1979). Adult striped bass are reported to prefer water temperatures from 68°F to 75.2°F (Emmett et al. 1991).

Striped bass spawn in water temperatures ranging from 59°F to 68°F (Moyle 2002). Therefore, spawning can begin in April but peaks in May and early June (Moyle 2002). In the Sacramento River, most striped bass spawning is believed to occur between Colusa and the mouth of the Feather River. In years of higher flow, spawning typically occurs farther upstream than usual because striped bass continue migrating upstream while waiting for temperatures to rise (Moyle 2002). No studies have definitively determined whether striped bass spawn in Sacramento River tributaries, including the lower American and Feather Rivers (CDFG 1971, 1986; DWR 2001).

Eggs are semibuoyant and are distributed throughout the water column by currents (Able and Fahay 1998). Egg survival requires a sufficiently strong current to keep the eggs suspended in the water column. If the current is not strong enough, eggs can settle on the bottom and become smothered (Collette and Klein-MacPhee 2002). After fertilization, eggs hatch within 2 to 3 days, followed by a net movement of the larval fish from upstream locations to downstream, tidal portions of the river (Moyle 2002). Striped bass larvae are generally distributed in the Delta or Suisun Bay, depending on flow through the estuary. In lower-flow years, striped eggs and larvae are generally found in the Delta, while during higher-flow years, eggs and larvae are transported downstream into Suisun Bay (Hassler 1988).

The number of striped bass entering Central Valley streams during the summer is believed to vary with flow levels and food production (CDFG 1986). Sacramento River tributaries can be nursery areas for young striped bass (CDFG 1971, 1986). Juvenile and sub-adult fish have historically been reported to be abundant in the lower American River and lower Yuba River during the fall (DeHaven 1977). Optimal water temperatures for juvenile striped bass rearing have been reported to range from about 61°F to 71°F (Fay et al. 1983).

1.1.2 Lower American River

The Primary Study Area includes the approximate 23 river miles of the lower American River extending from Nimbus Dam to the confluence with the Sacramento River. Details regarding fisheries resources and aquatic habitat in the lower American River are provided below.

As presented in NMFS (2009), historically over 125 miles of riverine habitat were available for anadromous salmonids in the American River watershed including the mainstem and the north, middle, and south forks (Yoshiyama et al. 1996).

In 1955, Folsom and Nimbus Dams were constructed on the mainstem American River about 28 miles and 23 miles, respectively, upstream from the confluence with the Sacramento River. Fish passage facilities were not built at Folsom or Nimbus Dams. Thus, with the closure of Nimbus Dam, upstream access to anadromous salmonids was blocked. Hydrological and ecological changes associated with the construction of Folsom and Nimbus Dams contributed to the extirpation of summer steelhead and spring-run Chinook salmon, which were already greatly diminished as a result of the effects of smaller dams (e.g., Old Folsom Dam and the North Fork Ditch Company Dam) and mining activities (Yoshiyama et al. 1996). All anadromous salmonids are now restricted to the lower 23 miles of the mainstem American River extending from Nimbus Dam downstream to the confluence with the Sacramento River (SWRI 2001). This 23-mile section of the mainstem river is now referred to as the lower American River.

Development of the American River watershed has modified the seasonal flow and water temperature patterns in the lower American River. Operation of the Folsom-Nimbus project significantly altered downstream flow and water temperature regimes (NMFS 2009). In addition, operation of Sacramento Municipal Utility District’s Upper American River Project since 1962, as well as Placer County Water Agency’s Middle Fork Project since 1967, altered inflow patterns to Folsom Reservoir (SWRI 2001).

Completion and operation of Folsom and Nimbus Dams resulted in higher flows during fall, lower flows during winter and spring, and higher flows during summer.

Seasonal water temperature regimes also have changed with development in the American River Basin, particularly with the construction and operation of Folsom and Nimbus Dams. Prior to the completion of Folsom and Nimbus Dams in 1955, maximum water temperatures during summer frequently reached temperatures as high as 75°F to 80°F in the lower American River (Gerstung 1971). Although summer water temperatures have been cooler in the lower river after Folsom Dam was constructed compared to the pre-dam conditions, prior to habitat elimination resulting from the dam, rearing fish had access to cooler habitats throughout the summer at higher elevations (NMFS 2009).

Historically, the riparian vegetation along the American River formed extensive, continuous forests in the floodplain, reaching widths of up to 4 miles (Water Forum 2005). Early settlers removed trees and converted riparian areas to agricultural fields. Hydraulic gold mining in the watershed caused deposits of 5 to 30 feet of sand, silt, and fine gravels on the riverbed of the lower American River, which resulted in an overall raising of the river channel and the surrounding floodplain (Water Forum 2005). This was later exacerbated by gravel extraction activities, and, as a result, the floodplain's water table has dropped, reducing the growth and regeneration of the riparian forest (Water Forum 2005). Urbanization throughout the greater Sacramento area has replaced agricultural land uses in the American River floodplain with urban land uses, causing a corresponding increase in urban runoff (SWRI 2001).

1.1.2.1.1 Historic Fisheries Resources Leading to Today's Species/Run Composition

The Chinook salmon that historically migrated into the upper reaches of the American River Basin were reportedly spring-run Chinook salmon (Gerstung 1971). Historically, fall-run Chinook salmon spawned in the lower reaches of the north, middle, and south forks of the American River and downstream in the mainstem American River (Gerstung 1971). In addition to spring- and fall-run Chinook salmon, historically summer-run, fall-run, and winter-run steelhead also annually returned to the American River Basin.

After 1950, when the fish ladder at Old Folsom Dam was destroyed by flood flows, summer-run steelhead perished in the warmwater in areas below Old Folsom Dam. By 1955, summer-run steelhead (and spring-run Chinook salmon) were completely extirpated from the American River Basin (Gerstung 1971).

Thus, the fish resources of the lower American River have experienced substantial changes over the years as a result of both natural and human-induced changes in population viability, habitat availability, and the hydrologic and thermal regimes of the river. The wide diversity of historic aquatic habitats and historic flow regimes (including thermal conditions) has been dramatically altered since the construction of Folsom Dam and Reservoir and the construction of Nimbus Dam and Lake Natoma. Presently, the runs of anadromous salmonids returning to the lower American River are restricted to fall- and winter-run steelhead and fall-run Chinook salmon.

1.1.2.1.2 Lower American River Physical Habitat Conditions

The lower American River provides a diversity of aquatic habitats including fast-water riffles, glides, runs, pools, and off-channel backwater habitats. The lower American River from Nimbus Dam (RM 23) to about Goethe Park (RM 14) is primarily unrestricted by levees but is bordered by some developed areas. Natural bluffs contain this reach of the river, and terraces cut into the side of the channel. The river reach downstream of Goethe Park, and extending to its confluence with the Sacramento River (RM 0), is bordered by levees. The construction of levees changed the channel geomorphology and has reduced river meanders and increased depth.

Dams upstream in the watershed have reduced gravel inputs to the system, but the lower American River contains large gravel bars and braiding in many locations, leaving gravel/cobble islands within the channel. The majority of the lower American River is bordered by the American River Parkway, which has preserved the surrounding riparian zone. The river channel does not migrate to a large degree because of the geologic composition that has allowed the river to incise deep into sediments, leaving tall cliffs and bluffs adjacent to the river.

Snider et al. (1992) divided the lower American River into three reaches. Reach 1, the 4.9 miles from the Sacramento River confluence to Paradise Beach, has a very low gradient and sand bed. Depth is normally controlled by the stage in the Sacramento River, rather than discharge, and varies with the tide (Williams 2001). Reach 2 includes the 6.7 miles of channel from Paradise Beach to Gristmill, with some slope (average gradient about 0.0005). The bed is mainly sand but includes some gravel riffles. Reach 3 covers 11.1 miles from Gristmill to the weir at Nimbus Hatchery with more slope (average gradient about 0.001) (Williams 2001). The bed is mainly gravel, but the river is still characterized by long pools separated by riffles. The average width of the river at a flow of 1,000 cfs is 350, 375, and 275 feet for reaches 1, 2, and 3, respectively (Williams 2001).

HABITAT RESTORATION ACTIONS

Since 2008, the U.S. Bureau of Reclamation (Reclamation), USFWS, the Water Forum, CDFW, and Sacramento County Regional Parks have collaborated to implement the Lower American River Gravel Augmentation and Side-Channel Habitat Enhancement project in an effort to improve salmonid habitat on the lower American River. This project is ongoing and has been developed in part to restore adult spawning and juvenile rearing habitat that was adversely affected by the construction of Folsom and Nimbus Dams on the American River.

The habitat-restoration activities have occurred at seven sites from the base of Nimbus Dam downstream 2.9 river kilometers (rkm) to the Upper Sunrise Recreational Area (USDOI 2008 as cited in PSMFC 2014b). Within that area, about 57,342 cubic meters of gravel were added to the river between 2008 and 2012 (PSMFC 2014b). During 2013, about 5,500 yards of improved spawning gravel and 400 yards of improved side channel juvenile rearing habitat were created (Reclamation 2013). Habitat-restoration actions in the lower American River continued in 2014, including placing an estimated 12,000 tons of gravel and creating a side channel about 350 yards long on the south side of the Nimbus Basin (Reclamation 2014).

During 2008–2010, the Water Forum, Sacramento County Regional Parks, the Sacramento Area Flood Control Agency, and the California Natural Resources Agency collaborated to deepen the existing Sunrise Side Channel to allow water to move through the side channel at lower flows, as well as construct more steep slopes to deter spawning on the margins of the side channel (Sacramento River Watershed Program

2014). Historically, the Sunrise Side Channel has supported up to about 10 percent of the total steelhead spawning in the lower American River. At flows greater than 4,000 cfs, the channel reportedly attracted spawning steelhead, which has resulted in redd dewatering once flows are reduced to below 3,500 cfs, as observed in 2002, 2003, and 2004. It is expected that this project will improve spawning habitat availability in the Sunrise Side Channel as well as reduce the potential for steelhead redd dewatering (Sacramento River Watershed Program 2014).

Zeug et al. (2013) analyzed changes in spawning utilization in the lower American River associated with gravel augmentation projects conducted during 2008, 2009, and 2010. The following discussion of the gravel augmentation actions evaluated is generally taken directly from Zeug et al. (2013).

The study area contained three gravel augmentation sites constructed during 2008, 2009, and 2010. The 2008 augmentation (hereafter referred to as Sailor Bar East) consisted of 6,350 metric tons of cleaned gravel between 6 and 102 mm with a D_{50} of about 24 mm. The 2009 augmentation (hereafter referred to as Sailor Bar West) extended Sailor Bar East downstream with 9,525 metric tons of gravel between 7 and 112 mm with a median grain size (D_{50}) of about 34 mm.

In 2010, 9,707 metric tons of gravel (hereafter referred to as Sunrise) was placed about 2 kilometers (km) downstream of Sailor Bar West. This augmentation contained gravel from 8 to 178 mm with a D_{50} of about 30 mm. A cobble island was included at Sunrise, which contained larger particles (D_{50} of 73 mm) than those in the surrounding augmentation.

An additional 4,989 metric tons of gravel were placed in the channel downstream of Sunrise. This gravel was not necessarily placed to provide spawning habitat but to (1) transport during high flows to replenish downstream spawning areas and (2) raise water levels in the main channel sufficiently to force flow down a side channel that was known to support salmonid spawning in the past but had been frequently dewatered during the spawning and incubation periods in recent years. Zeug et al. (2013) considered this newly rewatered side channel as an augmentation site and extended sampling to include this area (hereafter referred to as the Sunrise Side Channel).

The gravel in the Sunrise Side Channel has a D_{50} of 53.5 mm. In 2011, the Sunrise site was enhanced with an additional 8,135 metric tons of spawning gravel with a D_{50} of 64 mm. Also in 2011, 10,605 metric tons of large gravel and cobble were placed at the head of the Sunrise Side Channel to further enhance flooding of the side channel. Each year, gravel was placed in September prior to the Chinook and steelhead spawning period. Thus, the year of placement was also the first year of post-restoration evaluation.

Zeug et al. (2013) concluded that gravel augmentation increased utilization by steelhead and Chinook salmon for spawning. Differences in utilization among sites reportedly indicated that site design and selection of substrate size had a significant effect on the effectiveness of the augmentation for each species. Additionally, there were strong relationships between substrate size and redd dimensions within and among sites. Although all sites contained substrate sizes considered suitable for salmonids, spawning fish of both species responded most strongly at the site with the smallest D_{50} (Sailor Bar East). Thus, the value of substrate used for augmentation changes throughout the range considered as acceptable. Zeug et al. (2013) state that their results suggest that smaller substrates are favorable for augmentation actions because they provide spawning habitat to the widest size range of potential spawners.

1.1.2.1.3 Fish Species in the Lower American River

At least 44 species of fish have been reported to occur in the lower American River system historically or currently, including numerous resident native and introduced species as well as several anadromous species (**Table 3**). There are currently seven special-status fish species in the lower American River (**Table 4**).

Table 3. Fish Species Historically or Currently Reported to Occur in the Lower American River.

Common Name	Scientific Name	Occurrence
Anadromous Game Fish		
Chinook salmon	*Oncorhynchus tshawytscha*	Numerous in fall
Steelhead	*Oncorhynchus mykiss*	Numerous
Coho salmon	*Oncorhynchus kisutch*	Occasional
Pink salmon	*Oncorhynchus gorbuscha*	Rare
Chum salmon	*Oncorhynchus keta*	Rare
White sturgeon	*Acipenser transmontanus*	Uncommon
Striped bass [b]	*Morone saxatilis*	Numerous in summer
American shad [b]	*Alosa sapidissima*	Numerous in spring
Coldwater Game Fish		
Kokanee [b]	*Oncorhynchus nerka*	Numerous above Nimbus
Rainbow trout	*Oncorhynchus mykiss*	Numerous
Brown trout [b]	*Salmo trutta*	Rare
Warmwater Game Fish		
Largemouth bass [b]	*Micropterus salmonids*	Common in backwaters
Smallmouth bass [b]	*Micropterus dolomieui*	Common in backwaters
Green sunfish [b]	*Lepomis cyanellus*	Common in backwaters
Bluegill [b]	*Lepomis macrochirus*	Common in backwaters
Redear sunfish [b]	*Lepomis microlophus*	Few in backwaters
White crappie [b]	*Pomaxis annularis*	Few in backwaters
Sacramento perch	*Archoplites interruptus*	Rare
Channel catfish [b]	*Ictahurus punctatus*	Uncommon
White catfish [b]	*Ictahuruscatus*	Common in backwaters
Brown bullhead [b]	*Ictahurus nebulosus*	Few in backwaters
Black bullhead [b]	*Ictahurus melas*	Few in backwaters
Nongame Fish		
Sacramento sucker	*Catostomus occidentalis*	Numerous
Carp [b]	*Cyprinus carpio*	Numerous
Goldfish [b]	*Carassius auratus*	Numerous
Sacramento blackfish	*Orthodon microlepidotus*	Uncommon
Hardhead	*Mylopharodon conocephalus*	Occasional
Sacramento hitch	*Lavinia exilicauda*	Occasional
Sacramento pikeminnow	*Prychocheilus grandis*	Numerous
Splittail	*Pogonichthys macrolepidotus*	Occasional
Mosquitofish [b]	*Gambusia affinis*	Numerous in backwaters
Tule perch	*Hysterocarpus traski*	Numerous
Riffle sculpin	*Cottus gulosus*	Numerous
Pacific lamprey	*Lampetra tridentata*	Common and anadromous
River lamprey	*Lampetra ayresii*	Occasional and anadromous
Threadfin shad [b]	*Dorosoma petenense*	Occasional
Golden shiner [b]	*Notemigonus crysoleucas*	Present above Nimbus Dam
Fathead minnow [b]	*Pimephales promelas*	Present above Nimbus Dam
Thicktail chub	*Gila crassicauda*	Extinct
Sacramento-San Joaquin roach	*Lavinius symmetricus*	Uncommon
Sacramento tui chub	*Gila bicolor*	Uncommon
Speckled dace	*Rhinichthys osculus* sp.	Uncommon
Mississippi silverside	*Menidia beryllina*	Occasional
Smelt	*Hypomesus* sp.	Occasional

[a] Modified from Gerstung (1971)
[b] Introduced species

Table 4. Special-Status Fish Species in the Lower American River.

Common Name	Status
• Central Valley steelhead	Federal threatened
• Central Valley fall-/late fall-run Chinook salmon [a]	Federal species of concern State species of special concern
• Central Valley spring-run Chinook salmon (non-natal rearing only)	Federal and state threatened
• River lamprey	State species of special concern
• Pacific lamprey	Federal species of concern
• Sacramento splittail	State species of special concern
• Hardhead	State species of special concern
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

[a] Although the official designation of the Evolutionarily Significant Unit is Central Valley fall-/late fall-run Chinook salmon, the evaluation is for fall-run Chinook salmon on the lower American River because of the absence of late fall-run Chinook salmon.

Some fish species, including Sacramento perch and coho salmon, were identified as potentially occurring in the lower American River but were not carried forward for impact assessment in this evaluation. Historically, Sacramento perch (designated by CDFW as a species of special concern) were found throughout the Central Valley, the Pajaro and Salinas Rivers, and Clear Lake (Moyle 2002). The only populations that represent continuous habitation within their native range are those in Clear Lake and Alameda Creek (Moyle 2002). Most populations today are established in warm, turbid, moderately alkaline reservoirs or farm ponds. Therefore, Sacramento perch are not further discussed or evaluated. In the Sacramento River drainage, coho salmon (Federally endangered[3]) were never common, but a small population probably once spawned in the McCloud and Upper Sacramento Rivers (Moyle 2002). Coho salmon rarely, if at all, use the Sacramento River or its tributaries and, therefore, are not further evaluated in this document.

The lower American River is one of the few urban rivers in California that supports relatively large runs of anadromous salmonids, which results in the river receiving high angling pressure during many years. Additionally, anglers target striped bass and American shad seasonally (Sacramento County 2008). Resident rainbow trout are present in the upper segment of the river, and a warmwater population of largemouth bass, various sunfish, and catfish make up the remainder of the fishery (Sacramento County 2008). Fishing in the lower American River is permitted year-round, except during fall and early winter when the river is closed to protect spawning Chinook salmon as regulated by CDFG (Sacramento County 2008).

[3] There is not a coho salmon ESU within the Central Valley.

Provided below is species and lifestage-specific life history information specific to the lower American River. General life history information pertaining to the Central Valley and Sacramento River previously discussed under *Overview of Fish Species*, above, is not repeated in this section.

STEELHEAD

Critical habitat for the Central Valley steelhead DPS was designated on January 2, 2006, and includes the lower American River up to Nimbus Dam (70 FR 52488, September 2, 2005). Central Valley steelhead is not listed under the California ESA.

Between 1944 and 1947, annual counts of summer-run steelhead passing through the Old Folsom Dam fish ladder during May, June, and July at Old Folsom Dam (RM 27) ranged from 400 to 1,246 fish (Gerstung 1971). After 1950, when the fish ladder at Old Folsom Dam was destroyed by flood flows, summer-run steelhead perished in the warmwater in areas below Old Folsom Dam. By 1955, summer-run steelhead (and spring-run Chinook salmon) were completely extirpated, and only remnant runs of fall- and winter-run steelhead and fall-run Chinook salmon persisted in the American River (Gerstung 1971).

Estimates of historic run sizes for fall- and winter-run steelhead in the American River were not identified in the available literature. However, both of these runs of steelhead were likely historically relatively abundant in the American River considering (1) the over 125 miles of available habitat, (2) the historic run size estimates of Chinook salmon before massive habitat degradation associated with hydraulic mining occurred, and (3) the reported historic run size estimates for summer-run steelhead in the 1940s which occurred even after extensive habitat degradation and elimination (NMFS 2009).

The Central Valley steelhead DPS includes naturally spawning steelhead in the American River but excludes steelhead spawned and reared at the Nimbus Fish Hatchery. The Nimbus Fish Hatchery, located below Nimbus Dam, is operated by CDFW to meet an annual production goal of 430,000 steelhead yearlings (NMFS 2009).

Run size estimates of 305, 1,462, and 255 naturally spawning steelhead for the 1990/1991, 1991/1992, and 1992/1993 spawning seasons, respectively, were reported in Water Forum (2005), although the methodology for how these estimates were obtained was not stated. From 2002 through 2007, annual population abundance estimates for American River steelhead spawning in the river have ranged from about 160 to about 240 adults (Hannon and Deason 2008). Currently, the naturally spawning population of steelhead is believed to be composed mostly of fish originating from Nimbus Hatchery (Water Forum 2005).

General information pertaining to the various lifestages of steelhead in the lower American River is presented below, and lifestage-specific periodicities are represented in **Table 5**.

Table 5. Lifestage-Specific Generalized Periodicities for Steelhead in the Lower American River.

Lifestage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Adult immigration and holding	■	■	■	■	■	■															■	■	■	■
Spawning	■	■	■	■	■	■	■																	
Embryo incubation	■	■	■	■	■	■	■	■	■	■														
Juvenile rearing and downstream movement	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Smolt (yearling+) emigration	■	■	■	■	■	■	■	■																

Adult steelhead immigration and holding in the lower American River can begin as early as late spring or early summer but commonly begins in November and continues into April (SWRI 2001). Steelhead immigration generally peaks during January (CDFG, unpublished data; CDFG 1986; SWRI 2001). The adult immigration and adult holding lifestages are presented together because the timing of these two lifestages overlaps and the lifestages are inclusive. For this evaluation, the adult steelhead immigration and holding period is considered to extend from November through March.

Water temperatures can influence the timing of adult spawning migrations and can affect the viability of eggs in holding females. Few studies have been published that examine the effects of water temperature on either steelhead immigration or holding. The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid-50°F range and that immigration will be delayed if water temperatures approach about 70°F (SWRI 2001). Optimal immigration and holding temperatures have been reported to range from 46°F to 52°F (CDFG 1991). Increasing levels of thermal stress to this lifestage can reportedly occur above 52°F. Water depth in the lower American River does not appear to be a factor impeding the upstream migration of steelhead. The lower American River is a large, perennial river with water depths generally well above those minimally necessary (1 to 2 feet) for successful migration, even during very low-flow (e.g., 250-cfs) conditions.

Steelhead spawning includes the period from redd construction until spawning is completed with the deposition and fertilization of eggs. Spawning typically begins during late December and can extend through March but reportedly also can range from November through April (CDFG 1986). Steelhead redd surveys conducted during most survey years from 2002/2003–2012/2013 indicate that spawning in the lower American River can begin as early as late December but generally extends from January through mid-April, with the vast majority of spawning (nearly 80 percent) occurring from mid-January through February. Hannon and Deason (2008) reported that peak spawning varies annually but most frequently occurs during mid-February.

The lowermost 5 miles of the lower American River from Discovery Park to just below Paradise Beach is deficient of steelhead spawning habitat because tides and Sacramento River flows back the water up to this point (Hannon 2013; Hannon and Deason 2008). Steelhead spawning is concentrated in the upper section of the river. Slightly more than about 50 percent of all steelhead redds occurred in the upper 3 miles (RM 20–RM 23) of the lower American River on average during recent survey periods (2002/2003, 2003/2004, 2004/2005, 2006/2007, 2010/2011, 2011/2012, and 2012/2013), and on average more than 95 percent occurred upstream of Watt Avenue (Hannon 2013). Out of the approximately 1,200 steelhead redds reported during all 7 of these survey years, about 357 (30 percent) of the redds were reported to be found in side channels (**Table 6**).

Table 6. Number of Steelhead Redds by Side Channel for the 2003–2005, 2007, and 2011–2013 Steelhead Redd Surveys in the Lower American River.

RM	Location	2003	2004	2005	2007	2011	2012	2013	*Totals*
21	Sailor Bar side channel	11	13	10	4	1	0	0	*39*
21	Upper Sunrise side channel	28	24	12	1	16	14	37	*132*
19	Lower Sunrise side channel	16	13	7	0	2	8	14	*60*
15	Sacramento Municipal Utility District cable crossing side channel	22	20	11	7	10	0	2	*72*
14	Upper River Bend side channel	4	9	5	3	0	0	0	*21*
14	River Bend side channel	11	4	0	0	4	0	2	*21*
9	Watt side channel	1	3	0	1	0	0	7	*12*
	TOTAL	93	86	45	16	33	22	62	*357*

NMFS (2007) reported that the steelhead population in the lower American River does not appear to be ultimately limited by spawning habitat availability but rather appears to be limited by factors such as summer water temperatures and predation following fry emergence.

The embryo incubation period extends from egg deposition until emergence from the substrate as a free-swimming fry. The egg and alevin incubation lifestage for steelhead in the lower American River has been reported to generally extend from late December into May (SWRI 2001). Based on the timing of observations of newly constructed steelhead redds and the amount of time required for incubation, the embryo incubation period has been estimated to generally extend from late December through late May in the lower American River (Hannon and Deason 2004, 2005, 2008; Hannon et al. 2003). For this evaluation, the steelhead embryo incubation period in the lower American River is generally characterized as extending from January through May.

Optimal steelhead spawning temperatures have been reported to range from 39°F to 52°F (CDFG 1991). The upper water temperature value for optimal egg incubation has been reported as 52°F (Humpesch 1985; NMFS 2001, 2002; Reclamation 1997; USFWS 1995). In the lower American River, fish surveys that identified newly emerged steelhead through May indicated that incubating steelhead embryos do survive at water temperatures above the reported preferred range (NMFS 2007). Most of the studies of *O. mykiss* embryo incubation conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), and some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F could represent an inflection point between properly functioning water temperature conditions and the conditions that cause negative effects on steelhead spawning and embryo incubation.

Embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57.0°F (Rombough 1988; Velsen 1987). Thus, from the available literature, water temperatures in the low-50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high-50°F range and above.

CDFG (2001) conducted a 4-year flow fluctuation study during 1997 to 2000. The results of the study indicate that:

1. Flow fluctuations are regular occurrences in the lower American River;
2. Flow fluctuations are more common during the October-to-June period; and
3. Flow fluctuations could dewater steelhead redds (CDFG 2001).

The minimum flow requirements established by NMFS (2009) include limits on the percentage reduction in flow during January and February from those flows that occurred during December. These limits would minimize the potential for dewatering steelhead redds during these months under controlled flow conditions. However, flow reductions continue to represent a stressor to steelhead associated with redd dewatering, particularly from March through May.

From 1992 through 2008, CDFW conducted seining surveys and rotary screw trapping (RST) surveys to define the temporal and spatial distribution of steelhead and other fish in the lower American River. Steelhead captured by seining are reported in Snider and McEwan (1993), Snider and Keenan (1994), Snider and Titus (1996, 2000b), and CDFG (unpublished data). In general, juvenile steelhead usually appeared in the seine samples during April, increased in abundance through April and/or May, and decreased thereafter. Juvenile steelhead continued to be present in relatively low numbers in the summer, primarily at upstream locations.

YOY steelhead historically began appearing in RSTs at the earliest in mid-January, but typically in mid-March. Most YOY steelhead were captured in RSTs from mid-April through June (Snider and Titus 2000b). Steelhead YOY, however, began appearing in seine surveys as early as early February but typically before mid-March, which suggests that emergence and emigration are not coincident (CDFG 2000; Snider and McEwan 1993; Snider and Keenan 1994; Snider and Titus 1995, 1996, 2000b; Snider et al. 1997, 1998). During RST surveys conducted during 2013, 98 percent (1,019) of the steelhead fry were caught between March 19 and April 22 (PSMFC 2014b). Seventy percent (540) of the steelhead with a parr lifestage were caught between April 30 and May 20 during the 2013 survey (PSMFC 2014b).

Yearling-sized individuals that were captured early in the season (i.e., winter to early spring) in previous RST surveys strongly suggest some over-summer survival, but evidence is inconclusive as to the origin of these fish. Yearling steelhead first appeared in the RSTs in the lower American River during late December and continued to be collected until early May, with most captured during January (Snider and Titus 2000b). The presence of apparent YOY steelhead in October samples indicates some capability to survive summer conditions, and this presence increases the likelihood of survival to smolt. It has been speculated that steelhead might spend summers outside the lower American River and return during the fall (Snider and McEwan 1993).

Snorkel surveys were conducted by the Fishery Foundation of California in the lower American River from the late winters to the early summers of 2003, 2004, and 2005 (Cannon and Kennedy 2006). Fall-run Chinook salmon and steelhead fry were the dominant fish observed from February through April. Steelhead YOY were observed from April through September, although densities observed declined sharply during the spring.

These studies indicate that juvenile steelhead can rear in the lower American River for relatively short periods after emergence, or for several months, or even up to a year before moving downstream out of the lower American River. In summary, although it has been reported that steelhead that rear over summer in the lower American River generally emigrate as smolts from January through June (McEwan 2001; Newcomb and Coon 2001; Snider and Titus 2000b), most emigrate from January through April (R. Titus, CDFW, pers. comm., 2013, as cited in Reclamation and NMFS 2014). Steelhead juveniles that emigrate from the lower American River as YOY generally do so from March through September (McEwan 2001).

Steelhead YOY that can volitionally or nonvolitionally move downstream to enter the Sacramento River probably continue to rear until reaching a size at which smoltification is initiated. The small sizes of juvenile steelhead captured at the RSTs support the presumption that these juvenile fish have not yet undergone smoltification but instead are moving out of the river into downstream rearing habitat.

Most juvenile steelhead rearing occurs in the upper reaches of the lower American River from Watt Avenue upstream (CDFG, unpublished data; Snider and Keenan 1994; Snider and Titus 1996). The majority of post-emergent fry are collected in glides (Snider and Keenan 1994; Snider and Titus 1996). By late summer, YOY steelhead are distributed throughout the lower American River and exhibit strong site fidelity (R. Titus, CDFG, pers. comm., 2001, as cited in SWRI 2001). Limited mark and recapture evaluations of juvenile steelhead collected by seining in the lower American River since 1996 indicate that juveniles tend to occupy specific habitats throughout the summer. Larger juvenile steelhead typically inhabit fast-water areas such as riffles. Yearling steelhead are found in bar complex and side channel areas characterized by habitat complexity in the form of velocity shelters, hydraulic roughness elements, and other forms of cover (R. Titus, CDFG, pers. comm., 2001, as cited in SWRI 2001).

Cannon and Kennedy (2006) reported that juvenile steelhead were most abundant near spawning areas in riffle and run margins with abundant cover of the upper portion of the lower American River, especially in small stream-type habitats of side channels. During the summer, juvenile steelhead concentrated in riffle habitats of the main river and side channels.

Low flows can negatively affect steelhead rearing in the lower American River (NMFS 2009). Yearling steelhead are found in bar complex and side channel areas characterized by habitat complexity in the form of velocity shelters, hydraulic roughness elements, and other forms of cover (SWRI 2001). At low flow levels, the availability of these habitat types becomes limited, forcing juvenile steelhead densities to increase in areas that provide less cover from predation. With high densities in areas of relatively reduced habitat quality, juvenile steelhead become more susceptible to predation as well as disease (NMFS 2009).

Rearing steelhead fry and juveniles can be exposed to stranding and isolation from main channel flows when high flows are required for flood control or Delta outflow requirements and then subsequently reduced after the requirement subsides (NMFS 2007). The U.S. Bureau of Reclamation attempts to avoid flow fluctuations during non-flood-control events that raise flows above 4,000 cfs and then drop them back below 4,000 cfs, as recommended by Snider et al. (2001) and NMFS (2009).

During 2014, an investigation was conducted to assess the response of juvenile *O. mykiss* and fall-run Chinook salmon to three pulse flows in the lower American River (PSMFC 2014a). Two of those pulse flows were intended to benefit salmonid outmigration in consideration of the low-flow conditions, and the third pulse flow coincided with a notable rainfall event. The analysis presented in PSMFC (2014a) relied on RST data collected immediately downstream of the Watt Avenue bridge.

Figure 1 displays the relationship between the maximum daily discharge at Watt Avenue and the number of natural-origin juvenile *O. mykiss* emigrating past the Watt Avenue RST site on the lower American River during 2014.

- Blue bars in Figure 1 indicate days when both American River RSTs operated without problems during a 24-hour day and actual catch data were used to calculate *O. mykiss* production estimates.
- Red bars indicate days when one or both RSTs were not fished on weekends or experienced operational problems within a 24-hour period, and it was necessary to impute *O. mykiss* catch as *O. mykiss* production (PSMFC 2014a).

Although PSMFC (2014a) suggested that the pulse flows appeared to facilitate the emigration of modest numbers of juvenile *O. mykiss* from the American River and that the rainfall event had little or no effect on the number of *O. mykiss* caught in the RSTs, no clear relationship between pulse flow events and RST captures are readily apparent (Figure 1).

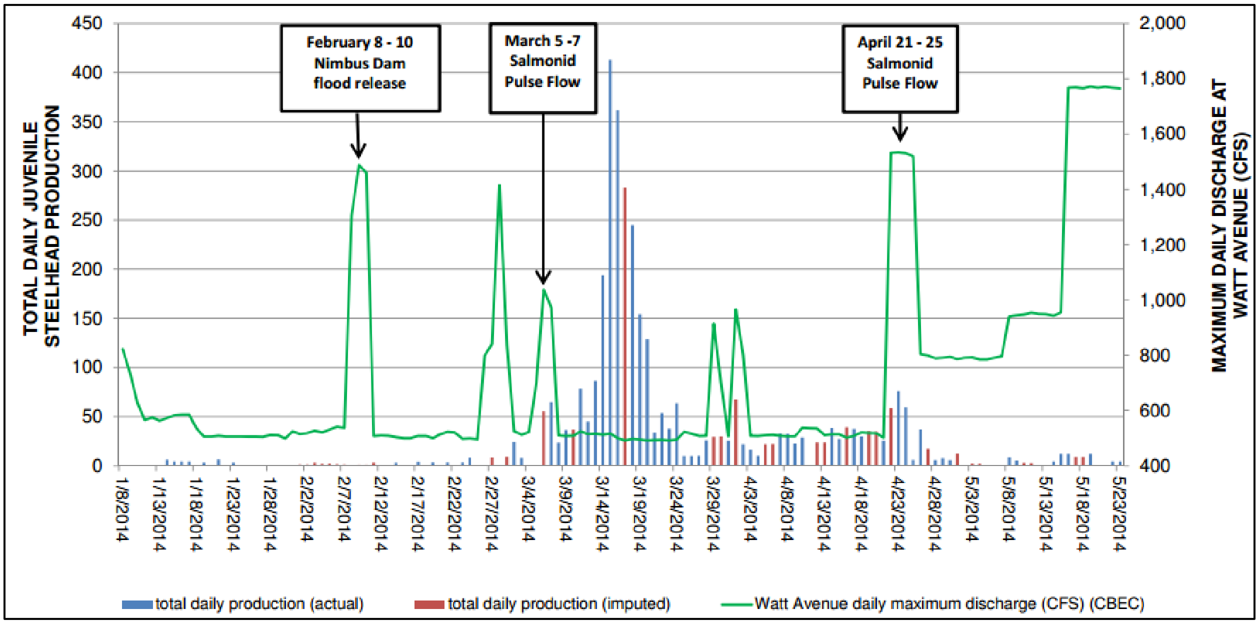

Figure 1. Maximum Daily Flow at Watt Avenue and the Number of Natural-Origin Juvenile *O. mykiss* Emigrating past the Watt Avenue RST Site on the Lower American River during 2014 (PSMFC 2014a).

Water temperature is the physical factor with perhaps the greatest influence on American River steelhead (NMFS 2009). Water temperature directly and indirectly affects growth rates, disease incidence, predation, and long-term survival (Myrick and Cech 2001). High water temperatures are a stressor to juvenile rearing steelhead in the lower American River, particularly during the summer and early fall (NMFS 2009).

Preferred water temperatures for fry and juvenile steelhead rearing are reported to range from 45°F to 65°F (NMFS 2002). The juvenile steelhead immune system properly functions up to about 60°F and then is dramatically compromised as water temperatures increase into the upper 60s (°F) (Water Forum 2005). With each 1-degree increase between 65°F and the upper lethal limit of 75°F, water temperature reportedly becomes increasingly less suitable and thermally more stressful for the fish (Bovee 1978).

The available information suggests that lower American River steelhead might be more tolerant to high temperatures than steelhead from regions farther north (Myrick and Cech 2004). Titus and Brown (2006) found that steelhead rearing in the lower American River occurs when temperatures exceed 65°F and that growth and condition appear good under the warmer summer and fall conditions, although these fish become very susceptible to bacterial infection and predation. They conclude that temperatures in excess of 65°F should be avoided and that improved habitat, including increased complex cover, could mitigate some of the effects of typically warm summer and fall water temperatures.

Elevated water temperatures in the lower American River likely result in increased predation rates on juvenile rearing steelhead (NMFS 2009). Juvenile rearing steelhead can be exposed to increased predation as a result of both increased predator abundance and increased digestion and consumption rates of these predators associated with higher water temperature (Vigg and Burley 1991 and Vigg et al. 1991, both as cited in NMFS 2009).

Specific flows have not been identified for juvenile steelhead emigration in the lower American River, although NMFS (2007) suggests that juvenile steelhead presumably do not need large pulses to emigrate effectively from the lower American River as long as water temperatures are suitable through the lower river.

FALL/LATE-FALL RUN CHINOOK SALMON

Fall-run Chinook salmon is currently the largest run of Chinook salmon to use the Sacramento River system and is the run of Chinook salmon using the lower American River (SWRI 2001).

Because fall-run Chinook salmon are not listed as threatened or endangered under the Federal or state ESAs, critical habitat has not been designated for fall-run Chinook salmon in the Central Valley. However, under the Magnuson-Stevens Fishery Conservation and Management Act, NMFS has identified essential fish habitat (EFH) for fall-run Chinook salmon in the lower American River from its mouth upstream to Nimbus Dam. EFH applies only to commercial fisheries, and EFH includes specifically identified waters and substrate necessary for fish spawning, breeding, feeding, or growing to maturity.

Historically, fall-run Chinook salmon spawned in the lower reaches of the north, middle, and south forks of the American River and downstream in the mainstem American River (Gerstung 1971). Annual salmon carcass surveys were conducted on the American River each fall beginning in 1944. Between 1944 and the construction of Folsom and Nimbus Dams in 1955, an estimated average of about 26,500 Chinook salmon (presumably fall-run) spawned in the mainstem of the American River below the city of Folsom. During this 11-year period, estimated annual Chinook salmon runs ranged from 12,000 to 38,652 (Gerstung 1971).

Since the early 1970s, tag-and-recapture data have been collected to estimate adult spawning escapement to several Central Valley tributary streams, including the American River. However, a review of spawning escapement surveys (Rich 1985) identified the need to standardize methodologies in surveying and estimating escapement populations in the lower American River. The inconsistencies between various survey methods identified in Rich (1985) included (1) differences in the timing of Nimbus Hatchery weir installation and removal, (2) survey problems, (3) differences in spawning survey (mark and recapture) methodologies, and (4) inaccurate and inconsistent spawning escapement estimation methodologies.

Using different methodologies of field survey and escapement estimation can cause problems when attempting to compare annual estimates. Since 1989, CDFW (and previously CDFG) has consistently used the Schaefer estimation procedure for annual fall-run Chinook salmon escapement in the lower American River.

In addition to spawning in the lower American River, returning fall-run Chinook salmon adults also ascend the Nimbus Hatchery fish ladder and enter the hatchery. Early adult spawners also can travel past the Nimbus Hatchery training weir, and adult spawners arriving throughout the spawning season have been able to pass through gaps in the foundation of Nimbus Hatchery training weir. These fish can either be caught by anglers or die. Some of the expired fish end up impinged on the weir. The hatchery operators routinely record “weir fish.”

The Anadromous Fish Restoration Program (AFRP) of the Central Valley Project Improvement Act has a goal of at least doubling the natural production of anadromous salmonids, including fall-run Chinook salmon, over the 1967–1991 baseline period. The AFRP defines natural production as the number of fish not produced in hatcheries that reach adulthood, including adults that are harvested prior to spawning (USFWS 1995). Although the main components included in the estimates of the total production and natural production vary on an annual basis and therefore add uncertainty into annual production estimates, total spawning escapement (in-river and hatchery returns, combined) serves as one index for comparative purposes. For the AFRP baseline period (1967–1991), in-river spawning escapement of fall-run Chinook salmon averaged 32,307 fish and hatchery returns averaged 8,733 fish, for a combined average of 41,040 spawning escapement (USFWS 1995). For the period from 1992 to 2008, in-river escapement averaged 64,507 fish and hatchery returns averaged 10,582 fish, for a combined average of 75,089 spawning escapement.

However, throughout the Central Valley including the lower American River, the number of Chinook salmon returning in the fall to spawn has declined in recent years. In the lower American River, CDFG estimated that fall-run Chinook salmon escapement (obtained from GrandTab) has declined each year since 2003, when the highest escapement in the entire period of record (1952–2013) occurred (163,742 in-river spawners and 14,887 hatchery returns, for a total of 178,629). The lowest estimated escapement in the entire period of record occurred during 2008 (2,514 in-river spawners and 3,232 hatchery returns, for a total of 5,746). Since 2008, total escapement has increased each subsequent year, particularly in-river escapement, with total escapement reaching 73,226 (64,150 in-river spawners and 9,076 hatchery returns) in 2013 (CDFW 2014).

General information pertaining to the various lifestages of fall-run Chinook salmon in the lower American River is presented below, and lifestage-specific periodicities are represented in
Table 7.

Table 7. Lifestage-specific Generalized Periodicities for Fall-run Chinook Salmon in the Lower American River.

Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult immigration and staging [a]												
Spawning												
Embryo incubation												
Juvenile rearing and downstream movement												

[a] Less than 10 percent of the adult fall-run Chinook salmon immigrate into the lower American River prior to September.

In the Central Valley, adult fall-run Chinook salmon are reported to generally begin migrating upstream annually in July, with immigration continuing through December in most years (NMFS 2004; Vogel and Marine 1991). The majority of the fall-run Chinook salmon adult immigration into the lower American River has previously been reported to occur from September through November and peak in November (SWRI 2001). As part of a study to evaluate angler effort and harvest of anadromous fishes in the Central Valley recreational river fishery, CDFW has performed periodic creel censuses in the lower American River that provide estimates of the fall-run Chinook salmon monthly catch that were used to assess the temporal distribution of pre-spawning adult fall-run Chinook salmon in the lower American River.

The length of time that fall-run Chinook salmon spend in the lower American River prior to spawning is not specifically known. The results of biotelemetry studies conducted on the upper Sacramento River at RBDD indicate that fall-run Chinook salmon can stay in the river from several days to over 1.5 months between their arrival in the upper river at RBDD and their observed movement onto the spawning grounds both upstream and downstream of the dam. These results suggest that fall-run Chinook salmon can spend a considerable amount of time in a river near their spawning grounds prior to spawning.

Estimated monthly catches of fall-run Chinook salmon in the lower American River were obtained by USACE for this Draft Technical Report from available CDFW angler survey reports (e.g., Massa and Schroyer 2003; Murphy et al. 2000; Murphy et al. 2001; Schroyer et al. 2002; Titus et al. 2008; Titus et al. 2009; Titus et al. 2010; and Wixom et al. 1995) and were used by USACE for this Draft Technical Report to obtain the temporal distribution of in-river adult fall-run Chinook salmon prior to spawning. The results of these analyses demonstrate that some adult fall-run Chinook salmon begin entering the lower American River as early as June and continuing through the summer prior to spawning from mid-October through December. Most immigrating fall-run Chinook salmon in the lower American River do not exhibit an extended staging period; rather, they spawn shortly after arriving in the spawning areas.

The process of developing information for the Water Forum and USACE (2015) updated Lower American River Mortality Model (see below) included fitting an asymmetric logistic function to 10 years of available creel survey data (over the period from 1991 to 2010) to represent the temporal distribution of adult fall-run Chinook salmon arriving in the lower American River prior to and during the spawning season (**Figure 2**). Thus, although the majority of fall-run Chinook salmon adults immigrate into the lower American River from September through November, the information recently developed by the Water Forum and USACE (2015) indicates that, in general, up to nearly 10 percent might immigrate into the river prior to September.

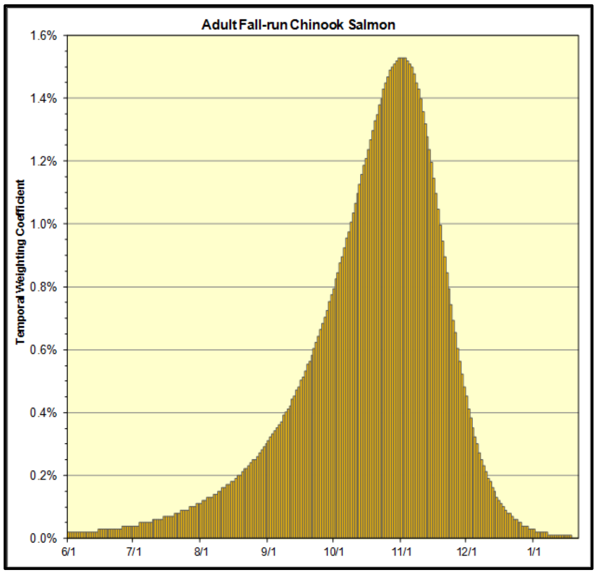

Figure 2. Daily Temporal Distribution of Adult Fall-run Chinook Salmon Immigration in the Lower American River.

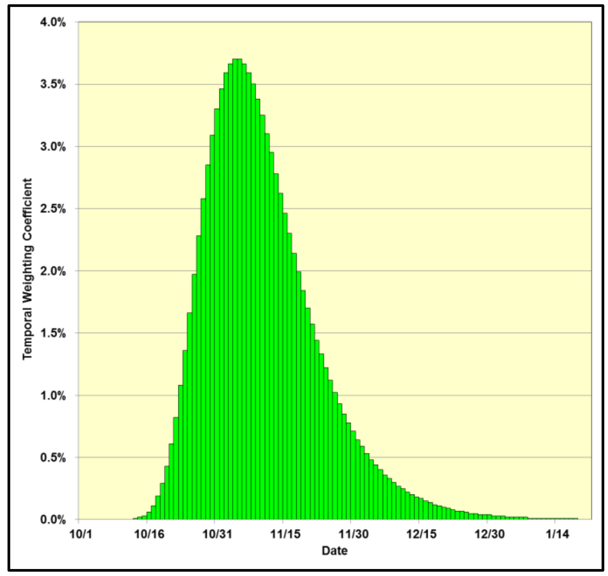

Figure 3. Daily Temporal Distribution of Fall-run Chinook Salmon Spawning in the Lower American River.

Water depth in the lower American River does not appear to impede the upstream migration of adult fall-run Chinook salmon (SWRI 2001). The lower American River is a large, perennial river with water depths generally well above those minimally necessary (about 1 foot) for successful migration, even during very low-flow (e.g., 250-cfs) conditions. Regarding operational considerations in the Central Valley, NMFS (2000) reported that 59°F to 60°F is "[t]he upper limit of the optimal temperature range for adults holding while eggs are maturing." Also, NMFS (1997) states that "[g]enerally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F" and that the "[a]cceptable range for adults migrating upstream range[s] from 57°F to 67°F." ODEQ (1995) further reports that "many of the diseases that commonly affect Chinook [salmon] become highly infectious and virulent above 60°F."

Water temperatures in the lower American River often exceed the reported upper optimal water temperature index value of 64°F (Bratovich et al. 2012) during much of the adult immigration and staging lifestage at Watt Avenue and particularly at the mouth of the lower American River.

The process of developing information by the Water Forum and USACE (2015) for the updated Lower American River Mortality Model included calculating lag times between fitted Chinook salmon redd and carcass distributions and developing an adjusted asymmetric logistic function to describe fall-run Chinook salmon spawning timing in the lower American River based on 21 years of carcass surveys (from 1992/1993 through the 2012/2013 seasons) (**Figure 3** above). Based on the appearance of fresh, non-adipose fin-clipped fall-run Chinook salmon in the carcass surveys (1992/1993–2012/2013) and estimation of the lag period between spawning and appearance in the carcass surveys in the lower American River, fall-run Chinook salmon spawning (based on the cumulative distribution representing 21 years of estimated spawning time) characteristically begins on October 15 and ends on December 31.

Over the range of conditions that have occurred from 1992 through 2012, typically, fall-run Chinook salmon spawning in the lower American River:

- Begins during mid- to late October,
- Ends during late December into early January, and
- Peaks during November (nearly 70 percent of the annual spawning run).

The majority of fall-run Chinook salmon redds are constructed from Ancil Hoffman Park at RM 16 upstream to the Nimbus Hatchery weir (about RM 23), assuming that spawning occurs nearby or upstream of the location of observed carcasses (Vincik and Kirsch 2009). Aerial redd surveys conducted on about a weekly basis over the course of the spawning season have been conducted on the lower American River from only 1991 to 1995, and these surveys have shown that most (92 percent of) redds are formed upstream of RM 16 (Snider and Vyverberg 1996).

During 2009, Vincik and Kirsch (2009) suggested that there had not been any notable change in the overall spatial distribution of fall-run Chinook salmon spawning in the lower American River since 1995. However, a recent program has established additional habitat. The Lower American River Salmonid Spawning Gravel Augmentation and Side Channel Habitat Establishment Program (Reclamation 2008b, 2011) was implemented over a 6-year period from 2008 to 2013. The purpose of the program was to increase and improve Chinook salmon and steelhead spawning and rearing habitat by replenishing spawning gravel and establishing additional side-channel habitat in the lower American River between Nimbus Dam and Upper Sunrise Recreation Area (Reclamation 2008b). The results from recent spawning surveys suggest that fish are using the newly enhanced areas of the lower American River for spawning (Hannon 2013).

Eggs deposited in redds incubate until hatching, at which time they are referred to as alevins. Alevins remain in the gravel until most of the egg yolk is absorbed, then begin to emerge from the gravel. The intragravel residence period of incubating eggs and alevins is highly dependent on water temperature. The estimated general intragravel lifestage period of fall-run Chinook salmon in the lower American River extends from about mid-October through March. After alevins emerge from the gravel, they begin the rearing and emigration stages of their life histories (SWRI 2001).

The temporal distributions presented above might be slightly influenced by late fall-run Chinook salmon having strayed into the lower American River, particularly during the 2008/2009 spawning season. Chinook salmon have been encountered in the CDFG carcass surveys (M. Healey 2005, 2004; Healey and Fresz 2007; Healey and Redding 2008; Vincik and Kirsch 2009) through January in recent years, although a low percentage of fresh carcasses has been encountered after the first week of January (generally 0.2 percent to 3 percent). The highest number of fresh Chinook salmon carcasses encountered after the first week of January was observed during the 2008/2009 survey season, when 12 percent of all fresh carcasses were observed after the first week of January 2009 (Vincik and Kirsch 2009).

Spawning during January, particularly during the latter part, is somewhat atypical of fall-run Chinook salmon but is phenotypically consistent with late fall-run Chinook salmon. During the 2008/2009 surveys, recovery and analysis of 53 coded-wire tagged carcasses obtained throughout January 2009 found that all of them were late fall-run Chinook salmon strays originating from the Coleman National Fish Hatchery on Battle Creek. In addition to adipose fin-clipped (i.e., hatchery) carcasses, non-adipose fin-clipped carcasses also were encountered during January. Thus, Vincik and Kirsch (2009) speculated that the late-spawning (i.e., January-spawning) Chinook salmon in the lower American River were either Chinook salmon that had strayed from a hatchery or were wild Chinook salmon from other systems and are not likely a self-sustaining run within the lower American River. However, they recognize the need to further explore this issue in future monitoring.

More recently, Kormos et al. (2012) found that, relative to the total of 23,945 Chinook salmon carcasses sampled during 2010/2011, 162 (less than 1 percent of all Chinook salmon) were classified as late fall-run Chinook salmon, of which about 23 percent (37 fish) were from a hatchery.

The timing of adult Chinook salmon spawning is influenced by both behavioral characteristics and appropriate spawning temperatures. It has been previously reported that fall-run Chinook salmon begin to spawn in the lower American River when water temperatures decline to about 60°F (SWRI 2001). Water temperature monitoring data are available for the U.S. Geological Survey's (USGS) Fair Oaks gage from 1998 to 2015. Based on carcass survey data (and estimating the lag period between the spawning and appearance of fresh carcasses in the carcass surveys) in the lower American River from 1998 through 2012, the initiation of fall-run Chinook salmon spawning (defined as 10 percent of the annual cumulative distribution) occurs when daily average water temperatures decreased to values generally ranging from 59.7°F to 64.0°F and to 67.4°F during one year (2001), with an average of 62.3°F.

Relatively high water temperatures at the beginning of the fall-run Chinook salmon spawning season can be detrimental to spawning success. Nimbus Hatchery data suggest that the percentage of egg fertilization rapidly increases when daily median temperatures decline below 60°F, and water temperatures of about 62°F or higher are reported to be lethal to incubating embryos (Hinze 1959; Reclamation 1991; Seymour 1956; USFWS 1992, 1999). In recent years, mean daily water temperatures at or below 60°F in the upper reaches of the lower American River have not occurred until dates ranging from October 27 to November 15. From 1998 through 2012, the average date on which mean daily water temperatures declined to 60°F in the upper reaches of the lower American River was November 6. For these same years, an average of 43 percent of the annual runs of fall-run Chinook salmon were estimated to have spawned by November 6.

Survival of Chinook salmon eggs and alevins is believed to decrease rapidly when incubation temperatures exceed about 56°F for much or all of the incubation period (Reclamation 1991). This temperature is the reported upper optimum water temperature for Chinook salmon egg development (NMFS 1993). For maximum survival of Chinook salmon eggs and yolk-sac larvae in the Central Valley, USFWS (1995) suggested an upper water temperature value of 56.0°F, and NMFS (1997) reported 56.0°F as the upper limit of suitable water temperatures for Chinook salmon egg incubation in the Sacramento River. Water temperatures above 56°F reportedly result in significantly higher Chinook salmon alevin mortality in the Sacramento River (USFWS 1999). Consistently higher egg losses resulted at water temperatures above 60.0°F than at lower temperatures (Johnson and Brice 1953).

T.P. Healey (1979) found, in an experiment that exposed Sacramento-strain fall-run Chinook salmon to a constant temperature, that mortalities to the fingerling stage were 80 percent or more when temperatures during incubation of eggs and fry development were 61°F to 61.9°F. These types of experiments using constant temperatures are common but generally do not provide information about the differences between constant and variable thermal conditions, the latter of which occur in the lower American River (SWRI 2001).

Eggs incubated at constant water temperatures greater than 60°F or less than 38°F have been reported to result in high mortalities (Boles et al. 1988). Survival increases, however, for eggs taken at high water temperatures but incubated at temperatures that gradually decline to the mid-40s to mid-50s (°F) range. Mortalities in fry were reduced to low levels when eggs were incubated at constant temperatures from 50°F to 55°F, or under declining temperatures from initial incubation temperatures ranging up to 60°F.

Variable water temperatures (those temperatures that emulate natural variation) have been shown to have reduced negative impacts at higher temperatures compared to constant-temperature incubation. The U.S. Environmental Protection Agency (EPA 1971 as cited in SWRI 2001) found that there was significantly greater survival in eggs incubated at fluctuating temperatures with peaks above 63°F (17.2°C) and significantly better survival for fry at all temperatures (with one exception) in the fluctuated-temperature group compared with constant-temperature groups.

Water temperatures in the lower American River nearly always exceed the reported upper optimal value of 56°F during October, and oftentimes exceed this value during the November portion of the fall-run Chinook salmon spawning and embryo incubation periods.

The juvenile fall-run Chinook salmon rearing period in the Central Valley reportedly extends from late December through June (Moyle 2002; Vogel and Marine 1991). According to Moyle (1976), juvenile Chinook salmon in California seldom spend more than 30 days in freshwater. This trend has been observed in the lower American River. In general, juvenile Chinook salmon spend little time in the lower American River for rearing, as demonstrated by RST surveys. Most fall-run Chinook salmon emigrate during the fry stage and, at the latest, the early juvenile stage in May and possibly into June. The vast majority of juvenile Chinook salmon caught during lower American River RST surveys conducted during 1994, 1995, 1996, 1997, 1998, and 1999 were fry (including yolk-sac fry) and parr, with very few emigrating as silvery parr or smolts (Snider and Titus 2002). The peak Chinook salmon catch occurred during February in most years but occurred in late January in 1996 and in early March in 1998 (Snider and Titus 2002).

Generally consistent with previous RST surveys, juvenile Chinook salmon catches during the most recent 2013 RST survey peaked between mid-February and early March, with fry passing Watt Avenue generally during January through March, parr passing generally during late March through April, and silvery parr passing generally during mid-April through May (PSFMC 2014). Emigration surveys conducted by CDFW have not demonstrated that peak juvenile emigration of Chinook salmon is related to the onset of peak spring flows in the lower American River (Snider et al. 1997).

Overall, the juvenile fall-run Chinook salmon rearing lifestage in the lower American River extends from January through May. The juvenile downstream movement period in the lower American River is coincident with the rearing period.

Water temperature is generally considered to be the most limiting factor for the juvenile rearing lifestage, particularly during late spring. Water temperatures reported to be optimal for rearing of Chinook salmon fry and juveniles are between 45°F and 65°F (NMFS 2002; Rich 1987; Seymour 1956). Raleigh et al. (1986) reviewed the available literature on Chinook salmon thermal requirements and suggested an upper limit of 75°F and a range of suitable water temperatures of about 53.6°F to 64.4°F. Water temperatures required during emigration are believed to be about the same as those required for successful rearing, although Zedonis and Newcomb (1997) report that the smoltification process can become compromised at water temperatures above 62.6°F.

Water temperatures in the lower American River can sometimes exceed the reported upper optimal value of 65°F during the warmest portion of the juvenile rearing and downstream movement lifestage (i.e., May) at Watt Avenue and particularly at the mouth of the lower American River.

Kormos et al. (2012) examined the percentage of hatchery-origin and natural-origin fall-run Chinook salmon spawners in the lower American River and the Nimbus Hatchery during 2010. They found that fall-run Chinook salmon adults spawning in the lower American River were predominantly of natural origin (68 percent), while returns to the Nimbus Fish Hatchery were predominantly of hatchery origin (79 percent).

SPRING-RUN CHINOOK SALMON

The lower American River from the outfall of the Natomas East Main Drainage Canal, also known as Steelhead Creek, downstream to the confluence with the Sacramento River was designated as critical habitat for spring-run Chinook salmon because it is believed to support non-natal rearing (70 FR 52488, September 2, 2005). NMFS further states that the lower American River can be used during high winter flows for rearing and refugia by multiple populations of spring-run Chinook salmon emanating from other rivers in the Central Valley. The downstream movement period for juvenile spring-run Chinook salmon in the lower Sacramento River reportedly occurs primarily from December through May (Snider and Titus 2000 as cited in NMFS 2014), which corresponds to the period when high winter flows typically occur.

Historically, spring-run Chinook salmon occurred in the headwaters of all major river systems in the Central Valley where natural barriers to migration were absent. Beginning in the 1880s, harvest, water development, construction of dams that prevented access to headwater areas, and habitat degradation significantly reduced the number and range of spring-run Chinook salmon in the Central Valley.

The Chinook salmon that historically migrated into the upper reaches of the American River watershed were reportedly spring-run Chinook salmon (Gerstung 1971). It has been estimated that the American River historically might have supported runs exceeding 100,000 Chinook salmon annually (spring-run and fall-run Chinook salmon combined) before mining and migration barriers from dam construction degraded the habitat (Sumner and Smith 1940).

The composition of the anadromous salmonid runs in the American River has changed over time because habitat has been degraded and eliminated. By 1955, spring-run Chinook salmon were extirpated from the American River (Gerstung 1971).

Currently, the lower American River does not support a spawning population of spring-run Chinook salmon. Habitat requirements for juvenile Chinook salmon were discussed above in the section on fall-run Chinook salmon.

RIVER AND PACIFIC LAMPREY

Both river and Pacific lampreys exhibit an anadromous, predatory life history pattern. Lamprey life history information specific to the lower American River is lacking. Generalized life histories for river lampreys and Pacific lampreys in the Central Valley are discussed above in *Overview of Fish Species*.

Most lampreys observed spawning in the lower American River have been reported as Pacific lampreys (Hannon and Deason 2008). However, both river lampreys and Pacific lampreys have been reported to be caught during RST surveys in the lower American River. During the 2013 RST survey, out of the 3,979 non-salmonids caught, 1,917 (48 percent of all non-salmonids) were identified as lampreys (PSFMC 2014). Most of the lampreys were identified as Pacific lampreys (83 percent), with 9 percent identified as river lampreys. The remaining 8 percent were lamprey ammocoetes that were not identified with regard to their species (PSFMC 2014). During the January through May 2013 RST survey, lampreys were caught throughout the season, but the majority of both species of lamprey were caught during May. In fact, 27 percent of the season’s lamprey catch was captured during one week in May (May 14–20) (PSFMC 2014).

Based on the identification of Pacific lamprey redds during steelhead spawning surveys in the lower American River (2002, 2003, 2004, 2005, 2007, and 2013), Pacific lamprey spawning is spatially concentrated downstream of Watt Avenue (particularly near Paradise Beach) and is temporally concentrated when Sacramento River flows are low and are not backing water up into the riffles in the lower reaches of the lower American River (Hannon 2013; Hannon and Deason 2005). The first observed fresh lamprey redd occurred during January in 2003, during March in 2004 and 2005, and during April in 2002 and 2013. An unconfirmed lamprey redd also was observed during February in 2007. The last fresh lamprey redd observed during the survey years when lamprey redds were identified generally occurred during April or May; however, redd surveys generally did not continue beyond April or May (Hannon 2013). The peak lamprey redd count date ranged from late March to early April (Hannon 2013).

Lamprey redds were not positively identified during steelhead spawning surveys during 2009, 2010, 2011, or 2013; however, redd surveys in the lower reaches of the lower American River have reportedly been less thorough since 2007 (Hannon 2013).

SACRAMENTO SPLITTAIL

Splittail might spawn in the lower American River in low numbers, with the majority of this spawning occurring in the lower sections of the river (i.e., downstream of RM 12) between February and May (SWRI 2001).

Fish community surveys have been conducted in the lower American River, encompassing the period from January through June annually from 1991 through 1997 (Brown et al. 1992; Snider and McEwan 1993; Snider and Keenan 1994; Snider and Titus 1996, 2000b; Snider et al. 1998); the results have been very low numbers of captured splittail (SWRI 2001).

At typical water temperatures in the lower American River in February through May (46°F–66°F), vegetation in the lower American River would need to be inundated for an estimated 2 to 4 weeks in order for spawning to occur, with the shorter end of this range applicable during April and May when water temperatures are higher. If an area is inundated for a substantially shorter period (e.g., a few days to a week) adults might spawn in the area, only to have the eggs or early larval stages stranded and dewatered when flows are reduced. When this occurs, strong year-classes are not produced (Sommer et al. 1997). Thus, inundation of riparian vegetation for such short periods is not expected to provide splittail with an opportunity to successfully produce swim-up fry capable of reaching the river's mainstem (SWRI 2001).

HARDHEAD

Little is known regarding use of the lower American River by hardheads. However, in Brown et al. (1992), larval hardheads were reportedly found in late May in the lower American River. In addition, hardheads were captured as early as November in CDFG emigration surveys using rotary screw traps (Snider and Titus 2000b; Snider et al. 1997). Generalized life history information for hardheads in the Central Valley is provided above in *Overview of Fish Species*.

AMERICAN SHAD

Adult American shad enter the lower American River beginning in April and can continue to be present in the river through the first week of July (CDFG 1986), with the majority of immigration and spawning occurring from mid-May through June (Urquhart 1987). Cannon and Kennedy (2003) observed adult American shad in the lower American River beginning in late May and continuing through August. American shad continue to provide a popular sport fishery during spring on the lower American River (Cannon and Kennedy 2006).

Since 1994, American shad have been captured in the lower American River during CDFW's emigration surveys using rotary screw traps (CDFG 2000; PSFMC 2014; Snider and Titus 1995, 2000b; Snider et al. 1997, 1998).

No specific estimates are available regarding the annual run size of American shad in the lower American River.

Generally about 70 percent of the annual spawning run consists of first-time spawners (Moyle 2002). Virgin fish have been reported to distribute themselves relative to the proportions of flow in the tributaries and the mainstem of the Sacramento River (Painter et al. 1978). Given that virgin fish often make up a majority of the spawners, the number of American shad spawning in the lower American River is expected to vary as flows in the lower American River change relative to flows in the Sacramento River.

Kelley et al. (1985b as cited in SWRI 2001) compared estimated lower American River shad catches in 1969 (Hooper 1970) and in 1976, 1977, and 1978 (Meinz 1981) with the relationship between American and Sacramento River flows during May and June of those years. In 1969 and 1978, when American River flows were 18 percent and 19 percent, respectively, of the Sacramento flows, catches were much higher than in 1976 and 1977, when American River flows were 10.5 percent and 5.4 percent, respectively, of the Sacramento River flows. No total catch estimates have been made since 1978, so further evaluations of these potential relationships have not been made (Kelley et al. 1985b as cited in SWRI 2001).

Previous reports have suggested that juvenile American shad do not use the lower American River as rearing habitat for extended periods and that the lower American River did not serve as a season-long nursery area for juvenile shad (Kelley et al. 1985b as cited in SWRI 2001; Meinz 1979; Painter et al. 1978). This suggestion apparently was based on CDFG seine surveys conducted for juvenile shad in the lower American River weekly from July through November 1977 and from mid-July through mid-September 1978. Only 98 juvenile American shad were collected, all from the mouth of the river, which suggests that juvenile American shad do not rear in the lower American River (Kelley et al. 1985b as cited in SWRI 2001).

By contrast, more-recent collections of juvenile American shad by CDFW suggest that juvenile American shad can rear in the lower American River for relatively extended periods. Emigration surveys conducted by CDFG from 1994 to 1999 (CDFG 2000; Snider and Titus 1995, 2000b; Snider et al. 1997, 1998) using a rotary screw trap indicate that juvenile American shad rearing occurs at least as far upstream as Watt Avenue well into November and even into December subsequent to spawning the previous spring.

Kelley et al. (1985b as cited in SWRI 2001) recommended flows of 2,000 cfs or greater from mid-May through June for attracting American shad. Snider and Gerstung (1986) recommended flow levels of 3,000 to 4,000 cfs in the lower American River during May and June as sufficient attraction flows to sustain the American shad fishery in the lower American River. Painter et al. (1978) recommended that to "[m]aintain a normal distribution of adult shad to tributaries in the watershed, the May/June flow of the American River should be not less than 10% of the Sacramento River at Sacramento."

STRIPED BASS

Limited information is available on striped bass in the lower American River. Few individuals have been captured by electrofishing, gill netting, seining, or rotary screw trapping. USFWS conducted Standard Fishing Method surveys throughout the year on a significant stretch of the lower American River from December 1976 through 1980 (DeHaven 1977, 1978, 1979, 1980). Those surveys provide information about the presence and distribution of striped bass both temporally and spatially.

No studies have definitively determined whether striped bass spawn in the lower American River (CDFG 1971; CDFG 1986 as cited in SWRI 2001). However, the scarcity of sexually ripe adults among sport-caught fish indicates that minimal, if any, spawning occurs in the lower American River and that adult fish that enter the river probably spawned elsewhere (DeHaven 1977, 1978).

Striped bass populations extend throughout Central Valley rivers, and juveniles and adults opportunistically use the lower American River as predators. Adult striped bass are present in the lower

American River throughout the year (DeHaven 1977), with peak abundance occurring during the summer (DeHaven 1977, 1978, 1979, 1980; Snider and McEwan 1993).

A spring “run” into the river might occur from the lower Sacramento River and Delta (Cannon and Kennedy 2006). Cannon and Kennedy (2003) fist observed adult striped bass in the lower American River during April and observed them in the largest numbers during June. Sacramento River tributaries, including the lower American River, can serve as opportunistic nursery areas for young striped bass (CDFG 1971, 1986). Numerous schools of 5-to-8-inch-long fish have been reported in the lower American River during the summer (CDFG 1971) and during fall (DeHaven 1977). Snider et al. (1998) collected some striped bass in their rotary screw traps in the summer period (May through August), which suggests an increase in abundance during that period. The majority of these fish caught were yearlings, and the remainder was divided between YOY and sub-adults. Catch rates of predominantly juvenile and subadult striped bass in the tidal reach of the lower American River reported in DeHaven (1977, 1978, 1979, 1980) seem to indicate an upstream movement of striped bass from winter and spring, to summer and fall, possibly peaking in late summer.

Optimal water temperatures for juvenile striped bass rearing have been reported to range from about 61°F to 71°F (Fay et al. 1983). The number of striped bass entering Central Valley streams during the summer is believed to vary with flow levels and food production (CDFG 1986). Snider and Gerstung (1986) suggested that flows of 1,500 cfs at the mouth during May and June would be sufficient to maintain the striped bass fishery in the lower American River. However, these investigators reported that, in any given year, the population level of striped bass in the Delta was probably the greatest factor determining the relative number of striped bass occurring in the lower American River.

1.1.3 Far-Field

The following watershed-specific sections provide descriptions of the waterbodies and associated fish species of focused evaluation. General life history information pertaining to the Central Valley, the Sacramento River, and the Delta previously discussed in *Overview of Fish Species* is not repeated in the following sections.

1.1.3.1 Sacramento River Basin

1.1.3.1.1 Sacramento River

Flows in the upper Sacramento River are regulated primarily by Shasta Dam and are reregulated 15 miles downstream at Keswick Dam. The watershed above Shasta Dam drains about 6,650 square miles with an average annual runoff of 5.7 million acre-feet (MAF). Shasta Dam has the largest capacity of any reservoir in California. Annual releases range from 9 MAF in wet years to 3 MAF in dry years. From 1964 to 1996, Keswick Dam releases averaged 7.3 MAF annually. More recently (1986 to 1996), Keswick Dam annual releases averaged 5.9 MAF (USFWS et al. 1999).

Shasta Reservoir releases, and therefore Sacramento River flow, are often governed by water temperature requirements below Keswick Dam for April through October and an end-of-September carryover storage target for Shasta Reservoir of 1.9 MAF to protect Sacramento River winter-run Chinook salmon (NMFS 2004, 2009, 2014). To meet the temperature objectives, Reclamation dynamically evaluates ambient air temperature, weather forecasts, water temperature at the release point, and release rate. Reclamation often determines the appropriate release rate based on the temperature of the water released rather than the rate needed to support Central Valley Project (CVP) operations. Generally, it takes higher releases to meet water temperature targets with warmer water and lower releases with colder water. The coldwater pool in the reservoir is essentially a function of the volume of water in the reservoir. During years when CVP facilities cannot be operated to meet required temperature and storage objectives, Reclamation reinitiates consultation with NMFS.

The upper Sacramento River is often defined as the portion of the river from Princeton (RM 163) (the downstream extent of salmonid spawning in the Sacramento River [Water Forum 1999]) to Keswick Dam (the upstream extent of anadromous fish migration and spawning). The upper Sacramento River provides a diversity of aquatic habitats including fast-water riffles and shallow glides, slow-water deep glides and pools, and off-channel backwater habitats. Consequently, this section of the river is of primary importance to native anadromous species and is presently used for spawning and early-life-stage rearing, to some degree, by all four runs of Chinook salmon (fall, late-fall, winter, and spring) and steelhead.

The lower Sacramento River is generally defined as the portion of the river from Princeton to the Delta at about Chipps Island (near Pittsburg), which includes the study area for this Project. The lower Sacramento River is predominantly channelized, leveed, and bordered by agricultural land. Aquatic habitat in the lower Sacramento River is characterized primarily by slow-water glides and pools, is depositional in nature, and has lower water clarity and habitat diversity relative to the upper portion of the river.

Many of the fish species using the upper Sacramento River also use the lower river to some degree, even if only as a migratory pathway to and from upstream spawning and rearing grounds. For example, adult Chinook salmon and steelhead primarily use the lower Sacramento River as an immigration route to upstream spawning habitats and an emigration route to the Delta. The lower river also is used by other fish species (e.g., Sacramento splittail and striped bass) that make little to no use of the upper river (upstream of RM 163).

Overall, fish species composition in the lower portion of the Sacramento River is similar to that of the upper Sacramento River and includes resident and anadromous cold- and warmwater species. Many fish species that spawn in the Sacramento River and its tributaries depend on river flows to carry their larval and juvenile lifestages to downstream nursery habitats. Native and introduced warmwater fish species use the lower river primarily for spawning and rearing, with juvenile anadromous fish species also using the lower river and non-natal tributaries, to some degree, for rearing.

Over 30 species of fish are known to use the Sacramento River. Of these, a number of both native and introduced species are anadromous. Anadromous species include Chinook salmon (winter-run, spring-run, fall-run, and late fall-run), steelhead, green and white sturgeon, Pacific lamprey, river lamprey, American shad, and striped bass.

Descriptions of life histories of fish species of focused evaluation in the Sacramento River are provided above in *Overview of Fish Species*.

1.1.3.1.2 Sutter and Yolo Bypasses

Flow from the Sacramento River spills into the Sutter and Yolo Bypasses during high-flow events. The bypasses form a floodplain corridor that is an important part of the flood-control system but also serves as important habitat for juvenile salmonids and other native fish. Fish can enter the bypasses through flood-relief structures and weirs. The Sacramento River enters the Sutter Bypass at Moulton, Colusa, and Tisdale Weirs and enters the Yolo Bypass at the Freemont Weir.

1.1.3.1.3 Sutter Bypass

Within the Sutter National Wildlife Refuge (NWR), native anadromous fish include steelhead and four distinct runs of Chinook salmon (USFWS 2009). Encompassing an area of about 2,600 acres, the Sutter NWR is located about 50 miles north of Sacramento, 10 miles southwest of Yuba City, and 5 miles south of Sutter, California. About 80 percent of the Sutter NWR is within the Sutter Bypass, which is west of Yuba City, California (USFWS 2009). The east and west Sutter Bypass canals are part of lower Butte Creek and are tributary to the larger Sacramento River system.

During periods of high flows in the Sutter Bypass, large numbers of Chinook salmon and steelhead can use the Sutter NWR (USFWS 2009). When the Sutter Bypass is inundated, the relatively warmer waters of the floodplain become very productive and produce an abundance of prey, resulting in rapid growth rates and relatively large sizes of juvenile anadromous salmonids outmigrating to the Delta and the Pacific Ocean.

During periods of flooding, the Sutter NWR provides high-value rearing habitat for migrating juvenile Chinook salmon. Water enters the Sutter Bypass in several ways. First, Butte Creek, a non–State Water Project (SWP)/CVP tributary of the Sacramento River, spills into Sutter Bypass via Butte Slough (Feyer et al. 2006). Second, when Sacramento River flows exceed between 90,000 and 100,000 cfs at Ord Ferry, water flows naturally over the banks into the Butte Basin. In addition to the Sacramento River overbank flows at Ord Ferry, the Sutter Bypass receives inflow at weirs along the Sacramento River during high-flow events. Water enters Sutter Bypass at Tisdale Weir when Sacramento River flow exceeds 21,012 cfs, at Moulton Weir when flow exceeds 44,990 cfs, and at Colusa Weir when flow exceeds 65,014 cfs (Feyer et al. 2006).

1.1.3.1.4 Yolo Bypass

The Yolo Bypass is a leveed, 59,000-acre floodplain on the west side of the lower Sacramento River. The bypass carries floodwaters from several northern California waterways to the Delta (Yolo Basin Foundation 2001). Yolo Bypass (and its upstream counterpart, the Sutter Bypass) conveys flood flows of the Sacramento River and smaller tributaries around and away from cities such as Sacramento (Sommer et al. 2008). The Yolo Bypass is inundated from flows from the Sacramento River during parts of winter and spring, in about 70 percent of years, when total flow in the Sacramento River exceeds 2,000 cubic meters per second at the northern boundary of the Yolo Bypass (Sommer et al. 2008).

The primary input to the Yolo Bypass is through Fremont Weir in the north, which conveys floodwaters from the Sacramento and Feather Rivers (Sommer et al. 2003). During major storm events (i.e., >5,000 cubic meters per second), additional water enters from the east via Sacramento Weir, adding flow from the American and Sacramento Rivers (Sommer et al. 2003). Flow also enters the Yolo Bypass from several small west-side streams, including Knight's Landing Ridge Cut, Cache Creek, the Willow Slough Bypass, and Putah Creek (Sommer et al. 2003).

At peak flows, up to 24,000 hectares of the Yolo Bypass are inundated (Sommer et al. 2008). Typical dimensions are 2 to 10 km (about 1.2 miles to about 6 miles) wide with a mean depth of 2 meters (about 6.5 feet) or less (Sommer et al. 2008). The floodwaters flowing through the Yolo Bypass re-enter the Sacramento River via Cache Slough (Moyle 2008). The principal permanent water channel in the Yolo Bypass is the Toe Drain, which runs along the levee on the eastern side (Moyle 2008).

The southern outlet of the Yolo Bypass is Liberty Island, which is an inundated island encompassing 5,209 acres (CALFED 2005). Liberty Island has been flooded since 1998 when its levees were breached during high flows through the Yolo Bypass (CALFED 2005). Between 1998 and 2005, Liberty Island has transformed from a large organic tomato farm to over 800 acres of freshwater tidal marsh and emerging marsh, 55 acres of herbaceous wetlands, and almost 20 acres of riparian habitat (CALFED 2005). While non-native fish have dominated sampling efforts at Liberty Island, native fish species observed include Chinook salmon, Sacramento splittail, longfin smelt, delta smelt, Sacramento tule perch, Sacramento pikeminnow, and starry flounder (CALFED 2005).

Important ecological processes within the overall Yolo Basin include streamflow and inundation, stream erosion, and natural sediment supply. Important aquatic habitats within the Yolo Basin include stream and slough channels for fish migration and holding, spawning, and nursery habitats (CALFED 2000). The Yolo Bypass provides diverse habitats for a wide variety of fish, wildlife, and plant communities, primarily native resident (nonmigratory) fish (see **Table 7**), riparian communities, seasonally and permanently flooded wetlands, wildlife, and waterfowl (CALFED 2000).

Sommer et al. (1997) demonstrated that the Yolo Bypass is one of the single most important habitats for Sacramento splittail. Introduced fish species frequently dominate the fauna in the Delta on a year-round basis (Bennett and Moyle 1996). However, unlike the other Delta habitats, the floodplain in the Yolo Bypass is seasonally dewatered during late spring through autumn, which prevents exotic species from establishing year-round dominance except in perennial water sources (Sommer et al. 2003).

Table 8. Native and Introduced Fish Species Observed in the Yolo Bypass.

Native Fish Species	Introduced Fish Species	
Chinook salmon	American shad	Redear sunfish
Steelhead	Threadfin shad	Green sunfish
Pacific lamprey	Common carp	Warmouth
River lamprey	Goldfish	Black crappie
Hitch	Fathead minnow	White crappie
Sacramento blackfish	Golden shiner	Bigscale logperch
Sacramento pikeminnow	Red shiner	Largemouth bass
Sacramento sucker	Channel catfish	Smallmouth bass
Sacramento splittail	White catfish	Spotted bass

Native Fish Species	Introduced Fish Species	
Prickly sculpin	Black bullhead	Striped bass
Pacific staghorn sculpin	Brown bullhead	Shimofuri goby
Threespine stickleback	Wakasagi	Yellowfin goby
Sacramento tule perch	Inland silverside	
Delta smelt	Western mosquitofish	
White sturgeon	Bluegill	
Source: Modified from Sommer et al. 2003		

The portion of the Yolo Bypass north of the Yolo Causeway on Interstate 80 is an important migratory route during wet years for downstream migrant Chinook salmon, steelhead, and other native and anadromous fish originating from upstream areas. When flooded, the Yolo Bypass provides valuable spawning habitat for native resident fish (CALFED 2000). For example, during flood pulses, the Yolo Bypass floodplain provides juvenile anadromous salmonids an alternative migration corridor to the lower Sacramento River (Sommer et al. 2003). The results of Sommer et al. (2001) indicated that this seasonal floodplain habitat provides better rearing conditions than the adjacent Sacramento River channel because of two major advantages: (1) increased area of suitable habitat (e.g., extensive shoals and increased habitat complexity); and (2) increased food resources. Sommer et al. (2001) found that improved rearing conditions allowed juvenile salmon to grow substantially faster in the Yolo Bypass floodplain than in the adjacent Sacramento River, primarily because of a higher abundance of invertebrate prey in the floodplain.

In addition to providing key habitat for native and non-native fish, seasonal inundation of the Yolo Bypass might also benefit organisms downstream in the brackish portion of the San Francisco Estuary through transfer of phytoplankton and detritus (Sommer et al. 2003). Modeling studies by Jassby and Cloern (2000) suggest that phytoplankton produced in the Yolo Bypass can be an important source of organic carbon to the San Francisco Estuary, at least during flood events. The Yolo Bypass also is probably a major pathway for detrital material to the phytoplankton-deficient San Francisco Estuary (Sommer et al. 2003). Schemel et al. (1996 as cited in Sommer et al. 2003) found that the Yolo Bypass is the major pathway for organic matter to the San Francisco Estuary during wet years.

The Cache Slough Complex, which includes Liberty Island, the Little Holland Tract, the Hastings Tract, and Prospect Island, has become an important focus for restoration activities in the North Delta to increase and improve the overall habitat for delta smelt (CDFG 2008). This region has high restoration potential as tidal freshwater marsh and slough habitat because:

1. Island subsidence is low compared to other parts of the Delta;
2. It maintains much of its original drainage pattern;
3. It is a major spawning and rearing region for delta smelt;
4. It has strong tidal currents that move water from the Sacramento River in and out of its channels;
5. It drains the lower end of the Yolo Bypass; and

6. It contains Liberty Island (which has already been flooded and provides high-quality habitat and ecological functions) (Moyle 2008).

The region can be converted relatively easily into favorable tidal habitat for native fish (Moyle 2008). This region could provide spawning beaches and productive rearing areas for larvae that are unsuitable to potential egg and larval predators, particularly inland silverside (Moyle 2008).

1.1.3.2 Feather River

The lower Feather River commences at the Low Flow Channel, which extends 8 miles from the Fish Barrier Dam (RM 67) to the Thermalito Afterbay Outlet (RM 59). Under an agreement with CDFG, flows in this reach of the river are regulated at 600 cfs, except during flood events when flows have been as high as 150,000 cfs (DWR 1983). Average monthly water temperatures typically range from about 47°F in winter to about 65°F in summer.

The majority of the Low Flow Channel flows through a single channel contained by stabilized levees. Side-channel or secondary channel habitat is extremely limited, occurring primarily in the Steep Riffle and Eye Riffle areas between RM 60 and RM 61. The channel banks and streambed consist of armored cobble as a result of periodic flood flows and the absence of gravel recruitment. However, there are nine major riffles with suitable spawning-size gravel, and about 75 percent of the Chinook salmon spawning takes place in this upper reach (Sommer et al. 2001). Releases are made from the coldwater pool in Oroville Reservoir, and this cold water generally provides suitable water temperatures for spawning in the Low Flow Channel (DWR 2001).

The lower reach extends 15 miles from the Thermalito Afterbay Outlet (RM 59) to Honcut Creek (RM 44). Releases from the outlet vary according to operational requirements. In a normal year, total flow in the lower reach ranges from 1,750 cfs in fall to 5,000 cfs to 8,000 cfs in spring. Water temperature in winter is similar to the Low Flow Channel but increases to 74°F in summer. Higher flows dramatically increase the channel width in this reach. Numerous mid-channel bars and islands braid the river channel, creating side-channel and backwater habitat. The channel is not as heavily armored, and long sections of riverbanks are actively eroding. In comparison to the Low Flow Channel, there is a greater amount of available spawning areas, which are isolated by longer and deeper pools (DWR 2001).

1.1.3.2.1 Spring-run Chinook Salmon

Adult spring-run Chinook salmon enter the Sacramento River Basin between March and September, primarily in May and June (Moyle 2002; Yoshiyama et al. 1998 as cited in NMFS 2014). Spring-run Chinook salmon adult immigration and holding in the lower Yuba River reportedly occurs from April through September (RMT 2013). Thus, spring-run Chinook salmon in the lower Feather River also might be holding into September. Adult Chinook salmon in the lower Feather River exhibiting the typical life history of the spring-run have been found holding at the Thermalito Afterbay Outlet and the Fish Barrier Dam as early as April (DWR 2007 as cited in NMFS 2014).

Spring-run Chinook salmon spawning and embryo incubation in the lower Feather River can occur from September through February (NMFS 2014). Spring-run Chinook salmon fry generally emerge from the gravel from November to March (Moyle 2002). Most juvenile Chinook salmon emigrate from the lower

Feather River within a few months of emergence (NMFS 2014). However, some spring-run Chinook salmon juveniles reportedly rear for up to 15 months prior to emigrating (NMFS 2014).

1.1.3.2.2 Fall-run Chinook Salmon

In the Central Valley, adult fall-run Chinook salmon are reported to generally begin migrating upstream annually in July, with immigration continuing through December in most years (NMFS 2004; Vogel and Marine 1991). Fall-run Chinook salmon spawning and embryo incubation generally extend from October through February or March (Moyle 2002; SWRI 2001; Vogel and Marine 1991). The juvenile fall-run Chinook salmon rearing period in the Central Valley reportedly extends from late December through June (Moyle 2002; Vogel and Marine 1991). In the Feather River, fall-run Chinook salmon fry emergence has been reported to occur as early as November (Seesholtz et al. 2003). Therefore, for this evaluation, USACE evaluated fall-run Chinook salmon juvenile rearing and downstream movement during November through June.

1.1.3.2.3 Steelhead

The majority of natural steelhead spawning in the Feather River is reported to occur in the Low Flow Channel, particularly in the upper reaches near Hatchery Ditch, although limited steelhead spawning also occurs below the Thermalito Afterbay Outlet (DWR 2007). The residence time of adult steelhead in the Feather River after spawning and the extent of adult steelhead post-spawning mortality are currently unknown (NMFS 2014). Recently, RMT (2013) identified steelhead lifestage periodicities in the lower Yuba River (a tributary of the Feather River), which are used in evaluating steelhead in the lower Feather River.

RMT (2010, 2013) identified the period extending from August through March as encompassing the majority of the upstream migration and holding of adult steelhead in the lower Yuba River. Steelhead adults typically spawn from December through April with peaks from January through March in small streams and tributaries where cool, well-oxygenated water is available year-round (McEwan 2001; Hallock et al. 1961). Based on all available information collected to date, RMT (2013) recently identified the steelhead spawning period in the lower Yuba River as extending from January through April, with embryo incubation extending into May.

Juvenile steelhead rearing in the lower Yuba River exhibits a variety of temporal periods. Some juvenile steelhead might rear in the lower Yuba River for a short duration (up to a few months) whereas others might spend from 1 to 3 years rearing in the river. A review of available data indicates that emigration of steelhead smolts 1 year old and older (yearling+) can extend from October through mid-April (RMT 2010, 2013).

1.1.3.2.4 Green Sturgeon

Limited information regarding green sturgeon distribution, movement and behavioral patterns, and lifestage-specific habitat utilization preferences is available for the Feather River. Although adult green sturgeon occurrence in the Feather River has been previously documented, larval and juvenile green sturgeons have not been collected despite attempts to collect them during the early spring through summer using rotary screw traps, artificial substrates, and larval nets deployed at multiple locations

(Seesholtz et al. 2003). Moreover, unspecific past reports of green sturgeon spawning (CDFG 2002; Wang 1986) have not been corroborated by observations of young fish or significant numbers of adults in focused sampling efforts (Beamesderfer et al. 2004; Niggemeyer and Duster 2003; Seesholz et al. 2003).

Based on these results, in 2006, NMFS concluded that an effective population of spawning green sturgeon did not exist in the lower Feather River (71 FR 17757). However, four fertilized green sturgeon eggs were collected near the Thermalito Afterbay Outlet on June 14, 2011, thus providing the first documentation of at least some successful spawning in the Feather River (A. Seesholtz, DWR, pers. comm., June 16, 2011, as cited in USACE 2013).

Green sturgeon in the Sacramento River have been documented and studied more widely than they have in the Feather River. For this evaluation, USACE assumes that green sturgeon in the Feather River would share the same life history traits as green sturgeon in the Sacramento River as described previously in *Overview of Fish Species*.

1.1.3.2.5 White Sturgeon

Although both green and white sturgeon are native to California, white sturgeon are more commonly observed in the Feather River (DWR 2003 as cited in DWR 2005) and are known to spawn in the Feather River (Moyle 2002). For this evaluation, USACE assumes that white sturgeon life history periodicities in the Feather River are the same as those previously discussed for the Sacramento River in *Overview of Fish Species*.

1.1.3.2.6 River Lamprey

River lamprey life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in *Overview of Fish Species*.

1.1.3.2.7 Pacific Lamprey

Pacific lamprey life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in *Overview of Fish Species*.

1.1.3.2.8 Sacramento Splittail

Sacramento splittail life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in *Overview of Fish Species*. Sacramento splittail spawning, embryo incubation, and initial rearing lifestages in the lower Feather River occur from February through May. Sacramento splittail spawning in the lower Feather River has been reported to occur predominantly on flooded vegetated benches (DWR 2004a).

1.1.3.2.9 Hardhead

Hardhead life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in *Overview of Fish Species*.

AMERICAN SHAD

American shad life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in *Overview of Fish Species*. American shad adult spawning in the lower Feather River occurs from April through June (DWR 2007). American shad juvenile rearing reportedly occurs in the Feather River below Yuba City (USFWS 1995).

STRIPED BASS

Striped bass life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in *Overview of Fish Species*. Striped bass spawning in the lower Feather River extends from April through June (DWR 2007).

1.1.3.3 Delta

The San Francisco Bay/Sacramento–San Joaquin Delta makes up the largest estuary on the west coast of the United States (EPA 1992). The Sacramento–San Joaquin Delta, the most upstream portion of the Bay-Delta estuary, is a triangle-shaped area composed of islands, river channels, and sloughs at the confluence of the Sacramento and San Joaquin Rivers. The northern Delta is dominated by the waters of the Sacramento River, which are of relatively low salinity, whereas the relatively higher-salinity waters of the San Joaquin River dominate the southern Delta. The central Delta includes many channels where waters from the Sacramento and San Joaquin Rivers and their tributaries converge. The Delta includes the river channels and sloughs at the confluence of the Sacramento and San Joaquin Rivers.

The Delta’s tidally influenced channels and sloughs cover a surface area of about 75 square miles. Data suggest that these intertidal waters favor a number of resident freshwater fish and invertebrate species at the deepest, most subsided sites. Marsh plains and tidal channels formed within these intertidal regions continuously drain and fill with the ocean tide, allowing movement of fish, in addition to primary and secondary production, inshore and offshore. Tidal action can therefore be important for pelagic organisms as inundation allows increased foraging success and opportunity resulting from the larger abundance of phytoplankton and zooplankton inshore.

Intertidal habitats can also provide reduced predation for young fishes (Brown 2003). These waters can also be used as migration corridors and rearing areas for anadromous fish species and as spawning and rearing grounds for many estuarine species. Similarly to intertidal regions, shallow-water habitats, defined as areas that are less than 3 meters in depth (mean low water), are considered particularly important forage, reproduction, rearing, and refuge areas for numerous fish and invertebrate species.

Historical modification of ecosystem processes and functions in the Delta and throughout the Sacramento and San Joaquin River watersheds have influenced the current aquatic habitat conditions, which directly affects special-status species and other species of focused evaluation (i.e., recreationally and commercially important species). Flow-related habitat conditions are the result of a combination of (1) unaltered discharges from surface water and groundwater flowing into the Delta and (2) managed releases from reservoirs. Flows in the Delta vary seasonally and annually with rainfall, runoff, and water supply management.

The majority of fish species in the Delta use the Tidal Perennial Aquatic community (see the *CALFED Ecosystem Restoration Program Plan* for detailed description of the aquatic communities in the Delta). Delta aquatic communities are used by fish for foraging, spawning, egg incubation and larval development, juvenile nursery areas, and migratory corridors. Most Delta resident fish species spend their entire lives in the Tidal Perennial Aquatic community, while other fishes in the Delta can spend certain seasons or part of their lives in different areas of the community, based on physical factors such as salinity, turbidity, dissolved oxygen, flow rates, and water temperature.

Use of the various aquatic habitats within the Delta by individual species is often determined by multiple physical factors (e.g., flow, salinity, wind, tide, and temperature), many of which vary at multiple temporal scales (Kimmerer 2004). Resident and migratory fish use Delta aquatic habitats for spawning, rearing, foraging, and escape cover. Striped bass, delta smelt, Sacramento splittail, and many resident Bay-Delta fish use this habitat for rearing and as adults (CALFED 2000). Young steelhead and Chinook salmon forage in these productive waters as fry and juveniles to gain weight and improve their condition before entering the ocean.

In the Delta, saline coastal oceanic water is mixed and diluted by the flowing freshwater of rivers. This mix of fresh and oceanic water forms a salinity gradient that varies by area and location with seasonal variations in freshwater inflow and tidal action. This gradient drives the location of species that depend on salinity, such as delta smelt and longfin smelt. The location of this gradient reportedly varies on multiple time scales as a result of multiple processes: daily tides, the monthly lunar cycle, intra-annual (seasonal) flow patterns, and interannual flow variation from interannual rainfall variation, and long-term global climate change (Kimmerer 2004). During low-flow periods, the salinity gradient is maintained at locations that provide freshwater in the Delta at levels that maintain human uses. Historically, the salinity gradient was generally farther downstream than it now occurs under similar hydrologic conditions.

As reported in the *Pelagic Organism Decline Progress Report: 2007 Synthesis of Results* (Baxter et al. 2008; Feyrer et al. 2007), habitat for pelagic fish species consists of open water, largely away from shorelines and vegetated inshore areas. These areas are used for the majority of the lifecycle needs of the pelagic fish species except perhaps during spawning. Pelagic open-water habitat includes the deeper areas of many of the larger channels in the Delta, in addition to large embayments such as Suisun Bay. Pelagic fish habitat is characterized by physical and chemical properties, including salinity, turbidity, and water temperature, and biological properties such as prey production. Thus, pelagic fish habitat suitability in the estuary is influenced by variation in freshwater flow (e.g., Delta outflow) (Bennett and Moyle 1996; Jassby et al. 1995; Kimmerer 2004).

Several fish species use a variety of behaviors to maintain themselves within open-water areas where water quality and food resources are favorable (Bennett et al. 2002 as cited in Reclamation 2008). Delta smelt, longfin smelt, striped bass, and threadfin shad distribute themselves at different concentrations of salinity within the estuarine salinity gradient (Feyrer et al. 2007; Kimmerer 2002a), which indicates that, at any point in time, salinity is a major factor affecting their geographic distributions. Because of the importance that salinity has on fish distribution in the estuary, the term *Low-Salinity Zone* (LSZ) within the San Francisco Estuary was created. This term is defined as the area within the estuary where salinity is about 0.5 to 6 ppt. X2 (i.e., roughly the center of the LSZ), is defined as salinity of around 2 ppt

(Kimmerer 2002b). The term *X2* is used to define the distance from the Golden Gate Bridge upstream to the location where salinity near the bottom of the water column is about 2 ppt.

Salinity between 2 ppt and about 30 ppt is roughly linearly distributed between X2 and the mouth of the estuary (Monismith et al. 1996 as cited in Kimmerer 2002b). X2 reflects the physical response of the San Francisco Estuary to changes in flow and provides a geographic frame of reference for estuarine conditions (Kimmerer 2002b). The estuary responds to freshwater flow on a time scale of 2 weeks, as characterized by the statistical relationship between X2 and flow (Jassby et al. 1995 as cited in Kimmerer 2004). Because the position of X2 relies on a number of physical parameters including river flows, water diversions, and tides, its position shifts over many kilometers on a daily and seasonal cycle. Over the course of a year, the location of X2 can range from San Pablo Bay during high-river-flow periods up into the Delta during the summer.

According to CDFG (2010), the available data and information indicate:

1. The abundances of many fish and aquatic species are related to water flow timing and quantity (or the placement of X2);
2. For many fish and aquatic species, more water flow translates into greater species production or abundance;
3. Fish and aquatic species are adapted to use the water resources of the Delta during all seasons of the year, but, for many species, important life history stages or processes consistently coincide with increased winter-spring flows; and
4. The source, quality, and timing of water flows through the estuary influences the production of Chinook salmon in both the San Joaquin River and Sacramento River Basins (CDFG 2010).

However, Delta outflow is affected by multiple factors and conditions, many of which are involved in hypothesized mechanisms for X2 relationships (Kimmerer 2004). Therefore, the presence of an X2 relationship does not necessarily imply anything about the conditions at the location where the salinity is near 2 ppt (Kimmerer 2004).

Delta inflow and outflow are important for species residing primarily in the Delta (e.g., delta smelt and longfin smelt) (USFWS 1994) and for juveniles of anadromous species (e.g., Chinook salmon) that rear in the Delta prior to ocean entry. Seasonal Delta inflows and outflows affect several key ecological processes including:

1. The migration and transport of various lifestages of resident and anadromous fish using the Delta (EPA 1992);
2. Salinity levels at various locations within the Delta as measured by the location of X2; and
3. The Delta's primary (phytoplankton) and secondary (zooplankton) production.

Species and lifestage-specific discussions are provided below for fish species of focused evaluation and for species that depend on the Delta for one or more lifestages. General life history information provided in Section 1.1.2.1, *Overview of Fish Species* is not repeated in this section.

1.1.3.3.1 Delta Smelt

Delta smelt are endemic to the Bay-Delta estuary (Moyle 2002). Delta smelt are found primarily downstream of Isleton on the Sacramento River, downstream of Mossdale on the San Joaquin River, and in Suisun Bay and Suisun Marsh. Delta smelt adults occur primarily in the tidally influenced low salinity region of Suisun Bay and the freshwater regions of the Delta and the Sacramento and San Joaquin Rivers (Moyle 2002). The downstream location of the low-salinity habitat for delta smelt is typically located in Suisun Bay but extends farther to the west in response to high Delta outflows and farther to the east in response to low Delta outflows.

Delta smelt have been collected in Carquinez Strait, the Napa River, and even as far downstream as San Pablo Bay in wet years (Moyle 2002). During September or October, adults begin upstream movement toward freshwater sloughs and channels of the western Delta to spawn. Spawning takes place between February and July but appears to be greatest during mid-April and May (Bennett 2005). Spawning can occur in the Sacramento River as far upstream as Sacramento, the Mokelumne River system, and the Cache Slough region (Moyle 2002). Since 1982, the center of adult delta smelt abundance in the fall has been the northwestern Delta in the channel of the Sacramento River near Decker Island. In any month, two or more lifestages (adult, larvae, and juveniles) of delta smelt could be present in Suisun Bay (DWR and Reclamation 1994; Moyle 2002; Wang 1991). Delta smelt are also found seasonally in Suisun Marsh.

1.1.3.3.2 Longfin Smelt

Longfin smelt larvae have a widespread distribution in the San Francisco Estuary and are detected each year in the western Delta, Suisun Bay, Suisun Marsh, and the southern Delta (Baxter 1999). Larval longfin smelt are also frequently caught in San Pablo Bay, and they are sometimes caught in the Central and South Bays and the eastern and southern Delta (Baxter 1999). In many years, longfin smelt are caught in the Napa River Estuary as well. Larval sampling in the South Bay is not extensive enough to characterize the presence or abundance (if any) of larval longfin smelt.

Longfin smelt are widespread within the Delta and, historically, they were found seasonally in all of its major open-water habitats and Suisun Marsh. Longfin smelt are believed to spawn at the transition zone between freshwater and saltwater, but the exact spawning locations and conditions that support egg deposition and incubation are unknown. Spawning almost certainly occurs in the Sacramento River mainstem, probably near Rio Vista and downstream.

Spawning longfin smelt scatter adhesive eggs on sand substrates from December through May (CDFG 2010). Based on the identified presence of newly hatched larvae and an assumed 25-day incubation period, CDFG (2009) estimated that longfin smelt likely spawn during November through April, with a peak in January. Longfin smelt spawning is believed to occur in the Sacramento River mainstem near Rio Vista and downstream (Reclamation 2008a). As water temperatures drop below 18°C during the fall, maturing adult longfin smelt migrate from the lower estuary to the LSZ and congregate prior to spawning (CDFG 2009). Spawning reportedly starts when water temperatures drop below 16°C and becomes consistent when water temperatures drop below 13°C (CDFG, unpublished data, as cited in CDFG 2009). Moyle (2002) states that longfin smelt inhabiting the Bay-Delta estuary are thought to spawn in freshwater or slightly brackish water over sandy or gravel substrates at temperatures ranging from 7°C to 14.5°C (44.6°F to 58.1°F) (Moyle 2002).

Movement patterns based on catches in CDFG fishery sampling suggest that longfin smelt actively avoid water temperatures greater than 22°C (72°F). In addition, sampling data suggest that longfin smelt do not occupy areas with temperatures greater than 22°C (72°F) in combination with salinities greater than 26 ppt.

1.1.3.3.3 Chinook Salmon

As reported in NMFS (2014), as Chinook salmon begin the smoltification stage, they are found rearing in the estuary where ambient salinity reaches 1.5 to 2.5 ppt (T.P. Healey 1979). Within the Delta, juvenile Chinook salmon forage in shallow areas with protective cover, such as tidally influenced sandy beaches and vegetated zones (T.P. Healey 1979). Juvenile Chinook salmon movements within estuarine habitat are dictated by the interaction between tidally driven saltwater intrusions through the estuary and freshwater outflow from the Sacramento and San Joaquin Rivers. Juvenile Chinook salmon follow rising tides into shallow-water habitats from the deeper main channels and return to the main channels when the tides recede (M.C. Healey 1991). Kjelson et al. (1981) reported that juvenile Chinook salmon demonstrated a diel migration pattern, orienting themselves to nearshore cover and structure during the day but moving into more open, offshore waters at night.

Juvenile Chinook salmon were found to spend about 40 days migrating through the Delta to the mouth of San Francisco Bay and grew little in length or weight until they reached the Gulf of the Farallones (MacFarlane and Norton 2002). Based on the mainly ocean-type life history observed (i.e., fall-run), MacFarlane and Norton (2002) concluded that, unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon show little estuarine dependence and might benefit from expedited ocean entry (NMFS 2009).

1.1.3.3.3.1 Winter-run Chinook Salmon

Because spawning adult winter-run Chinook salmon use only the Sacramento River Basin, adults are likely to migrate upstream primarily along the western edge of the Delta through the Sacramento River corridor. Because juvenile winter-run Chinook salmon have been collected at various locations in the Delta (including the SWP and the CVP south Delta export facilities), juveniles likely use a wider range of the Delta for migration and rearing than adults (ICF 2013).

Winter-run Chinook salmon fry and smolts emigrate downstream from July through March through the Sacramento River, reaching the Delta from September through June. Winter-run Chinook salmon juvenile rearing in the Delta reportedly occurs primarily from November through early May (NMFS 2014). Juveniles reportedly remain in the Delta until they reach a fork length of about 118 mm and are from 5 to 10 months of age, and emigrate to the ocean as early as November (NMFS 2014). The importance of the Delta in the life history of Sacramento River winter-run Chinook salmon is reportedly not well understood (NMFS 2014).

1.1.3.3.3.2 Spring-run Chinook Salmon

Adult Central Valley spring-run Chinook salmon reportedly migrate primarily along the western edge of the Delta through the Sacramento River corridor, and juvenile spring-run Chinook salmon use the Delta, Suisun Marsh, and the Yolo Bypass for migration and rearing (ICF 2013). As reported by NMFS (2009), the emigration period for spring-run Chinook salmon extends from November to early May, with up to 69 percent of the YOY fish outmigrating through the lower Sacramento River and Delta during this period (CDFG 1998). NMFS (2014) stated that juvenile spring-run Chinook salmon have been found at Chipps Island in the Delta primarily during December through June. However, by the time that yearling spring-run Chinook salmon reach Chipps Island, they cannot be distinguished from fall-run Chinook salmon yearlings.

1.1.3.3.3.3 Fall and Late Fall-run Chinook Salmon

Adult fall-run and late fall-run Chinook salmon migrating into the Sacramento River and its tributaries primarily use the western and northern portions of the Delta, whereas adults entering the San Joaquin River system reportedly use the western, central, and southern Delta as a migration pathway (ICF 2013). Juvenile fall-run and late fall-run Chinook salmon use the Delta, Suisun Marsh, and the Yolo Bypass for rearing to varying degrees, depending on their lifestage (fry versus juvenile), size, river flows, and time of year (ICF 2013).

Adult fall-run Chinook salmon reportedly migrate through the Delta and into Central Valley rivers from June through December, while adult late fall-run Chinook salmon migrate through the Delta from October through April (ICF 2013). In general, fall-run Chinook salmon fry abundance in the Delta increases following high winter flows. Most fall-run Chinook salmon fry rear in freshwater from December through June, with emigration as smolts occurring primarily from January through June (ICF 2013). Late fall-run fry rear in freshwater from April through the following April and emigrate as smolts from October through February (Snider and Titus 2000 as cited in ICF 2013). In general, fall-run and late fall-run Chinook salmon juveniles primarily occur in the Delta during November through June (ICF 2013).

1.1.3.3.4 Central Valley Steelhead

Steelhead adults entering the Sacramento River system to spawn reportedly use the northern, western, and central Delta as a migration pathway (ICF 2013).

Some juvenile steelhead might use brackish tidal marsh areas, nontidal marshes, and other shallow water areas in the Delta as rearing areas for short periods of time prior to their emigration to the ocean (ICF 2013). Hallock et al. (1961) found that juvenile steelhead in the Sacramento River Basin migrate downstream during most months of the year, but the peak emigration period occurred during the spring, with a smaller peak during the fall. Nobriga and Cadrett 2003 as cited in NMFS 2009) reportedly verified these temporal findings based on analysis of captures in USFWS monitoring surveys conducted near Chipps Island. NMFS (2009) reported that steelhead rearing and outmigration in the Delta occurs during October through July.

1.1.3.3.5 Green Sturgeon

The Delta serves as a migratory corridor, feeding area, and juvenile rearing habitat for southern DPS green sturgeon (ICF 2013). Adults migrate upstream primarily through the western edge of the Delta into the lower Sacramento River between March and June (Adams et al. 2002; ICF 2013). Although little is known about the distribution of and movement of YOY and juvenile green sturgeon, observations suggest that they are distributed in the mainstem Sacramento River below Anderson and in fresh and brackish portions of the north and interior Delta (Israel and Klimley 2008). Larvae and post-larvae are reportedly present in the lower Sacramento River and northern Delta between May and October, primarily during June and July (CDFG 2002 as cited in ICF 2013). Juvenile green sturgeon have been captured in the Delta during all months of the year (Borthwick et al. 1999 and CDFG 2002, both as cited in ICF 2013). Juvenile green sturgeon have been reported to be caught by anglers in the Sacramento River between Rio Vista and Chipps Island, in the Sacramento Deep Water Ship Channel, in Montezuma Slough, in the Napa River, in the Carquinez Strait, and in Suisun Bay (Gleason et al. 2007 as cited in Israel and Klimley 2008).

Subadult green sturgeon inhabit the Delta and bays during summer, while adults reportedly are most often in the seawater and mixing zones of bays and estuaries and are occasionally found in the lower stretches of some rivers (Environmental Protection Information Center et al. 2001).

1.1.3.3.6 White Sturgeon

The Delta serves as a migratory corridor, feeding area, and juvenile rearing area for white sturgeon. White sturgeon spend most of their lives in the brackish portions of the upper estuary, although a small number of individuals move extensively in the ocean (Moyle 2002, Surface Water Resources, Inc. 2004, and Welch et al. 2006, all as cited in ICF 2013). Adult white sturgeon move from the waters of San Francisco Bay into the Delta and the lower Sacramento River during the late fall and winter to spawn (ICF 2013). Juvenile white sturgeon can be present in the Delta year-round.

1.1.3.3.7 Sacramento Splittail

Splittail spend most of their life in the San Francisco Estuary throughout the Delta, Suisun Bay, and Suisun Marsh (Moyle 2002). Spawning occurs in the tidal freshwater and euryhaline habitats of the Sacramento–San Joaquin Estuary on terrestrial vegetation and floodplain debris that is inundated by spring high flows, typically at depths between 1.6 and 6.6 feet (0.5 and 2 meters) (Moyle 2002).

Most juvenile splittail move downstream to the Sacramento–San Joaquin Estuary during late spring and early summer (ICF 2013). YOY splittail are salvaged at the SWP and CVP facilities primarily from late May through mid-July during their downstream migrations from upstream floodplains to tidal rearing habitat in Suisun Marsh and Suisun Bay. However, during wet water years, salvage can continue into July (Moyle et al. 2004).

1.1.3.3.8 River and Pacific Lamprey

Because lamprey macropthalmia are difficult to identify and are not reported by species in Delta surveys, river and Pacific lamprey macropthalmia are discussed together. Lamprey ammocoetes are reportedly found throughout all of the Delta, although there are no abundance estimates from Delta sampling programs (ICF 2013). The extent to which lampreys use the Delta for purposes other than a migration corridor is unknown. However, outmigrating lamprey macropthalmia (juveniles) in the final stages of metamorphosis to adults hold just upstream of saltwater until late spring (ICF 2013). River and Pacific lamprey juveniles might be present in the Delta year-round.

1.1.3.3.9 American Shad

Adult American shad enter the Delta from San Francisco Bay via Suisun and Honker Bays on spawning migrations and return to the ocean after spawning in freshwater. Juvenile American shad are reported to sometimes rear in the Delta (CDFG 2010), although little information exists regarding the distribution of juvenile American shad in the Delta. However, juvenile and adult American shad might be present in the Delta year-round.

1.1.3.3.10 Striped Bass

Most striped bass larvae and fry are transported from the spawning areas to the Delta or Suisun Bay within days of spawning. Therefore, striped bass egg and larval lifestages can occur in the Delta during April through June. Juvenile and adult striped bass can occur in the Delta year-round.

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Appendix 7B

1.1 Impact Assessment Methodology

This appendix describes the impact assessment methodology, impact indicators, and significance criteria used by the U.S. Army Corps of Engineers (USACE) to evaluate, for regulatory compliance purposes, the effects of the Folsom WCM alternatives on fisheries and aquatic habitat compared to the CEQA Existing Condition and NEPA No Action Alternative scenarios.

Several fish species are sensitive to changes in both river flows and water temperatures throughout the year. Because USACE anticipates that the Folsom WCM alternatives would change water temperatures and river flows, the fisheries impact assessment focuses on these and other habitat-based elements. Taking into account species and lifestage-specific habitat requirements, USACE assessed the operational components of the Folsom WCM alternatives in order to evaluate their effects on identified fish species and associated aquatic habitats.

The assessment of effects on identified fish species and associated aquatic habitat is organized and conducted by geographic regions within the Project Area based on the anticipated magnitude of changes in aquatic habitat conditions with the Folsom WCM alternatives and based on the types of modeling tools available for each geographic region, or study area, listed below.

- **Lower American River**
- **Far-Field**
  - Sacramento River downstream of Keswick Dam
  - Lower Feather River
  - Yolo Bypass
  - Sacramento–San Joaquin Delta

Because the Folsom WCM alternatives are most likely to affect fisheries habitat conditions in the lower American River, USACE conducted more-detailed water temperature modeling and fisheries analyses for the lower American River than for other potentially affected areas within the Far-Field. Specifically, fisheries evaluations in the Far-Field Study Area were conducted in order to determine whether more-detailed modeling or analyses were warranted in order to identify the effects of the Folsom WCM alternatives.

For each component of the Far-Field Study Area, the impact assessment identifies fish species of focused evaluation within potentially affected geographic regions within the study areas. Evaluation species consist of special-status fish species (Federal- and state- listed threatened and endangered species, Federal candidate species and species of concern, and state species of special concern) as well as other recreationally important species (e.g., striped bass and American shad).

Both quantitative and qualitative assessments were conducted by USACE to evaluate the effects on fisheries and aquatic habitat that would occur with the Folsom WCM alternatives. Mass balance hydrologic and water temperature modeling was performed to provide a quantitative basis from which to assess the operations-related effects of the Folsom WCM alternatives on fish species of focused evaluation and aquatic habitats within the lower American River and Far-Field Study Area, relative to the basis of comparison.

Specifically, USACE used the hydrological modeling analyses to simulate data representing State Water Project/Central Valley Project (SWP/CVP) operational conditions that would occur with the Folsom WCM alternatives, which were compared to modeled data representing operational conditions under the basis of comparison (i.e., the Existing Condition). Appendix 4A, Modeling Technical Memorandum, describes the methodologies that were used to simulate comparative operational scenarios with the Folsom WCM alternatives, relative to the basis of comparison.

The impact assessment of fisheries and aquatic habitat consists of hydrologic and water temperature–related changes associated with the Project operations. The general analytical framework used to assess the effects of each component of the Folsom WCM alternatives evaluated is described below.

1.1.1 Analytical Tools

The fisheries and aquatic habitat impact assessment relies on hydrologic modeling to provide a quantitative basis from which to assess the effects of the Folsom WCM alternatives on fish species of focused evaluation and aquatic habitats within the SWP/CVP system, relative to the basis of comparison. Specifically, USACE used the hydrological modeling and post-processing applications to simulate the operations that USACE expects to occur in SWP/CVP reservoirs and rivers and the Sacramento–San Joaquin Delta (Delta) with the Folsom WCM alternatives, relative to the basis of comparison.

Hydrologic simulation results from CalSim II hydrologic model (see Appendix 4A, Modeling Technical Memorandum) of mean monthly river flows and end-of-month reservoir storages provide a quantitative basis for assessing the effects of the Folsom WCM alternatives on fish species, relative to the basis of comparison, for the period of simulation from water year 1922 through 2003 (an 82-year simulation period) the Far-Field Study Area. These simulated results were used as inputs to the Bureau of Reclamation's (Reclamation) Water Temperature Models (Reclamation 1997) for the Sacramento and Feather Rivers; these models simulate mean monthly water temperature of the main river systems for the same simulation period. For the lower American River, CalSim II hydrologic output was used as input to daily flow and water temperature models to simulate daily flow and water temperature in the lower American River (see Appendix 4A, Modeling Technical Memorandum).

Simulated daily water temperatures for the lower American River (LAR) were used as inputs to Reclamation's Mortality Model, as modified and updated by the Water Forum and USACE (2015), referred to in this appendix as the LAR Mortality Model, to estimate annual mortality rates for the early lifestages (in-vivo eggs, incubating eggs, and pre-emergent fry) of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the lower American River. Simulated flows were used as inputs to tools that model salmonid spawning habitat (weighted usable area, or WUA) and salmonid redd dewatering to quantify specific effects of the Folsom WCM alternatives on salmonid habitat in the lower American River. (A *redd* is a spawning nest built by salmon and steelhead.)

The following sections identify specific nodes from hydrologic and water temperature model output for the purpose of assessing effects on fisheries, as well as identify the types of model outputs for flow, water temperature, habitat and population analyses (e.g., cumulative probability exceedance distributions, long-term average monthly flows, and average monthly flows by water year type).

The following sections summarize the evaluation tools that USACE used to support the fisheries and aquatic habitat impact assessment. Appendix 4A, Modeling Technical Memorandum, presents detailed information about specific modeling tools and the modeling assumptions used to characterize Project operations. Detailed discussion regarding each species and waterbody evaluated in this Draft Technical Report is presented below in assessment approach sections that are specific to each waterbody.

1.1.1.1 Model Uncertainty

Although the physical habitat models used in the analyses are mathematically precise, they should be viewed as having inherent uncertainty because of limitations in the theoretical basis of the model and the scope of the formulation and function for which the model is designed. Although models can provide useful insight to complex systems, they are a simplification of the system and processes and provide results with limitations (Reclamation 2008). Nonetheless, physical habitat models developed for planning and impact assessment purposes represent the best available information with which to conduct evaluations of proposed changes in SWP and CVP operations. Therefore, USACE used physical habitat models as analytical tools to identify simulated changes in aquatic habitat variables (e.g., flows and water temperatures) as well as inputs to species-specific analytical tools. Appendix 4A, Modeling Technical Memorandum, presents a detailed discussion of the hydrologic and water temperature modeling tools, the modeling assumptions used, and the uncertainty associated with the models.

1.1.1.2 Application of Model Output

USACE used computer simulation models and post-processing tools to assess changes in river flows, water temperatures, and associated changes in species-specific habitat conditions that could occur with the Folsom WCM alternatives, relative to the basis of comparison.

Model assumptions and results were used for comparative purposes rather than for absolute predictions, and the focus of the analysis is on differences in the results among comparative scenarios. The simulation results were designed for a comparative evaluation because the physical models use generalized rules to operate the CVP and SWP systems, and the results are a gross estimate that might not reflect how actual operations would occur (Reclamation 2008). Further, generalizations also are made for programs based on adaptive management that are too dynamic to capture the range of factors used in actual operations decision-making (Reclamation 2008). All of the assumptions were the same for both the with-project and without-project model runs, with the exception of the assumptions associated with the Folsom WCM Project itself, and the focus of the analysis is the differences in the results.

1.1.2 General Analytical Approach for Evaluating Fisheries and Aquatic Habitat (Flow)

Streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems (Poff et al. 1997). Streamflow, which is strongly correlated with many critical physicochemical characteristics of rivers, can be considered a master variable that limits the distribution and abundance of riverine species (Power et al. 1995; Resh et al. 1988) and regulates the ecological integrity of flowing water systems.

Components of the flow regime can be used to characterize the entire range of flows and specific hydrologic phenomena (e.g., floods and low flows) that are vital to the integrity of river ecosystems. The five components of the flow regime are (1) magnitude, (2) frequency, (3) duration, (4) timing, and (5) rate of change of hydrologic conditions (Poff et al. 1997). Furthermore, Poff et al. (1997) report that, by defining flow regimes in these terms, the ecological consequences of particular human activities that modify one or more components of the flow regime can be considered explicitly. The following discussion regarding these components is taken directly or modified from Poff et al. (1997).

- **Magnitude**: The *magnitude* and frequency of high and low flows regulate numerous ecological processes. The composition and relative abundance of species that are present in a stream or river often reflect the frequency and intensity of high flows (Schlosser 1985; Meffe and Minckley 1987). Flows of low magnitude can also provide ecological benefits through recruitment opportunities for riparian plant species in regions where floodplains are frequently inundated (Wharton et al. 1981).
- **Frequency**: The *frequency* of occurrence refers to how often a flow above a given magnitude recurs over some specified time interval. Frequency of occurrence is inversely related to flow magnitude. For example, a 100-year flood is equaled or exceeded on average once every 100 years, and the median flow over a specified time period has a 50 percent probability of occurrence.
- **Duration**: *Duration* is the period of time associated with a specific flow condition. Duration can be defined relative to a particular flow event (e.g., a floodplain might be inundated for a specific number of days by a 10-year flood), or it can be defined as a composite expressed over a specified time period (e.g., the number of days in a year when flow exceeds some value).

  The duration of a specific flow condition often determines its ecological significance, and changes in the duration of flow conditions have significant biological consequences (Poff et al. 1997). For aquatic species, prolonged flows of particular levels can be damaging. For example, differences in tolerance to prolonged flooding in riparian plants (Chapman et al. 1982) and to prolonged low flow in aquatic invertebrates (Williams and Hynes 1977) and fishes (Closs and Lake 1996) allow these species to persist in locations from which they might otherwise be displaced by dominant, but less tolerant, species.
- **Timing:** The *timing*, or predictability, of flows of defined magnitude refers to the regularity with which they occur. For example, annual peak flows might occur with low seasonal predictability or with high seasonal predictability. The timing, or predictability, of flow events is critical ecologically because the lifecycles of many aquatic and riparian species are timed to either avoid or exploit flows of variable magnitudes.
- **Rate of Change**: The *rate of change* typically refers to how quickly flow changes from one magnitude to another. For this Draft Technical Report, rate of change specifically applies to the magnitude of hydrologic change over specified time periods for impact assessment.

For the Folsom WCM Project, the river-specific fisheries impact assessment includes quantitative evaluation of the types of flow-related changes described above, as further described in the following sections.

1.1.2.1 Long-Term Average Flow and Average Flow by Water Year Type

Post-processing tools use monthly hydrologic output (Far-Field) and daily hydrologic output (lower American River) to calculate the long-term average flows, by month, occurring over the respective simulation periods with the Folsom WCM alternatives and the basis of comparison. Monthly average simulated flows by water year type are used to compare differences between the basis of comparison and the Folsom WCM alternatives. Presented in tabular format, the data tables for the long-term average flows by month, and the monthly average flows by water year type, demonstrate the simulated changes with the Folsom WCM alternatives, relative to the basis of comparison.

1.1.2.2 Flow Exceedance Distributions

USACE developed monthly flow exceedance distributions (or curves) from monthly hydrologic output (Far-Field) and from daily hydrologic output (lower American River). These distributions illustrate the distribution of simulated flows with the Folsom WCM alternatives and the basis of comparison. Exceedance distributions generally represent the monthly flow output for a given month sorted by magnitude for the entire period of record (e.g., 1922–2003). In general, flow exceedance distributions represent the probability, as a percentage of time that modeled flow values would be met or exceeded at a specific location, during a certain time period. Therefore, exceedance distributions demonstrate the cumulative probabilistic distribution of flows for each month at a given river location under a given simulation. Exceedance distributions also allow a comparison of flow output among model scenarios without attributing unwarranted specificity to changes between particular model years.

Exceedance distributions are particularly useful for examining flow changes occurring at lower flow levels. Results from past instream flow studies indicate that salmonid spawning and rearing habitat is most sensitive to changes during lower-flow conditions (CDFG 1994; USFWS 1985). Given the sensitivity of various lifestages to lower-flow conditions, this impact assessment specifically evaluates flow differences during low-flow conditions.

1.1.2.3 Flow-Dependent Habitat Availability

1.1.2.3.1 Spawning WUA

Flow-dependent habitat availability refers to the quantity and quality of habitat available to individual species and lifestages for a particular instream flow. The physical habitat simulation (PHABSIM) system is a commonly used method to express indices of the quantity and quality of habitat associated with specific flows. PHABSIM is the combination of hydraulic and habitat models, the output of which is expressed as WUA and is used to predict the relationship between instream flow and the quantity and quality of habitat for various lifestages of one or more species of fish.

For the Chinook salmon and steelhead spawning lifestage, *flow-dependent habitat availability* refers to the amount of spawning habitat, characterized by the suitability of water depths, velocities, and substrate, for successful spawning that is, in part, contingent on stream flow. Salmonids typically deposit eggs within a range of depths and velocities that ensure adequate exchange of water between surface and substrate interstices to maintain high oxygen levels and remove metabolic wastes from the redd. Stream flow directly affects the availability of spawning habitat (SWRI 2002).

USACE applied spawning WUA-discharge relationships to simulated mean daily flows for anadromous salmonids in the lower American River. Although USACE does not expect substantial flow changes in the Far-Field, because the relationship between flow and flow-dependent spawning habitat is not linear, simulated mean monthly flow output was applied to spawning WUA-discharge relationships for anadromous salmonids in the lower Feather River and the upper Sacramento River.

In the lower American River, available spawning habitat for fall-run Chinook salmon and steelhead is expressed by a scaled composite WUA that corresponds to the available spawning habitat associated with the monthly flows during the spawning season. The scaled composite WUA annual index (i.e., $CWUA_Y$) is calculated as the sum of the WUAs that correspond to the daily flows during the species' spawning season at five sampled reaches within the species' spawning area, multiplied by a temporal weighting coefficient that represents the average relative spawning intensity on the particular day of the spawning season, divided by the maximum WUA for the sum of the five spawning reaches, over the flow range for which the WUA-flow relationship was developed. Appendix 7E, Analysis of Spawning Weighted Usable Area for Lower American River Salmonids, provides a detailed discussion of the spawning WUA-discharge relationships used for fall-run Chinook salmon and steelhead in the lower American River.

After calculating the scaled composite WUAs for fall-run Chinook salmon and steelhead spawning in the lower American River over the entire simulation period of flows modeled for the Folsom WCM alternatives and basis of comparison, USACE used the resulting annual scaled composite WUAs to develop exceedance distributions and to calculate long-term average spawning WUA and average spawning WUA by water year type. Spawning WUA exceedance distributions and long-term average spawning WUA and average spawning WUA by water year type were used to evaluate changes in spawning habitat with the Folsom WCM alternatives, relative to the basis of comparison.

USACE evaluated spawning WUA for anadromous salmonids in the Sacramento and Feather Rivers using similar methodologies as described above for the lower American River, but with monthly flow output. USACE also developed species-specific spawning WUA exceedance distributions and long-term average and average by water year type spawning WUA to evaluate spawning WUA with the Folsom WCM alternatives, relative to the basis of comparison. Appendix 7D, Analysis of Spawning Weighted Usable Area for Upper Sacramento River and Feather River Salmonids, provides a detailed discussion of the spawning WUA-discharge relationships used for winter-run, fall-run, and late fall-run Chinook salmon and steelhead spawning in the upper Sacramento River and for steelhead and spring-run and fall-run Chinook salmon spawning in the lower Feather River.

Because of the lack of habitat-discharge relationships for fry and juvenile Chinook salmon and steelhead rearing in the lower American River, the lower Feather River, and the upper Sacramento River, these lifestages are not evaluated using PHABSIM habitat-discharge relationships in this Draft Technical Report. Rather, the evaluation of juvenile fall-run Chinook salmon and steelhead habitat suitabilities in the lower American River in this Draft Technical Report focuses on differences in flow and differences in the primary stressor to these lifestages—water temperature.

1.1.2.3.2 Redd Dewatering

Changes in flow and resultant changes in river stage have the potential to affect the probability of anadromous salmonid redd dewatering during the embryo incubation periods. An annual redd dewatering index is calculated in this Draft Technical Report to assess the potential effects of flow fluctuations on Chinook salmon and steelhead redd dewatering in the lower American River by incorporating information on the spatial and temporal distributions of spawning activity, redd depth distribution, duration of embryo incubation through fry emergence, and maximum reduction in river stage throughout the incubation periods.

Typically, the evaluation of the potential redd dewatering effects of flow fluctuations on salmonids involves calculating flow (or river stage) reductions between consecutive days along the spawning area during the spawning and embryo incubation season, and expressing the number of stage reductions of a given magnitude that occurred during the spawning and embryo incubation period. Interpretations of results using this approach are often limited because information concerning the percentage of the spawning population potentially affected by the stage reductions occurring during the spawning and embryo incubation season were not incorporated. In general, most redds are constructed during identifiable peaks of fall-run Chinook salmon and steelhead spawning activity, with variable overall temporal and spatial distributions.

In this Draft Technical Report, the potential for fall-run Chinook salmon and steelhead redd dewatering due to daily flow fluctuations in the lower American River under the Folsom WCM alternatives and basis of comparison is analyzed through an annual weighted redd dewatering index. The potential dewatering effects of changes in daily flows and corresponding changes in river stage and water temperatures are weighted by the expected temporal and spatial distributions of Chinook salmon and steelhead spawning activity in the lower American River. In addition to the information on the expected temporal and spatial distributions of spawning activity, the index incorporates information on the expected depth distributions of Chinook salmon and steelhead redds, the duration of embryo incubation and the maximum river stage reduction through fry emergence experienced by redds of a same cohort (*i.e.*, redds built on the same day and within the same spawning area or reach during the Chinook salmon and steelhead spawning seasons). Details on the calculation of the annual dewatering index as well as on the various distributions used in the calculations are provided in Appendix 7F.

The annual weighted redd dewatering index provides annual estimates of the maximum proportions of redds, relative to the total number of redds built during the species' spawning periods, that were potentially dewatered at least once due to decreases in flow and associated drops in water elevation occurring from the date of redd construction through the corresponding date of fry emergence.

The annual redd dewatering index is generated for both fall-run Chinook salmon and steelhead in the lower American River for the entire simulation period for the Folsom WCM Project Alternatives and the basis of comparison. The resulting series of annual values for redd dewatering index for each species are used to calculate and compare the corresponding redd dewatering exceedance distributions and long-term averages and averages by water year type for the Folsom WCM alternatives and basis of comparison.

Although Chinook salmon and steelhead redd dewatering has been estimated for the lower American River, those estimates cannot be directly integrated into a redd dewatering methodology for this Draft

Technical Report due to the estimates being developed under different annual flow conditions, at varying spatial and temporal scales, and often with different estimation and sampling techniques (see Appendix 7F).

1.1.2.4 Evaluation Criteria

1.1.2.4.1 Flow

The U.S. Geological Survey's *Handbook of Hydrology* (Maidment 1993) considers a flow estimate within 10 percent of the actual flow to be acceptable or good and within five percent to be excellent. Additionally, a decrease in monthly flow of 10 percent or greater has been previously identified by various environmental documents as an appropriate criterion to evaluate flow changes. For example, in the Trinity River Mainstem Fishery Restoration Draft Environmental Impact Statement (EIS)/Environmental Impact Review (EIR) (USFWS et al. 1999), the U.S. Fish and Wildlife Service (USFWS) identified reductions in flow of 10 percent or greater as changes that could be sufficient to reduce habitat quantity or quality to an extent that could significantly affect fish. The Trinity River EIS/EIR further states, "… [t]his assumption [is] very conservative … [i]t is likely that reductions in stream flows much greater than 10 percent would be necessary to significantly (and quantifiably) reduce habitat quality and quantity to an extent detrimental to fishery resources." Conversely, the Trinity River EIS/EIR considers increases in stream flow of 10 percent or greater, relative to the basis of comparison, to be "beneficial" to fish species.

In addition to the USFWS criteria, the San Joaquin River Agreement EIS/EIR (San Joaquin River Group Authority 1999) used criteria thresholds based on the ability to accurately measure stream flow discharges to ±10 percent. The criterion used to determine the level of riverine impacts associated with implementation of the San Joaquin Agreement was based on average percentage changes to stream flow, relative to the basis of comparison. The San Joaquin River Agreement EIS/EIR considered instream flow changes of less than ±10 percent to be insignificant (San Joaquin River Group Authority 1999).

The Freeport Regional Water Project Draft EIR/EIS (Jones & Stokes 2003) used a similar rationale for selecting criteria to evaluate changes in flow. The Freeport EIR/EIS states, "Relative to the base case, a meaningful change in habitat is assumed to occur when the change in flow equals or exceeds approximately 10 percent. The 10-percent criterion is based on the assumption that changes in flow less than 10 percent are generally not within the accuracy of flow measurements, and will not result in measurable changes to fish habitat area."

Although the environmental documents listed above have been legally certified (i.e., Trinity River Mainstem Fishery Restoration Record of Decision on December 19, 2000; San Joaquin River Agreement Record of Decision in March 1999; and Freeport Regional Water Project Record of Decision on January 4, 2005), biological justifications specific to using a 10 percent change as a criterion for a meaningful change in habitat affecting fisheries resources in a particular river have not been provided. Nevertheless, these documents apparently have resulted in consensus in the use of 10 percent when evaluating flow changes. Accordingly, the fisheries impact assessment relies on previously established information and, therefore, evaluates changes in flow of 10 percent or greater between compared scenarios as an index of potential impact.

Results from past instream flow studies indicate that Chinook salmon spawning and rearing habitat is most sensitive to changes during lower-flow conditions (CDFG 1994; USFWS 1985). Research quantifying the relationship between anadromous salmonid (e.g., Chinook salmon) spawning habitat (suitability and availability) and flow typically show a relatively rapid increase in habitat with an increase in flow at relatively low flow levels until reaching an apex and then declining thereafter. This generalized pattern has been demonstrated for the Sacramento (USFWS 2003a), Feather (DWR 2004), and American Rivers (USFWS 2003b).

Studies that have attempted to quantify habitat-flow relationships have often shown that rearing habitat area for juvenile salmonid tends to reach maximum abundance at low flows that inundate most of the channel area in a river (Reclamation and Freeport Regional Water Authority 2003). Rearing habitat area has been shown to decline as flows increase, primarily in response to increased average velocity. Because juvenile Chinook salmon and steelhead fry generally prefer relatively low-velocity areas, increasing flows often lead to reductions in habitat area. However, this flow-habitat relationship might be misleading because it might not adequately reflect local habitat conditions (i.e., availability of low velocity) or the importance of flow-related habitat attributes (e.g., water temperature conditions or cover and prey availability).

For example, yearling steelhead in the lower American River are reportedly found in bar complex and side channel areas characterized by habitat complexity in the form of velocity shelters, hydraulic roughness elements, and other forms of cover (SWRI 2001). During low-flow conditions in the lower American River, the availability of these habitat types becomes limited, resulting in increased juvenile steelhead densities in areas that provide less cover from predation (NMFS 2009). In addition, low-flow conditions in large riverine systems can crowd fish and increase the potential for disease, reduce macroinvertebrate food production, and reduce accessibility to (and the functionality of) shaded riverine aquatic (SRA) habitat and riparian vegetation. SRA habitat and riparian vegetation can provide cooler localized water temperatures, allochthonous food sources, and refuge from predators.

The impact assessment specifically evaluates changes during low-flow conditions (e.g., flows for critical and dry water year types). Recent and current hydrologic modeling of the SWP/CVP includes an 82-year period of record for evaluation (water years 1922–2003), of which 30 years (37 percent) are classified as dry or critical according to the Sacramento Valley (40-30-30) Index. Recent regulatory and environmental documents evaluating fisheries in the Central Valley, including the Reclamation (2008) Biological Assessment (BA) on the continued long-term operations of the SWP and CVP, the National Marine Fisheries Service (NMFS 2009) Biological Opinion on the long-term operations of the SWP and CVP, and the Public Review Draft of the Bay Delta Conservation Plan (ICF International 2013), evaluate flows and/or some fisheries indicators of potential impact by water year type. In accordance with the selected flow criteria described above, a change in flow generally encompassing dry and critical conditions (i.e., the lowest 40 percent of the monthly flow exceedance probability distributions) of 10 percent or greater under an alternative, relative to the basis of comparison, is used as an impact indicator.

This approach is generally consistent with the methodology in previous environmental documentation, including the Freeport Regional Water Project EIS/EIR (Reclamation and Freeport Regional Water Authority 2003) and the Yuba Accord EIR/EIS (YCWA et al. 2007). Specifically, net changes in flow of 10 percent or more are calculated to determine whether flow increases by 10 percent or more with higher frequency, or whether flow decreases by 10 percent or more with higher frequency (i.e., the percentage of the time that flow increases by 10 percent or more minus the percentage of time that flow decreases by 10 percent or more). The net change in flow of 10 percent or more is evaluated on a monthly basis, for the entire distribution of flows, and/or for the lowest 40 percent of the distribution of flows, depending on the species and lifestage being evaluated.

1.1.2.4.2 Spawning Habitat

Another impact indicator is changes in spawning habitat availability (expressed as a percentage of maximum WUA), relative to the basis of comparison, of sufficient magnitude and frequency to substantially affect anadromous salmonids over the entire simulation periods. There have been no definitive determinations regarding how much WUA represents a stressor to specific species/lifestages. The use of 80 percent of maximum spawning WUA as a benchmark is based on testimony presented as part of the State Water Resources Control Board (SWRCB) Mono Lake Decision 1631 process.

Dr. Tom Hardy (a fisheries biologist retained by the Los Angeles Department of Water and Power) testified that "… no objective criteria [have] been validated to guide investigators on what percentage reduction in optimal habitat represents a significant impact, or at what exceedance value associated with either optimal or median habitat represents adequate protection for the aquatic resources." However, Dr. Hardy testified that several instream flow studies in which he had participated targeted a range of 80 percent to 85 percent of the maximum WUA as optimal habitat conditions. Therefore, the impact assessment in this Draft Technical Report uses as an impact indicator the probability of achieving 80 percent of maximum spawning WUA over the probability of exceedance distribution with the Folsom WCM alternatives, relative to the basis of comparison.

In addition, differences in spawning WUA over the exceedance distributions when spawning WUA is below 80 percent of maximum with both scenarios are also used to evaluate changes in spawning habitat with the Folsom WCM alternatives, relative to the basis of comparison.

1.1.2.4.3 Redd Dewatering

Changes in potential redd dewatering (using an index of the annual percent of redds dewatered at least one time) under the alternatives, relative to the basis of comparison, of sufficient magnitude and frequency to substantially affect fall-run Chinook salmon and steelhead spawning in the lower American River over the entire simulation period also is used as an impact indicator. There have been no definitive determinations of how much redd dewatering represents a stressor to steelhead or fall-run Chinook salmon redds. The evaluation of changes in the redd dewatering index resulting from implementation of the Folsom WCM Project Alternatives, relative to the basis of comparison, involves the examination of the annual average relative difference in the species-specific redd dewatering index over the long-term and by water year type. Additionally, annual redd dewatering exceedance probabilities are evaluated to identify differences in the probability of occurrence of the redd dewatering index evaluated by the model. Examination of the relative difference is necessary to avoid the masking of more severe impacts on evaluated species, and to evaluate the biological significance of changes in the redd dewatering index. Relative difference comparisons appropriately assess the magnitude of change in conditions between the Folsom WCM Project Alternatives and the basis of comparison.

1.1.3 General Analytical Approach for Evaluating Fisheries and Aquatic Habitat (Water Temperature and Early Lifestage Mortality)

USACE recognizes that water temperature changes can exhibit an equal or greater influence on coldwater fish species, including anadromous salmonids, relative to flow, as described below.

- Among all environmental parameters, water temperature is suggested to have the greatest influence on the status of fish and aquatic life (McCullough et al. 2001; Myrick and Cech 2001).
- Coldwater species such as Chinook salmon and steelhead that are near the southernmost edge of their geographic distributional range (i.e., the California Central Valley) might be particularly constrained by elevated water temperatures, especially during the summer when instream conditions tend to exhibit increased warming due to ambient solar radiation.
- Water temperature is perhaps the physical factor with the greatest influence on steelhead in the lower American River (NMFS 2009).

Thus, the flow analyses are supplemented by separate species and lifestage-specific water temperature evaluations, as described in the following sections.

1.1.3.1 Water Temperature Exceedance Distributions

Monthly exceedance distributions (or curves) of simulated water temperature from monthly water temperature model output (Far-Field) and from daily water temperature model output (lower American River) were developed by USACE for the entire simulation period. These distributions illustrate the distribution of simulated water temperatures with the Folsom WCM alternatives and the basis of comparison. In general, water temperature exceedance distributions represent the probability, as a percentage of time, that modeled water temperature values would be met or exceeded at a specific location during a certain period. Monthly water temperatures (Far-Field) and daily water temperatures (lower American River) were applied to species and lifestage-specific water temperature index values with the alternatives, relative to the basis of comparison, as further described below.

1.1.3.2 Water Temperature Guidelines

Impact indicators and evaluation guidelines have been developed as a means to assess the operational-related effects of the Folsom WCM alternatives on aquatic resources. For the fisheries and aquatic habitat impact assessment, water temperature impact indicator values are used to evaluate whether the project would affect a species' habitat. Changes in water temperatures during certain periods of the year could affect all lifestages of fish species. Therefore, changes in water temperatures during the adult upstream migration and holding, spawning and embryo incubation, juvenile rearing, and outmigration lifestages of anadromous species were used by USACE as impact indicators.

Water temperature evaluation guidelines have been developed more extensively for Chinook salmon and steelhead than for other species because Chinook salmon and steelhead are native to the Pacific Coast and historically have been socially, recreationally, commercially, and economically important to the region (Bratovich et al. 2012; YCWA et al. 2007).

As further described in Bratovich et al. (2012), water temperature impact indicators and evaluation guidelines for anadromous salmonids have been developed based on an extensive review of fisheries literature, with special emphasis on research conducted in the Central Valley. Although there could be small local variations in the periods associated with stream-specific habitat utilization by different species and lifestages, the temporal applications of timing periods used for analytical purposes in this Draft Technical Report are based on studies in the Central Valley and are applied uniformly throughout the document.

The water temperature index (WTI) values presented in this appendix represent a gradation of potential biological effects from optimal to lethal water temperatures for each lifestage. Literature on salmonid water temperature requirements generally reports water temperature thresholds using various descriptive terms including *optimal*, *preferred*, *suitable*, *suboptimal*, *tolerable*, *stressful – chronic and acute*, *sublethal*, *incipient lethal*, and *lethal*. Water temperature effects on salmonids are often discussed in terms of *lethal* and *sublethal* effects and depend on both the magnitude and the duration of exposure (Sullivan et al. 2000) as well as on acclimation water temperatures. Exposure to adverse water temperatures can result in adverse effects on salmonids' biological functions, feeding activity, lifestage timing, growth, reproduction, competitive interactions, susceptibility to disease, growth and development, and ultimately probability of survival (McCullough 1999).

Lifestage-specific WTI values were based on long-term (≥ 7 days) chronic temperature exposure rather than acute (< 7 days) temperature exposure. The boundary between the upper end of the chronic exposure range and the lower end of the acute exposure range is typically measured as the upper incipient lethal temperature (UILT) where 50-percent mortality occurs after 7 days (Elliott 1981).[1]

The UILT for both juvenile steelhead and Chinook salmon is similar and is between 75°F and 79°F (24°C and 26°C) depending on the study (McCullough 1999; McCullough et al. 2001; Sullivan et al. 2000). The UILT for adult steelhead and Chinook salmon is between 70°F and 72°F (21°C and 22°C) (Becker 1973; Coutant 1970; McCullough et al. 2001), which is much lower than that for juveniles and is approximately the same temperature that has been identified as an upstream migration barrier for Chinook salmon (McCullough 1999).

Acute (< 7 days) temperature response strongly depends on the duration of exposure. **Figure 1** shows some example acute exposure relationships for juvenile salmonids. The hourly (60-minute) acute temperature is 5.4–9.0°F (3–5°C) higher than the 7-day (10,000-minute) chronic temperature. Because the acute temperature for juvenile salmonids (approximately 82.4°F [28.4°C]) is relatively high, it rarely becomes a factor affecting survival in natural streams (Sullivan et al. 2000). However, the acute temperature for adult salmonids is lower—it could become a survival factor particularly for adult Chinook salmon holding through the summer.

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[1] Note that some authors have measured the UILT using shorter duration exposure than 7 days (e.g., 1,000 minutes or 24 hours). UILT values based on a shorter duration exposure than 7 days will be higher than the UILT values based on a 7-day exposure.

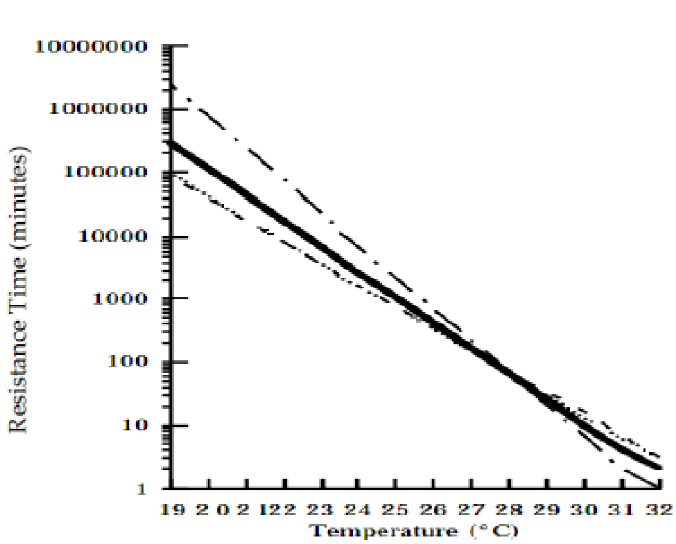

Figure 1. Relationship between the Time (Minutes) to Mortality and the Lethal Temperature for Rainbow Trout (Left) (Bidgood 1969) and Brown Trout (Right) (Elliott 1981). Note the effect of acclimation temperature in the figure on the right.

The temperature range between the UILT (7 days) and very-short-duration mortality (minutes) (e.g., critical thermal maximum) is called the *zone of resistance*. Below the UILT is a zone of tolerance where fish can tolerate the temperature for an extended period (> 7 days). At the higher temperatures in the tolerance zone, fish might not feed, grow, or reproduce, and they could have modified behavior (e.g., holding in temperature refugia locations). An important point to note is that the effects of water temperature are associated with duration of exposure and, depending on the actual water temperature value, short-duration exposure to relatively high temperatures might not cause sustained adverse effects if temperatures quickly decrease to non-impactive levels.

At lower temperatures in the tolerance zone, denoted as *tolerable*, growth and/or reproduction occur but are reduced from optimal levels due to temperature effects. The zone of temperature where fish processes (e.g., growth, reproduction, and behavior) are not affected appreciably by temperature is denoted as the *optimum* temperature range (**Figure 2**).

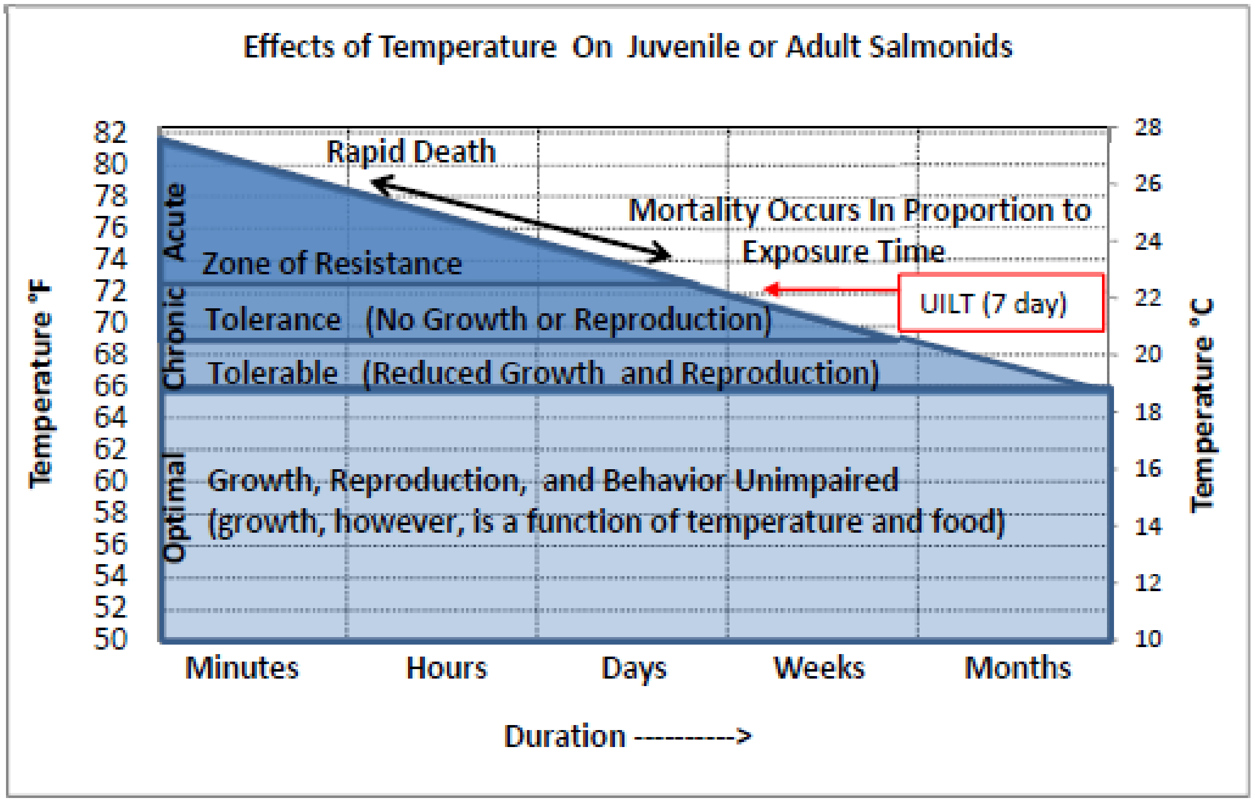

Figure 2. Acute, Chronic and Optimum Temperature Zones.

There are inherent limitations associated with developing and applying WTI values. Some of the limitations are summarized by McEwan (2001); namely, that WTI values serve only as general guidelines, because WTI values are often developed based on laboratory studies conducted under specific conditions and/or on studies conducted in specific streams that differ from the stream that the WTI values are being applied to. Research studies conducted under controlled laboratory conditions or in specific streams do not take into account ecological considerations associated with water temperature regimes or considerations such as predation risk, inter- and intra-specific competition, long-term survival, and local adaptation in the stream that the WTI values are being applied to.

Species- and lifestage-specific WTI values developed by Bratovich et al. (2012) were used by USACE as a means to assess the effects of the Folsom WCM alternatives, relative to the basis of comparison, on Chinook salmon and steelhead in the Project Area. Bratovich et al. (2012) evaluated water temperature suitabilities associated with reintroducing spring-run Chinook salmon and steelhead into the upper Yuba River Basin, and describe development of the upper optimum (UO) WTI values and upper tolerable (UT) WTI values used for this assessment.

- **Upper Optimum Temperature (UO).** The upper optimum temperature represents the upper boundary of the optimum range and represents a temperature below which growth, reproduction, and/or behavior are not affected by temperature.

- **Upper Tolerable Temperature (UT).** The upper tolerable temperature represents a water temperature at which fish can survive indefinitely without experiencing substantial detrimental effects to their physiological and biological functions such that survival occurs, but growth and reproduction success are less than at the optimum water temperature.

The UO and UT WTI values represent boundaries above which water temperatures could be considered to affect evaluated fish species. The WTI values are not meant to be significance thresholds but instead provide a mechanism by which to compare the resulting water temperatures associated with the Folsom WCM alternatives, relative to the basis of comparison.

Table 1 presents the UO and UT WTI values for Chinook salmon and steelhead. These two species of anadromous salmonids are presented here because of their ubiquitous distribution throughout the Project Area for this Draft Technical Report. Chinook salmon holding WTI values are applied only to the holding of winter-run and spring-run Chinook salmon, because fall-run Chinook salmon generally enter freshwater in a sexually mature state and reportedly spawn soon after reaching freshwater spawning grounds.

The Chinook salmon smolt emigration WTI values are applied only to spring-run Chinook salmon, because fall-run and winter-run Chinook salmon generally emigrate from Central Valley rivers as young-of-the-year (Kimmerer and Brown 2006).

Table 1. Lifestage-specific Upper Optimum and Upper Tolerance WTI Values for Chinook Salmon and Steelhead.

Chinook Salmon			Steelhead		
Lifestage	**Upper Optimum WTI**	**Upper Tolerance WTI**	**Lifestage**	**Upper Optimum WTI**	**Upper Tolerance WTI**
Adult immigration	64°F	68°F	Adult immigration	64°F	68°F
Adult holding	61°F	65°F	Adult holding	61°F	65°F
Spawning	56°F	58°F	Spawning	54°F	57°F
Embryo incubation	56°F	58°F	Embryo incubation	54°F	57°F
Juv. rearing & outmigration	61°F	65°F	Juv. rearing & outmigration	65°F	68°F
Smolt emigration	63°F	68°F	Smolt emigration	52°F	55°F

For other fish species of focused evaluation, WTI values evaluated in this Draft Technical Report are presented in **Table 2**. Appendix 7C provides background information on reported lifestage-specific water temperature tolerances and preferences for the other fish species of focused evaluation and the rationale for selecting the representative WTI values and ranges evaluated in this Draft Technical Report. WTI value ranges are typically used for a lifestage when insufficient information is available to identify specific WTI values (see Appendix 7C).

Table 2. Lifestage-specific WTI Values and Ranges for Other Fish Species of Focused Evaluation.

Species	Lifestage	Water Temperature Index Values and Ranges (°F)
Green sturgeon	Adult immigration and holding	61
	Spawning and embryo incubation	68
	Juvenile rearing and downstream movement	66
White sturgeon	Adult immigration and holding	77
	Spawning and embryo incubation	68
	Juvenile rearing and downstream movement	66
River lamprey	Adult immigration	42–60
	Spawning and embryo incubation	50–64
	Ammocoete rearing and downstream movement	72
Pacific lamprey	Adult immigration	42–60
	Spawning and embryo incubation	50–64
	Ammocoete rearing and downstream movement	72
Hardhead	Adults and other lifestages	65–82
	Spawning	59–64
American shad	Adult immigration and spawning	60–70
	Juvenile rearing and downstream movement	63–77
Striped bass	Adult immigration and spawning	59–68
	Juvenile rearing	61–71

1.1.3.3 Chinook Salmon Early Lifestage Mortality

The water temperature modeling results for the lower American River also were used by USACE as inputs to the updated LAR Early Lifestage Chinook Salmon Mortality Model (LAR Mortality Model) (Water Forum and USACE 2015) to estimate thermally induced annual mortality rates for the embryonic lifestage of fall-run Chinook salmon in the lower American River. The LAR Mortality Model was initially developed by Reclamation in 1983 for the Sacramento River and was later applied to the lower American River in the 1990s. Since the LAR Mortality Model was originally developed, additional information has become available that could be incorporated into the model to improve its accuracy. For this reason, the Water Forum and USACE (2015) updated the LAR Mortality Model during 2013 through 2015. The following LAR Mortality Model assumptions were refined based on new data and information that has become available:

1) The temporal distribution for the arrival of spawning fall-run Chinook salmon adults in the lower American River.
2) The temporal distribution for fall-run Chinook salmon spawning in the lower American River
3) The spatial distribution of spawning fall-run Chinook salmon in the lower American River
4) The thermally induced Chinook salmon daily mortality rates for pre-spawn eggs, fertilized eggs, and pre-emergent fry

5) The Accumulated Thermal Unit (ATU) thresholds associated with the end of the fertilized-egg and pre-emergent-fry lifestages.

Appendix 7G, Lower American River Chinook Salmon Early Lifestage Mortality Model: Updates and Refinements, provides a detailed description of the updates and modifications that the Water Forum and USACE made to the original model, documents the coding modifications and programming language conversion that the Water Forum and USACE performed on the original model, and identifies the cumulative effects of each update and refinement made by the Water Forum and USACE to the model on its annual average mortality estimates for the lower American River.

Annual early lifestage mortality of fall-run Chinook salmon in the lower American River was generated with the updated LAR Mortality Model for the entire simulation period for the Folsom WCM alternatives and the basis of comparison. The resulting series of annual values for early lifestage mortality was compared over the corresponding exceedance distributions and long-term averages and averages by water year type for the Folsom WCM alternatives and basis of comparison.

1.1.3.3.1 Evaluation Criteria

WATER TEMPERATURE

Differences in the frequency of exceeding a particular WTI value between the Folsom WCM alternatives and the basis of comparison were used by USACE to evaluate thermal impacts to individual species and lifestages at a particular location. Differences in the frequency of exceeding WTI values are represented by the difference in the percentage of time that the WTI value would be exceeded with the alternatives, relative to the basis of comparison. However, a difference in the probability of exceeding a WTI value does not necessarily constitute an impact. Impact determinations are based on USACE's consideration of all evaluated impact indicators for all lifestages for a particular species. USACE considers an impact to be potentially significant if implementing a Folsom WCM alternative would adversely affect an individual species, in consideration of all evaluated impact indicators for all lifestages.

EARLY LIFESTAGE MORTALITY

USACE's assessment of the survival of early life-stages of fall-run Chinook salmon resulting from the Folsom WCM alternatives, relative to the basis of comparison, involves examining of the annual average relative difference in total early lifestage mortality over the long term and by water year type. Additionally, total annual mortality over the exceedance distribution is evaluated by USACE to identify differences in the probability of occurrence of mortality evaluated by the model. Examining the relative difference is necessary to avoid masking more-severe effects on evaluated species and to evaluate the biological significance of changes in water temperature conditions on early lifestage survival. Comparisons of relative difference appropriately assess the magnitude of change in conditions between the Folsom WCM alternatives and the basis of comparison.

1.1.4 Lower American River

This section describes applications of output resulting from computer simulation models and post-processing tools specific to the lower American River.

1.1.4.1 Tools and Application of Model Output

The mass-balance modeling tools have previously been used by agencies including Reclamation (2008) and NMFS (2009), among others, to characterize flows and water temperatures in the lower American River for various regulatory compliance applications. These previously applied modeling tools capture the general concepts of lower American River planning operations and incorporate coldwater pool availability in Folsom Reservoir (e.g., monthly isothermograph and seasonal operational planning) on an average monthly basis. Within the context of integrated SWP/CVP operations, monthly outputs have been used for general planning applications.

However, monthly mass balance models are restricted in their temporal timestep. More-focused, detailed technical evaluations of flow and water temperature–related effects (both adverse and beneficial) associated with different operational characterizations require model outputs on a finer temporal scale. By applying daily flow and water temperature modeling to the lower American River, USACE used daily hydrologic and water temperature model output to evaluate the effects of alternative operational characterizations. Detailed discussion of the hydrologic and water temperature modeling for the lower American River is provided in Appendix 4A, Water Temperature Modeling Technical Memorandum.

1.1.4.2 Lower American River

Flows and water temperatures in the lower American River are strongly influenced by the operations of Folsom Dam and Reservoir. For example, seasonal releases from Folsom Reservoir's coldwater pool provide thermal conditions in the lower American River that affect the water temperature suitability for the various lifestages of fall-run Chinook salmon and steelhead. Folsom Reservoir's coldwater pool is typically not large enough to allow coldwater releases during the warmest months (July through September), releases that would provide maximum thermal benefits to lower American River steelhead, and coldwater releases during October and November that would maximally benefit fall-run Chinook salmon immigration and staging, spawning, and embryo incubation. Consequently, managing the reservoir's coldwater pool on an annual basis is essential to providing thermal benefits to both fall-run Chinook salmon and steelhead, within the constraints of the coldwater pool.

1.1.4.2.1 Evaluation Species

For this Draft Technical Report, the fish species in the lower American River that are the focus of evaluation are presented below. These species are included in the impact assessment either because of the importance of their commercial and/or recreational fisheries (American shad [*Alosa sapidissima*] and striped bass [*Morone saxatilis*]) and/or because they are special-status species (i.e., currently listed under the Federal Endangered Species Act [ESA] and/or the California ESA, or are a Federal species of concern or a state species of special concern). Because the species selected by USACE for species-specific assessments include those sensitive to changes in both river flow and water temperature throughout the year, USACE believes that an evaluation of effects on these species will reasonably encompass the range of effects on fish resources in the lower American River that could occur with the Folsom WCM alternatives. Refer to Appendix 7A, Environmental Setting, for more-detailed descriptions of the habitat requirements and lifestage periodicities for fish species of focused evaluation in the lower American River.

Table 3. Fish Species of Focused Evaluation in the Lower American River.

Common Name	Status
• Central Valley steelhead distinct population segment (DPS)	Federal threatened Recreational and/or commercial importance
• Central Valley fall-/late fall-run Chinook salmon evolutionarily significant unit (ESU) [a]	Federal species of concern State species of special concern Recreational and/or commercial importance
• Central Valley spring-run Chinook salmon ESU (non-natal rearing only)	Federal and state threatened
• River lamprey	State species of special concern
• Pacific lamprey	Federal species of concern
• Hardhead	State species of special concern
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

[a] Although the official designation of the ESU is Central Valley fall-/late fall-run Chinook salmon, the evaluation is for fall-run Chinook salmon on the lower American River because of the absence of late fall-run Chinook salmon.

1.1.4.2.2 Species-Specific Analytical Approach

Flow and water temperature–related evaluations (described above in Sections 1.1.2 and 1.1.3) were applied by USACE at a species- and lifestage-specific level. Species- and lifestage-specific specific flow and water temperature–related evaluations for the lower American River fisheries assessment generally included the following metrics:

- Long-term average flow and average flow by water year type
- Daily flow (as represented by probability of exceedance distributions)
- Daily water temperature (as represented by probability of exceedance distributions) applied to specific WTI values
- Long-term average and average by water year type annual spawning WUA (steelhead and fall-run Chinook salmon)
- Annual spawning WUA (as represented by probability of exceedance distributions) (steelhead and fall-run Chinook salmon)
- Long-term average and average by water year type annual redd dewatering index (steelhead and fall-run Chinook salmon)
- Annual redd dewatering index probability of exceedance distributions (steelhead and fall-run Chinook salmon)
- Long-term average and average by water year type annual early lifestage mortality (fall-run Chinook salmon)
- Annual early lifestage mortality (as represented by probability of exceedance distributions) (fall-run Chinook salmon)

The potential for changes in flows and water temperatures resulting from the Folsom WCM alternatives to affect fish resources in the lower American River depends on the species- and lifestage-specific spatial and temporal distributions, which are summarized in the following sections. In addition, the specific periods of evaluation and model nodes evaluated by USACE for each lifestage are also identified. For further details on the life history, spatial and temporal distributions, and habitat requirements of the species of focused evaluation, refer to Appendix 7A, Environmental Setting.

STEELHEAD

Adult steelhead immigration and holding in the lower American River can begin as early as late spring or summer but occur primarily beginning in November and continue into April (SWRI 2001). Steelhead immigration into the lower American River generally peaks during January (CDFG 1986; SWRI 2001). Spawning typically begins during late December and can extend through March, but also can range from November through April (CDFG 1986). Steelhead redd surveys conducted during most survey years from 2001/2002 through 2012/2013 indicate that spawning generally occurs in the lower American River from late December through mid-April, with nearly all spawning (about 98 percent) occurring from January through April, with the majority (nearly 80 percent) of spawning occurring from mid-January through February (Hannon 2013).

Hannon and Deason (2008) reported that the peak of steelhead spawning varies annually, but most frequently occurs during mid-February. Based on the timing of observations of newly constructed steelhead redds and the amount of time required for incubation, the embryo incubation period has been estimated to generally extend from late December through late May in the lower American River (Hannon et al. 2003; Hannon and Deason 2004, 2005, 2008). For this Draft Technical Report, the steelhead embryo incubation period in the lower American River is generally characterized as extending from January through May.

Previously conducted studies (e.g., PSFMC 2014; Snider and Titus 2000a) indicate that juvenile steelhead might rear in the lower American River for short periods after emergence, or for several months, or even up to a year before moving downstream out of the lower American River. In summary, steelhead that rear in the lower American River year-round reportedly emigrate as smolts generally from January through June (McEwan 2001; Newcomb and Coon 2001; Snider and Titus 2000a), although most emigrate from January through April (Reclamation and NMFS 2014), particularly during January (Snider and Titus 2000a).

Steelhead juveniles that emigrate from the lower American River as young-of-the-year (YOY) do so from March through September (McEwan 2001). YOY steelhead historically began appearing in rotary screw traps (RSTs) at the earliest in mid-January, but typically in mid-March, with most YOY steelhead captured in RSTs from mid-April through June (Snider and Titus 2000a). During RST surveys conducted during 2013, 98 percent (1,019) of the steelhead fry were caught between March 19 and April 22 (PSMFC 2014). Seventy percent (540) of the steelhead with a parr lifestage were caught between April 30 and May 20 during the 2013 survey (PSMFC 2014).

Steelhead might rear in freshwater for 1 to 2 years before undergoing smoltification. Some individuals might rear in their natal streams, while others might volitionally or non-volitionally move downstream to enter the mainstem rivers, where they continue to rear until reaching a size at which smoltification is initiated, as observed by many YOY steelhead captured in rotary screw traps in the Yuba, Feather, and lower American Rivers. The small sizes of juvenile steelhead captured at the rotary screw traps support the presumption that these juvenile fish have not yet undergone smoltification but instead are moving out of the river into downstream rearing habitat. Therefore, habitat conditions for YOY downstream-moving juveniles were assessed using the WTI values for juvenile rearing, whereas separate WTI values were used for the smolt emigration lifestage.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on steelhead in the lower American River for each of the following lifestages, life history periodicities, and modeled locations. Flow was evaluated for the spawning lifestage through evaluating spawning WUA, and is evaluated for the embryo incubation lifestage through evaluation of redd dewatering.

- ❑ Adult immigration (November through March)
  - Flows at Watt Avenue and at river mile (RM) 1
  - Water temperatures at Watt Avenue and RM 1
- ❑ Adult holding (November through March)
  - Flows below Nimbus Dam and at Watt Avenue
  - Water temperatures below Nimbus Dam and at Watt Avenue
- ❑ Spawning (January through mid-April)
  - Spawning WUA percentage of maximum)
  - Water temperatures below Nimbus Dam and at Watt Avenue
- ❑ Embryo incubation (January through May)
  - Redd dewatering index (%)
  - Water temperatures below Nimbus Dam and at Watt Avenue
- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows below Nimbus Dam, at Watt Avenue, and at RM 1
  - Water temperatures below Nimbus Dam, at Watt Avenue, and at RM 1
- ❑ Smolt emigration (December through April)
  - Flows at Watt Avenue and RM 1
  - Water temperatures at Watt Avenue and RM 1

FALL-RUN CHINOOK SALMON

The majority of the fall-run Chinook salmon adult immigration into the lower American River has previously been reported to occur from September through November and to peak in November (SWRI 2001). However, as part of a study to evaluate angler effort and harvest of anadromous fishes in the Central Valley recreational river fishery, the California Department of Fish and Wildlife (CDFW) has performed periodic creel censuses in the lower American River that provide estimates of the fall-run

Chinook salmon monthly catch that were used by the Water Forum and USACE (2015) to assess the temporal distribution of pre-spawning adult fall-run Chinook salmon in the lower American River.

The Water Forum and USACE (2015) obtained the results of analyses of estimated monthly catches of fall-run Chinook salmon in the lower American river from available CDFW angler survey reports (see Water Forum and USACE [2015]; Appendix 7G). These results demonstrate that adult fall-run Chinook salmon begin entering the lower American River as early as June, continuing through the summer prior to spawning from mid-October through December. Information that the Water Forum and USACE (2015) developed for the updated LAR Mortality Model included fitting an asymmetric logistic function to 10 years of available creel survey data (over the period extending from 1991 to 2010) to represent the temporal distribution of adult fall-run Chinook salmon arriving in the lower American River prior to and during the spawning season.

Although some fall-run Chinook salmon adults immigrate into the lower American River as early as June, the recently developed information indicates that, in general, over 90 percent immigrate into the river from September through December. Because the vast majority of fall-run Chinook salmon in the lower American River do not exhibit an extended staging period prior to spawning, the adult immigration WTI values were used by USACE to evaluate this lifestage from September through December. Moreover, the effects of water temperature on the relatively low percentage of adults immigrating into the lower American River from June to September are addressed by USACE through applying the Water Forum and USACE (2015) updated LAR Mortality Model.

Fall-run Chinook salmon spawning in the lower American River generally begins on October 15 and ends on December 31, based on carcass survey data from 1992/1993 through 2012/2013 and the estimated lag period between spawning and carcass survey observations (Water Forum and USACE 2015). Over the range of conditions that have occurred from 1992 through 2012, fall-run Chinook salmon spawning in the lower American River generally peaks during November (when nearly 70 percent of the annual spawning occurs).

The majority of fall-run Chinook salmon redds are formed from Ancil Hoffman Park at RM 16 upstream to the Nimbus Hatchery weir (about RM 23), assuming that spawning occurs nearby or upstream of the location of observed carcasses (Vincik and Kirsch 2009). Aerial redd surveys were conducted on about a weekly basis over the course of the spawning season on the lower American River from only 1991to 1995. These surveys showed that most (92 percent of) redds were formed upstream of RM 16 (Snider and Vyverberg 1996). Vincik and Kirsch (2009) suggested that, as of 2009, there had not been any notable change in the overall spatial distribution of fall-run Chinook salmon spawning in the lower American River since 1995.

Most fall-run Chinook salmon emigrate during the fry stage and, at the latest, the early juvenile stage. The vast majority of juvenile Chinook salmon caught during lower American River RST surveys conducted during 1994, 1995, 1996, 1997, 1998, and 1999 were fry (including yolk-sac fry) and parr, with very few emigrating as silvery parr or smolts (Snider and Titus 2002). The peak Chinook salmon catch occurred during February of most years, while also occurring in late January of 1996 and in early March of 1998 (Snider and Titus 2002). Generally consistent with previous RST surveys, juvenile Chinook salmon catches during the most recent 2013 RST survey peaked between mid-February and early March, with fry passing Watt Avenue generally during January through March, parr passing generally during late March through April, and silvery parr passing generally during mid-April through May (PSMFC 2014).

Overall, the fall-run Chinook salmon juvenile rearing lifestage in the lower American River extends from January through May. The juvenile downstream movement period in the lower American River is coincident with the rearing period.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on fall-run Chinook salmon in the lower American River for each of the following lifestages, life history periodicities, and modeled locations. Flow was evaluated for the spawning lifestage through evaluation of spawning WUA, and is evaluated for the embryo incubation lifestage through evaluation of redd dewatering.

- ❑ Adult immigration and staging (August through December)
  - Flows below Nimbus Dam, at Watt Avenue, and at RM 1 of the lower American River
  - Water temperatures below Nimbus Dam, at Watt Avenue, and at RM 1
- ❑ Spawning (Mid-October through December)
  - Spawning WUA (percentage of maximum)
  - Water temperatures below Nimbus Dam and at Watt Avenue
- ❑ Embryo incubation (Mid-October through March)
  - Redd dewatering index (%)
  - Water temperatures below Nimbus Dam and at Watt Avenue
- ❑ Total early lifestage mortality (June through May)
- ❑ Juvenile rearing and outmigration (January through May)
  - Flows below Nimbus Dam, at Watt Avenue, and at RM 1
  - Water temperatures below Nimbus Dam, at Watt Avenue, and at RM 1

SPRING-RUN CHINOOK SALMON

Currently, the lower American River does not support a spawning population of spring-run Chinook salmon.

USACE's analysis of effects on spring-run Chinook salmon in the lower American River is based on the only individual lifestage (i.e., non-natal juvenile rearing) for which critical habitat has been designated by the National Marine Fisheries Service (NMFS). NMFS designated critical habitat for the Central Valley spring-run Chinook salmon evolutionarily significant unit (ESU) on September 2, 2005. The critical habitat designation includes the reach of the lower American River extending from the outfall of the Natomas East Main Drainage Canal downstream to the confluence with the Sacramento River (70 Federal Register [FR] 52488; September 2, 2005). This section of the lower American River was included in the critical habitat designation because it might be used during high winter flows for non-natal rearing and refugia by spring-run Chinook salmon originating from other rivers in the Sacramento River Basin.

The downstream movement period for spring-run Chinook salmon in the lower Sacramento River reportedly occurs from November through April (NMFS 1997), which corresponds to the period when high winter flows typically occur. Therefore, USACE's impact assessment in this Draft Technical Report considers flow- and water temperature–related changes to affect non-natal spring-run Chinook salmon rearing in the lower American River during the November-through-April period.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on spring-run Chinook salmon in the lower American River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Non-natal juvenile rearing (November through April)
  - Flows at RM 1
  - Water temperatures at RM 1

RIVER LAMPREY

The life history periodicities for river lamprey that are evaluated in this report for the lower American River are based on reported river lamprey life history periodicities in the Sacramento River.

Adult river lampreys migrate into freshwater in the fall and spawn during the winter or spring months in small tributary streams, although the timing and extent of their migration in California is poorly known (UC Davis 2012). For this Draft Technical Report, USACE assumed that adult river lampreys could immigrate from September through June. River lampreys have been reported to spawn from February through May (Moyle 2002) and from April through June (Wang 1986). Moyle (2002) reported that Pacific lamprey embryos hatch in about 19 days at 15 degrees Celsius (°C) (59°F). USACE assumed that river lamprey embryos might incubate for a duration similar to that of Pacific lamprey embryos and therefore assumed that river lamprey embryos could incubate into July. Therefore, for this Draft Technical Report, USACE assumed that river lamprey spawning and embryo incubation could occur from February through July. Lamprey redds observed in the lower American River suggest that lamprey spawn primarily downstream of Watt Avenue (Hannon 2013; Hannon and Deason 2005).

Because river lamprey ammocoetes can remain buried for several years, USACE evaluated ammocoete rearing and downstream movement year-round.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on river lampreys in the lower American River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (September through June)
  - Flows at Watt Avenue and RM 1
  - Water temperatures at Watt Avenue and RM 1
- ❑ Spawning and embryo incubation (February through July)
  - Flows at Watt Avenue

- Water temperatures at Watt Avenue

- ❑ Ammocoete rearing and downstream movement (year-round)
  - Flows at Watt Avenue and RM 1
  - Water temperatures at Watt Avenue and RM 1

PACIFIC LAMPREY

The life history periodicities for Pacific lampreys that are evaluated in this report for the lower American River are based on reported Pacific lamprey life history periodicities in the Sacramento River as well as on additional information based on Pacific lamprey redd observations in the lower American River. Specifically, Pacific lamprey redds were reportedly observed as early as January in the lower American River (Hannon 2013; Hannon and Deason 2005). Based on lamprey redd observations from 2002 through 2007, the peak lamprey redd count date ranged from late March to early April, and occurred during late April in 2013 (Hannon 2013). However, the reported peak dates of lamprey redd counts could be biased as a result of lack of sampling after the peak number of redds was observed. Therefore, USACE assumes that peak lamprey spawning could begin as early as late March or early April but could extend later.

Lamprey redds observed in the lower American River suggest that lamprey spawn primarily downstream of Watt Avenue (Hannon 2013; Hannon and Deason 2005).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on Pacific lampreys in the lower American River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (January through June)
  - Flows at Watt Avenue and RM 1
  - Water temperatures at Watt Avenue and RM 1
- ❑ Spawning and embryo incubation (January through August)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue
- ❑ Ammocoete rearing and downstream movement (year-round)
  - Flows at Watt Avenue and RM 1
  - Water temperatures at Watt Avenue and RM 1

HARDHEAD

Hardheads often make spawning migrations in the spring into smaller tributary streams (Moyle 2002). Hardheads spawn primarily during April through June (Grant and Maslin 1999; Reeves 1964; Wang 1986). In Brown et al. (1992), larval hardheads were reportedly found in late May in the lower American River. In addition, hardheads were captured as early as November in emigration surveys using rotary screw traps (Snider et al. 1997; Snider and Titus 2000a).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on hardheads in the lower American River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Spawning (April through June)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue
- ❑ Adults and other lifestages (year-round)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue

AMERICAN SHAD

The primary American shad spawning migration period in the lower American River is believed to occur during April through June (Urquhart 1987), and extended juvenile rearing could occur into December, based on CDFW surveys in the lower American River.

Several flow indicators have been identified in the literature to evaluate adult American shad attraction to the lower American River: (1) Kelley et al. (1985b as cited in SWRI 2001) recommended flows of 2,000 cubic feet per second (cfs) or greater from mid-May through June for American shad attraction, (2) Snider and Gerstung (1986) recommended flow levels of 3,000 to 4,000 cfs in the lower American River during May and June, and (3) Painter et al. (1978) recommended that lower American River outflow be at least 10 percent of the Sacramento River flow during May and June. Therefore, USACE assessed changes in American shad attraction flows by determining the number of years in which May and June flows at the mouth of the lower American River would be: (1) greater than 2,000 cfs, (2) within the range of 3,000 cfs to 4,000 cfs, and (3) at least 10 percent of the Sacramento River flow with the Folsom WCM alternatives, compared to the frequency of these flows with the basis of comparison.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on American shad in the lower American River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult attraction (May and June)
  - Attraction flows at RM 1
- ❑ Adult immigration and spawning (April through June)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue
- ❑ Juvenile rearing and downstream movement (April through December)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue

STRIPED BASS

There is little information regarding specific lifestage periodicities for striped bass in the lower American River. The striped bass spawning period in the Central Valley reportedly occurs from April through June. Although it is not known whether striped bass spawn in the lower American River, adult striped bass have been observed in the lower American River during the spawning season (Cannon and Kennedy 2003; DeHaven 1977). Therefore, striped bass spawning was evaluated by USACE in the lower American River during April through June. Primary rearing areas for juvenile striped bass are located in the Sacramento–San Joaquin Delta; however, the lower American River is used as an opportunistic nursery area during the summer and into the fall (CDFG 1971, 1986; DeHaven 1977). For this Draft Technical Report, striped bass juvenile rearing in the lower American River was evaluated by USACE from May through October.

The number of adult striped bass entering the lower American River is believed to vary with flow levels and food production. Snider and Gerstung (1986) suggested that flows of 1,500 cfs at the mouth of the lower American River during May and June would be sufficient to maintain the striped bass sport fishery. Hence, USACE assessed flow-related changes on the striped bass sport fishery by determining the percentage of time that flows at the mouth of the lower American River would be less than 1,500 cfs in May and June with the Folsom WCM alternatives (and the No Action Alternative), relative to the basis of comparison.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on striped bass in the lower American River for each of the following lifestages, life history periodicities, and modeled locations:

- Adult attraction (May and June)
  - Attraction flows at RM 1
- Adult immigration and spawning (April through June)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue
- Juvenile rearing (May through October)
  - Flows at Watt Avenue
  - Water temperatures at Watt Avenue

1.1.5 Far-Field

The Far-Field Study Area consists of the SWP and CVP water operations within the Sacramento River watershed. Specifically, the Far-Field includes the Sacramento River downstream of Keswick Dam, the lower Feather River, Yolo Bypass, and the Sacramento–San Joaquin Delta (Delta).

Because the Folsom WCM Project could change hydrology and water temperature as well as Delta habitat parameters (e.g., X2 location) in the Secondary Study Area, the impact assessment focuses on these and other habitat-based elements. This "initial evaluation" focuses on an evaluation of mean monthly flows and water temperatures at representative nodes for species of focused evaluation in the Far-Field (i.e., net changes in mean monthly flow of 10 percent or more, and changes in the probability of exceeding lifestage-specific WTI values of 10 percent or more).

USACE's decision regarding whether or not to conduct more-detailed impact determinations was based on a consideration of all flow and water temperature indicators of potential impact for all lifestages for a particular species. Detailed evaluations were conducted by USACE if the initial evaluation indicated that the Folsom WCM alternatives could adversely affect an individual species or run, for its defined geographic area (e.g., upper Sacramento River, lower Feather River, etc.), in consideration of all evaluated impact indicators for all lifestages during the initial screening.

A substantial difference in mean monthly flow or in the probability of exceeding a WTI value over a portion of a particular species and lifestage-specific evaluation period does not necessarily constitute an impact. Impact determinations are based on USACE's consideration of all evaluated impact indicators for all lifestages for a particular species. USACE considers an impact to be potentially significant if implementing the Folsom WCM alternatives would adversely affect an individual species or run, for its defined geographic area, in consideration of all evaluated impact indicators for all lifestages.

The following section describes the analytical framework used by USACE to assess the effects of the Folsom WCM alternatives in the Far-Field as part of the initial evaluation.

1.1.5.1 Tools and Application of Model Output

Applications of output resulting from hydrologic and water temperature models and post-processing tools previously described in Section 1.1.4.1 for the lower American River generally pertain to the Far-Field. Hydrologic and water temperature model output are provided on a monthly timestep for the Far-Field.

1.1.5.2 River-Specific Assessment Approach

Changes in SWP/CVP operations resulting from the Folsom WCM alternatives could alter seasonal flows and water temperatures in the Sacramento River, the Feather River, and the Delta.

Because the fish species that inhabit, traverse, or use these areas could differ among regions, USACE's fisheries impact assessment approach varies among geographic areas. The river-specific impact assessment includes identification of fish species of focused evaluation, model output and node locations, and species and lifestage-specific evaluation methodologies for the Folsom WCM alternatives.

Where specific flow requirements have not been developed for species evaluated in a specific river, USACE based potential flow-related impacts determinations on an evaluation of the frequency and magnitude of change in modeled monthly mean flow with the Folsom WCM alternatives, relative to the basis of comparison. USACE based water temperature-related impact determinations on species- and lifestage-specific water temperature index values. The species- and lifestage-specific evaluation periodicities identified below in Section 1.1.5.3 are based on the reviews of river- and species/lifestage-specific literature summarized in Appendix 7A, Environmental Setting as well as on additional information presented below in Section 1.1.5.3.

1.1.5.3 Sacramento River

The Sacramento River below Keswick Dam is used by several fish species, either as habitat during one or more of their lifestages or as a migration corridor to one of its tributaries. Operation of Folsom Dam and Reservoir with the Folsom WCM alternatives could trigger changes in SWP/CVP operations, which could alter seasonal flows and water temperatures in the Sacramento River, which, in turn, could affect habitat conditions for fish species in the Sacramento River. Hence, USACE conducted species-specific impact assessments for the following species in the Sacramento River.

Table 4. Fish Species of Focused Evaluation in the Sacramento River.

Common Name	Status
• Sacramento River winter-run Chinook salmon ESU	Federally and state endangered
• Central Valley spring-run Chinook salmon ESU	Federally and state threatened
• Central Valley fall-/late fall-run Chinook salmon ESU	Federal species of concern State species of special concern Recreational and/or commercial importance
• Central Valley steelhead DPS	Federally threatened Recreational and/or commercial importance
• Southern DPS of North American green sturgeon	Federally threatened State species of special concern
• River lamprey	State species of special concern
• Pacific lamprey	Federal species of concern
• Sacramento splittail	State species of special concern
• Hardhead	State species of special concern
• White sturgeon	Recreational and/or commercial importance
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

SPECIES-SPECIFIC ANALYTICAL APPROACH

Winter-run Chinook Salmon

Immigration and pre-spawning holding for adult winter-run Chinook salmon in the Sacramento River occurs from November through July (NMFS 2009, 2014). Winter-run Chinook salmon are unique because they spawn during the summer when air temperatures usually approach their yearly maximum (NMFS 2014). Spawning occurs primarily from mid-April to mid-August, with peak spawning during May and June in the Sacramento River reach between Keswick Dam (RM 302) and Red Bluff Diversion Dam (RBDD) (RM 243) (NMFS 2014; Vogel and Marine 1991). Chinook salmon embryo incubation in the Sacramento River can extend into September during wet water years (Vogel and Marine 1991). Winter-run fry begin to emerge from the gravel in late June and continue to emerge through October (Fisher 1994 as cited in NMFS 2009). Emigration of juvenile winter-run fry past RBDD can begin as early as mid-July, typically peaking in September and continuing through March in dry years (NMFS 1997 as cited in NMFS 2014; Vogel and Marine 1991).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on winter-run Chinook salmon in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (November through July)
  - Flows below Keswick Dam, at Bend Bridge, at Verona, and at Freeport
  - Water temperatures below Keswick Dam, at Bend Bridge, below the Feather River confluence, and at Freeport
- ❑ Adult holding (November through July)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam and at Bend Bridge
- ❑ Spawning and embryo incubation (April through September)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, and at Bend Bridge
- ❑ Juvenile rearing and downstream movement (July through March)
  - Flows below Keswick Dam, at Bend Bridge, at Verona, and at Freeport
  - Water temperatures below Keswick Dam, at Bend Bridge, below the Feather River confluence, and at Freeport

Spring-run Chinook Salmon

Adult spring-run Chinook salmon enter the Sacramento River between March and September, primarily during May and June (Moyle 2002; Yoshiyama et al. 1998). Spring-run Chinook salmon spawn during September and October, depending on water temperature (NMFS 2009). Spawning and embryo incubation has been reported to occur primarily during September through mid-February, with spawning peaking in mid-September (Moyle 2002; Vogel and Marine 1991). Spring-run Chinook salmon fry emerge from the gravel from November through March (Moyle 2002).

Emigration timing for juvenile spring-run Chinook salmon varies based on life history. Juvenile spring-run Chinook salmon can begin emigrating soon after they emerge from the gravel as YOY, whereas others over-summer and emigrate as yearlings (CDFG 1998; NMFS 2009). As described in NMFS (2009), juvenile spring-run Chinook salmon emigration at RBDD occurs primarily from November through January and can extend into mid-May. Most spring-run Chinook salmon are believed to rear in the upper Sacramento River during the winter and spring and to emigrate as juveniles or smolts. Some spring-run Chinook salmon can spend as long as 18 months in freshwater and move downstream as smolts during the first high flows of the winter from November through January (CDFG 1998; USFWS 1995). In the Sacramento River, spring-run Chinook salmon smolt reportedly emigrate from October through March (CDFG 1998).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on spring-run Chinook salmon in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (March through September)
  - Flows below Keswick Dam, at Bend Bridge, at Verona, and at Freeport
  - Water temperatures below Keswick Dam, at Bend Bridge, below the Feather River confluence, and at Freeport
- ❑ Adult holding (March through September)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam and at Bend Bridge
- ❑ Spawning and embryo incubation (September through January)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, and at Bend Bridge
- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows below Keswick Dam, at Bend Bridge, and at Verona
  - Water temperatures below Keswick Dam, at Bend Bridge, and below the Feather River confluence
- ❑ Smolt emigration (October through May)
  - Flows at Red Bluff, Verona, and Freeport
  - Water temperatures at Red Bluff, below the Feather River confluence, and at Freeport

Fall-run Chinook Salmon

Migration of adult fall-run Chinook salmon into the Sacramento River begins in July, peaks in October, and ends in December (Vogel 2011). Fall-run Chinook salmon spawn from October through December (Reclamation 2008; Vogel 2011). In general, the fall-run Chinook salmon embryo incubation period extends from October through March (NMFS 2004; Vogel and Marine 1991). The rearing period for juvenile fall-run Chinook salmon in the Sacramento River extends from late December through June (Moyle 2002; Vogel and Marine 1991). Fall-run Chinook salmon juvenile emigration in the Sacramento River occurs from January through June (Moyle 2002; Vogel 2011; Vogel and Marine 1991). Juvenile fall-run Chinook salmon emigration at RBDD begins as early as December, peaks in January and February during winter flow events, decreases through the spring, and extends as late as July (Gaines and Martin 2001 as cited in USFWS and CDFG 2012).

Although fall- and late fall-run Chinook salmon are considered part of the same ESU, their lifestages were evaluated separately by USACE due to distinct differences in the timing of various lifestages.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on fall-run Chinook salmon in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and staging (July through December)
  - Flows below Keswick Dam, at Red Bluff, at Verona, and at Freeport
  - Water temperatures below Keswick Dam, at Red Bluff, below the Feather River confluence, and at Freeport

- Spawning and embryo incubation (October through March)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, and at Bend Bridge
- Juvenile rearing and downstream movement (December through July)
  - Flows at Bend Bridge, Verona, and Freeport
  - Water temperatures at Bend Bridge, below the Feather River confluence, and at Freeport

Late Fall-run Chinook Salmon

Adult immigration of late fall-run Chinook salmon in the Sacramento River generally begins in late October and extends through March (USFWS and CDFG 2012). Late fall-run Chinook salmon spawning occurs from January through April in the Sacramento River (Moyle 2002; NMFS 2004; Vogel and Marine 1991). Late fall-run Chinook salmon embryo incubation extends from January through June (USFWS and CDFG 2012; Vogel and Marine 1991). Late-fall run Chinook salmon juveniles rear in the Sacramento River beginning in late April and continuing through the following December (USFWS and CDFG 2012). Downstream migration of juveniles occurs from April through December, with the primary movement of yearlings taking place during the late fall and early winter months (Reclamation 2008).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were by USACE conducted to identify the effects of the alternatives on late fall-run Chinook salmon in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- Adult immigration and holding (October through April)
  - Flows below Keswick Dam, at Red Bluff, at Verona, and at Freeport
  - Water temperatures below Keswick Dam, at Red Bluff, below the Feather River confluence, and at Freeport
- Spawning and embryo incubation (January through June)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam, at Ball's Ferry, at Jelly's Ferry, and at Bend Bridge
- Juvenile rearing and downstream movement (April through December)
  - Flows at Bend Bridge, Verona, and Freeport
  - Water temperatures at Bend Bridge, below the Feather River confluence, and at Freeport

Steelhead

Sacramento River steelhead immigration typically begins in August and continues into March or April (McEwan 2001; NMFS 2014), with peak immigration during January and February (Moyle 2002). Sacramento River steelhead spawning occurs from December through April, with peak spawning from January though March (NMFS 2009). McEwan (2001) reports that steelhead fry and fingerlings rear and move downstream in the Sacramento River year-round, although most steelhead smolts reportedly emigrate from January through June. Based on CDFW sampling at Knights Landing, juvenile steelhead emigration occurs primarily from January through May with peaks occurring during March and April (Snider and Titus 2000b).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on steelhead in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- Adult immigration (August through March)
  - Flows below Keswick Dam, at Red Bluff, at Verona, and at Freeport
  - Water temperatures below Keswick Dam, at Red Bluff, below the Feather River confluence, and at Freeport
- Adult holding (August through March)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam and at Bend Bridge
- Spawning and embryo incubation (December through May)
  - Flows below Keswick Dam and at Bend Bridge
  - Water temperatures below Keswick Dam and at Bend Bridge
- Juvenile rearing and downstream movement (year-round)
  - Flows below Keswick Dam, at Bend Bridge, and at Verona
  - Water temperatures below Keswick Dam, at Bend Bridge, and below the Feather River confluence
- Smolt emigration (January through June)
  - Flows at Red Bluff, Verona, and Freeport
  - Water temperatures at Red Bluff, below the Feather River confluence, and at Freeport

Green Sturgeon

North American green sturgeon adults in the Sacramento River begin their upstream spawning migrations into freshwater during late February, prior to spawning between March and July, with peak spawning believed to occur between April and June (Adams et al. 2002). Green sturgeon eggs in the Sacramento River incubate during April through August (NMFS 2009). At day 110 to day 118 after emergence, juvenile green sturgeon move downstream (Kynard et al. 2005). Juvenile green sturgeon are taken in traps at RBDD, primarily in May through August, with peak counts reported for June and July (68 FR 4433). Juvenile emigration reportedly extends through September (Environmental Protection Information Center et al. 2001).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on the Southern distinct population segment (DPS) of North American green sturgeon in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- Adult immigration and holding (February through July)

- Flows below Keswick Dam, at Red Bluff, and at Freeport
- Water temperatures below Keswick Dam, at Red Bluff, and at Freeport

- ❑ Spawning and embryo incubation (March through August)
  - Flows below Keswick Dam, at Red Bluff, and at Wilkins Slough
  - Water temperatures below Keswick Dam, at Red Bluff, and at Wilkins Slough

- ❑ Adult post-spawning and emigration (July through November)
  - Flows below Keswick Dam, at Red Bluff, and at Freeport
  - Water temperatures below Keswick Dam, at Red Bluff, and at Freeport

- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows at Red Bluff, Wilkins Slough, and Freeport
  - Water temperatures at Red Bluff, Wilkins Slough, and Freeport

White Sturgeon

Adult white sturgeon upstream spawning movements are apparently triggered by photoperiod (Doroshov et al. 1997; Webb et al. 1999 as cited in Israel et al. 2011) and increases in river flow (Schaffter 1997). Adult white sturgeon initiate their upstream migration into the lower Sacramento River from the Delta and estuary during late fall and winter (Kohlhorst and Cech 2001). The relatively larger adults migrate to about a 90-kilometer section of the river to spawn between Knights Landing and several kilometers upstream of Colusa (Kohlhorst 1976; Schaffter 1997). White sturgeon spawning typically occurs between February and June when water temperatures are 46°F to 66°F (Moyle 2002), with peak spawning activity occurring during March and April (Kohlhorst 1976; Kohlhorst and Cech 2001). Juvenile rearing and emigration can occur year-round. For this Draft Technical Report, USACE assumes that white sturgeon adult immigration and holding occur primarily from November through May and that spawning and embryo incubation generally occur from February through June.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on white sturgeon in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and holding (November through May)
  - Flows at Red Bluff, Wilkins Slough, and Freeport
  - Water temperatures at Red Bluff, Wilkins Slough, and Freeport

- ❑ Spawning and embryo incubation (February through June)
  - Flows at Red Bluff, Verona, and Freeport
  - Water temperatures at Red Bluff, at Wilkins Slough, and below the Feather River confluence

- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows at Wilkins Slough, Verona, and Freeport
  - Water temperatures at Wilkins Slough, below the Feather River confluence, and at Freeport

River Lamprey

Based on studies of river lampreys in British Columbia, adult upstream migration occurs in autumn (Moyle 2002), beginning in about September extending through late winter (Beamish 1980).The exact timing of upstream migration of adults in California is unknown (Moyle 2002). Adult river lampreys migrate into freshwater in the fall and spawn during the winter or spring in small tributary streams, although the timing and extent of their migration in California is poorly known (UC Davis 2012). For this Draft Technical Report, USACE assumes that river lamprey adult immigration occurs from September through June. River lampreys reportedly spawn during February through May (Moyle 2002). Ammocoete metamorphosis begins during the summer (Moyle 2002), which indicates that embryo incubation could extend into July. The length of the ammocoete lifestage is not known but is probably 3 to 5 years (Moyle 2002). Therefore, ammocoete rearing occurs year-round. Ammocoete emigration might be associated with large pulse flows during the winter. After reaching the Delta, ammocoetes are considered to be macropthalmia (i.e., juveniles).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on river lampreys in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- Adult immigration (September through June)
  - Flows below Keswick Dam, at Wilkins Slough, and at Freeport
  - Water temperatures below Keswick Dam, at Wilkins Slough, and at Freeport
- Spawning and embryo incubation (February through July)
  - Flows below Keswick Dam, at Red Bluff, and at Wilkins Slough
  - Water temperatures below Keswick Dam, at Red Bluff, and at Wilkins Slough
- Ammocoete rearing and downstream movement (year-round)
  - Flows below Keswick Dam, at Wilkins Slough, and at Freeport
  - Water temperatures below Keswick Dam, at Wilkins Slough, and at Freeport

Pacific Lamprey

Adult Pacific lampreys typically migrate into the Sacramento River in March through June (Moyle 2002), but upstream migrations have been observed during January and February (Entrix 1996 as cited in Moyle 2002; Trihey and Associates 1996a as cited in Moyle 2002). Pacific lampreys have been reported to spawn between March and July, depending on the location (USFWS 2008), which indicates that eggs could be incubating as late as August. The length of the Pacific lamprey ammocoete lifestage is not known but is estimated to be 5 to 7 years (Moyle 2002). Therefore, ammocoete rearing occurs year-round.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on Pacific lampreys in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- Adult immigration (January through June)
  - Flows below Keswick Dam, at Wilkins Slough, and at Freeport

- Water temperatures below Keswick Dam, at Wilkins Slough, and at Freeport

- ❑ Spawning and embryo incubation (March through August)
  - Flows below Keswick Dam, at Red Bluff, and at Wilkins Slough
  - Water temperatures below Keswick Dam, at Red Bluff, and at Wilkins Slough

- ❑ Ammocoete rearing and downstream movement (year-round)
  - Flows below Keswick Dam, at Wilkins Slough, and at Freeport
  - Water temperatures below Keswick Dam, at Wilkins Slough, and at Freeport

Sacramento Splittail

Sacramento splittail spawning can occur anytime between late February and early July, with peak spawning occurring during March and April (Moyle 2002). The California Department of Water Resources (DWR) reported that Sacramento splittail spawning, embryo incubation, and initial rearing occur primarily during February through May (DWR 2004). Therefore, for this Draft Technical Report, Sacramento splittail spawning and embryo incubation is evaluated during February through May.

Juvenile Sacramento splittail prefer shallow-water habitat with emergent vegetation during rearing (Meng and Moyle 1995). Although it has been generally reported that downstream movement of juvenile Sacramento splittail appears to coincide with drainage from the floodplains between May and July (Caywood 1974; Meng and Moyle 1995; Sommer et al. 1997), large numbers of YOY Sacramento splittail are typically captured in screw traps (set at the base of floodplains) in the Yolo and Sutter Bypasses in May, with diminishing numbers in June (Sommer et al. 2004).

Because Sacramento splittail occur primarily in the Yolo Bypass, and because of their tolerance for a wide range of water temperatures (e.g., 45°F–75°F), changes in habitat for Sacramento splittail were evaluated by USACE using simulated changes in Yolo Bypass outflow, as identified in the Yolo Bypass section, below.

Hardhead

Hardheads generally occur in large, undisturbed, low- to mid-elevation rivers and streams throughout the Sacramento River system (Moyle 2002). Hardheads mature during their third year and often make spawning migrations in the spring into smaller tributary streams (Moyle 2002; USFWS and CDFG 2012). Most hardhead spawning is reportedly restricted to Sacramento River tributaries and foothill streams (Wang and Reyes 2007). Hardheads reportedly spawn primarily during April and May (Grant and Maslin 1999; Reeves 1964); however, hardhead larvae have been collected in Clear Creek, Stony Creek, and Mud Creek during July (Wang and Reyes 2007), which indicates that spawning can occur during June. Because hardhead is a resident fish species, adult and juvenile lifestages might be present in the river year-round.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on hardheads in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adults and other lifestages (year-round)

- Flows below Keswick Dam, at Verona, and at Freeport
- Water temperatures below Keswick Dam, below the Feather River confluence, and at Freeport

❑ Spawning (April through June)

- Flows below Keswick Dam, at Wilkins Slough, and at Freeport
- Water temperatures below Keswick Dam, at Wilkins Slough, and at Freeport

American Shad

Adult American shad enter the Sacramento River from April through early July (CDFG 1986), with the majority of immigration and spawning occurring from mid-May through June (Urquhart 1987). American shad larvae are planktonic for about 4 weeks and drift downstream from spawning areas during this time (Stier and Crance 1985 as cited in Moyle 2002). Outmigration of young American shad reportedly occurs from June through November (Stevens 1966 as cited in CDFG 2010). However, juvenile rearing and downstream movement in the Sacramento River can occur year-round (Moyle 2002).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on American shad in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

❑ Adult immigration and spawning (April through June)

- Flows at Red Bluff, Verona, and Freeport
- Water temperatures at Red Bluff, below the Feather River confluence, and at Freeport

❑ Juvenile rearing and downstream movement (year-round)

- Flows at Wilkins Slough, Verona, and Freeport
- Water temperatures at Wilkins Slough, below the Feather River confluence, and at Freeport

Striped Bass

Adult striped bass are present in Central Valley rivers throughout the year, with peak abundance occurring during the spring. Spawning can begin in April but peaks during May and early June (Moyle 2002). In the Sacramento River, striped bass spawning is believed to generally occur between Sacramento and Princeton (CDFW 2015). Larval and initial juvenile striped bass nursery areas are located primarily in the Delta and in Suisun Bay (Hassler 1988). However, juvenile rearing can occur in the lower Sacramento River year-round.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on striped bass in the Sacramento River for each of the following lifestages, life history periodicities, and modeled locations:

❑ Adult Immigration and Spawning (April through June)

- Flows at Wilkins Slough and Verona
- Water temperatures at Wilkins Slough and below the Feather River confluence

❑ Juvenile rearing (year-round)

- Flows at Wilkins Slough and Verona
- Water temperatures at Wilkins Slough and below the Feather River confluence

1.1.5.4 Feather River

The Feather River watershed in the Secondary Study Area includes Oroville Reservoir and the lower Feather River extending from the Fish Barrier Dam to the confluence with the Sacramento River. Because the Folsom WCM alternatives could change Feather River flows and water temperatures, the impact assessment focuses on these and other habitat-based elements.

1.1.5.4.1 Feather River

The lower Feather River begins at the river's Low Flow Channel, which extends 8 miles from the Fish Barrier Dam (RM 67) to the Thermalito Afterbay Outlet (RM 59). Water is released through a powerhouse, then through the Fish Barrier Dam into the Low Flow Channel. The Thermalito Afterbay has a dual purpose as an afterbay for upstream peaking power releases to ensure constant river and irrigation canal flows and as a warming basin for irrigation water being diverted to rice fields (NMFS 2009). Thus, water temperatures in the approximately 14 miles of salmon spawning area from the Thermalito Afterbay Outlet to the mouth of Honcut Creek (referred to as the High Flow Channel) are always higher than those in the 8 miles of the Low Flow Channel (USFWS 1995).

Through the Oroville Facilities Federal Energy Regulatory Commission (FERC) Relicensing, operational changes increase the minimum instream flow from the historic 600 cfs to 700 cfs in the Low Flow Channel during most of the year to increase the amount of available anadromous spawning habitat and decrease water temperatures. During the Chinook salmon spawning season (generally from September through March), the minimum instream flows in the Low Flow Channel are increased to 800 cfs (FERC 2006; SWRCB 2010).

The majority of the Low Flow Channel flows through a single channel contained by stabilized levees. Side-channel or secondary channel habitat is limited, occurring primarily in the Steep Riffle (located 2 miles upstream of the Thermalito Afterbay Outlet) and Eye Riffle areas between RM 60 and RM 61. The channel banks and streambed consist of armored cobble as a result of periodic flood flows and the absence of gravel recruitment. However, there are nine major riffles with suitable spawning-size gravel, and about two-thirds of the natural Chinook salmon spawning in the lower Feather River occurs in the Low Flow Channel, which extends between the Fish Barrier Dam and the Thermalito Afterbay Outlet (DWR 2007; NMFS 2009). Releases are made from the coldwater pool in Oroville Reservoir, and this cold water generally provides suitable water temperatures for spawning in the Low Flow Channel (DWR 2001).

The remaining amount (about one-third) of Chinook salmon spawning in the lower Feather River occurs in the High Flow Channel, which is located downstream of the Thermalito Afterbay Outlet to Honcut Creek (RM 59 to RM 44) (DWR 2007; NMFS 2009). Flows in the High Flow Channel are maintained between the minimum flow and a flow no greater than 2,500 cfs from October 15 through November 30 to prevent Chinook salmon redd dewatering in the event that flows were to decrease during the egg incubation period (FERC 2006). The High Flow Channel also is an important migration corridor for both juvenile and adult anadromous fish (NMFS 2004).

Releases from the Thermalito Afterbay Outlet vary according to operational requirements, and the flow regime in the reach of the Feather River extending from the Thermalito Afterbay Outlet (RM 59) to the confluence of the Feather and Sacramento Rivers (RM 0) varies depending on runoff and month (FERC 2006).

According to SWRCB (2010), studies have shown it is unlikely that adult Chinook salmon can use the lower Feather River below the Thermalito Afterbay Outlet except as a migration corridor. As a result of elevated water temperatures, increased incidence of disease, developmental abnormalities, increased in-vivo egg mortality, and temporary cessation of Chinook salmon and steelhead migration could occur in some areas of the lower Feather River (SWRCB 2010).

Currently, there are several temperature objectives for the Feather River downstream of the Thermalito Afterbay Outlet. From May through August, water temperature objectives address American shad, striped bass, and other warmwater fish. During the fall (e.g., after September 15), water temperature objectives address fall-run Chinook salmon (DWR 1983, 2007).

To protect spring-run Chinook salmon and steelhead, NMFS (2004, 2009) has previously established water temperature targets for the lower Feather River at the Feather River Fish Hatchery and for the Low Flow Channel, which is monitored near Robinson Riffle (RM 61.6). Water temperature targets for the Low Flow Channel at Robinson Riffle, located near where the Low Flow Channel meets the High Flow Channel, specify that mean daily water temperatures shall not exceed 65°F from June 1 to September 30 (SWRCB 2010). From June 1 through September 30, DWR is required to control Feather River water temperatures at RM 61.6 (Robinson Riffle in the Low Flow Channel) unless DWR consults with the Feather River Technical Team and receives approval from NMFS to deviate from the Biological Opinion temperature requirement (DWR 2007).

The Feather River Fish Hatchery's water supply is diverted directly from the Thermalito Diversion Pool, which receives cold, hypolimnetic water (which is rarely warmer than the mid- to high 50s [°F]) from Oroville Reservoir. Because the hatchery's water supply comes from stored water in the Thermalito Diversion Pool and does not come directly from the Feather River, it is not subject to the thermal warming effects of downstream in-channel transport. Thus, the hatchery and the Thermalito Diversion Pool are not specifically evaluated in this assessment.

EVALUATION SPECIES

The lower Feather River is used by several fish species of focused evaluation, primarily as habitat during one or more of their lifestages but also as a migration corridor to upstream habitat in other river systems (e.g., the Yuba River). Changes caused by the Folsom WCM alternatives could alter seasonal Oroville Reservoir operations and, thus, alter Feather River flows and water temperatures, which could change the relative habitat suitability for the following fish species of focused evaluation.

Table 5. Fish Species of Focused Evaluation in the Feather River.

Common Name	Status
• Central Valley spring-run Chinook salmon ESU	Federally and state threatened
• Central Valley fall-/late fall-run Chinook salmon ESU [a]	Federal species of concern State species of special concern Recreational and/or commercial importance
• Central Valley steelhead DPS	Federally threatened Recreational and/or commercial importance
• Southern DPS of North American green sturgeon	Federally threatened State species of special concern
• White sturgeon	Recreational and/or commercial importance
• River lamprey	State species of special concern
• Pacific lamprey	Federal species of concern
• Sacramento splittail	State species of special concern
• Hardhead	State species of special concern
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

[a] Although the official designation of the ESU is Central Valley fall-/late fall-run Chinook salmon, the evaluation is for fall-run Chinook salmon on the lower Feather River because of the general absence of late fall-run Chinook salmon.

SPECIES-SPECIFIC ANALYTICAL APPROACH

Spring-run Chinook Salmon

Adult spring-run Chinook salmon enter the Sacramento River basin between March and September, primarily in May and June (Moyle 2002; Yoshiyama et al. 1998). Spring-run Chinook salmon adult immigration and holding in the lower Yuba River reportedly occur from April through September (RMT 2013). Thus, spring-run Chinook salmon in the lower Feather River also might be holding into September. Adult Chinook salmon in the lower Feather River exhibiting the typical life history of the spring run have been found holding at the Thermalito Afterbay Outlet and the Fish Barrier Dam as early as April (DWR 2007 as cited in NMFS 2014). Spring-run Chinook salmon spawning and embryo incubation in the lower Feather River might occur from September through February (NMFS 2014). Some spring-run Chinook salmon reportedly emigrate as smolts from the Feather River from October through June (Cavallo, pers. comm., 2004 as cited in YCWA et al. 2007).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on spring-run Chinook salmon in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (March through September)
  - Flows below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
  - Water temperatures below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River

- ❑ Adult holding (March through September)
  - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
  - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Spawning and embryo incubation (September through February)
  - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
  - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the lower Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the lower Feather River
- ❑ Smolt emigration (October through June)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

Fall-run Chinook Salmon

In the Central Valley, adult fall-run Chinook salmon are reported to generally begin migrating upstream annually in July, with immigration continuing through December in most years (NMFS 2004; Vogel and Marine 1991). Fall-run Chinook salmon spawning and embryo incubation generally extend from October through February or March (Moyle 2002; SWRI 2001; Vogel and Marine 1991). The juvenile fall-run Chinook salmon rearing period in the Central Valley reportedly extends from late December through June (Moyle 2002; Vogel and Marine 1991). In the Feather River, fall-run Chinook salmon fry emergence has been reported to occur as early as November (Seesholtz et al. 2003). Therefore, for this evaluation, fall-run Chinook salmon juvenile rearing and downstream movement are evaluated during November through June.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on fall-run Chinook salmon in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and staging (July through December)
  - Flows below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
  - Water temperatures below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
- ❑ Spawning and embryo incubation (October through March)
  - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
  - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Juvenile rearing and downstream movement (November through June)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River

- Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

Steelhead

The majority of natural steelhead spawning in the Feather River is reported to occur in the Low Flow Channel, particularly in the upper reaches near Hatchery Ditch, although limited steelhead spawning also occurs below the Thermalito Afterbay Outlet (DWR 2007). Recently, RMT (2013) identified steelhead lifestage periodicities in the lower Yuba River (a tributary of the Feather River) based on various studies, including the use of VAKI Riverwatcher systems, which have not been implemented in the lower Feather River. Therefore, lower Yuba River steelhead periodicities were used by USACE to evaluate steelhead in the lower Feather River.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on steelhead in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (August through March)
    - Flows below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
    - Water temperatures below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
- ❑ Adult holding (August through March)
    - Flows below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
    - Water temperatures below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
- ❑ Spawning and embryo incubation (January through May)
    - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
    - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Juvenile rearing and downstream movement (year-round)
    - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
    - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Smolt emigration (October through April)
    - Flows below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River
    - Water temperatures below the Fish Barrier Dam, below the Thermalito Afterbay Outlet, and at the mouth of the Feather River

Green Sturgeon

Limited information is available regarding green sturgeon distribution, movement, and behavioral patterns, as well as lifestage-specific habitat utilization preferences, for the Feather River. Green sturgeon in the Sacramento River have been documented and studied more widely than they have in the Feather

River. For this Draft Technical Report, USACE assumes that green sturgeon in the Feather River share the same life history traits as green sturgeon in the Sacramento River as described previously in Section 1.1.4.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on green sturgeon in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and holding (February through November)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River
- ❑ Spawning and embryo incubation (March through August)
  - Flows below the Thermalito Afterbay Outlet
  - Water temperatures below the Thermalito Afterbay Outlet
- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

White Sturgeon

Although both green and white sturgeon are native to California, white sturgeon are more commonly observed in the Feather River (DWR 2003 as cited in DWR 2005) and are known to spawn in the Feather River (Moyle 2002). For this Draft Technical Report, USACE assumes that white sturgeon life history periodicities in the Feather River are the same as those previously discussed for the Sacramento River in Section 1.1.4.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on white sturgeon in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and holding (November through May)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River
- ❑ Spawning and embryo incubation (February through June)
  - Flows below the Thermalito Afterbay Outlet
  - Water temperatures below the Thermalito Afterbay Outlet
- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River

- Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

River Lamprey

River lamprey life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in Section 1.1.4.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on river lampreys in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (September through June)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River
- ❑ Spawning and embryo incubation (February through July)
  - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
  - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Ammocoete rearing and downstream movement (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

Pacific Lamprey

Pacific lamprey life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed for the Sacramento River in Section 1.1.4.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on Pacific lampreys in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration (January through June)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River
- ❑ Spawning and embryo incubation (March through August)
  - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
  - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
- ❑ Ammocoete rearing and downstream movement (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River

- Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

Sacramento Splittail

Sacramento splittail life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed in Section 1.1.4 for the Sacramento River. Sacramento splittail spawning, embryo incubation, and initial rearing lifestages in the lower Feather River occur from February through May.

Because Sacramento splittail occur primarily in the Yolo Bypass, and because of their tolerance for a wide range of water temperatures (e.g., 45°F–75°F), the evaluation of changes in habitat for Sacramento splittail was conducted for the Yolo Bypass and is presented in the Yolo Bypass section below.

Hardhead

Hardhead life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed in Section 1.1.4 for the Sacramento River.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on hardheads in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adults and other lifestages (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River
- ❑ Spawning (April through June)
  - Flows below the Fish Barrier Dam and below the Thermalito Afterbay Outlet
  - Water temperatures below the Fish Barrier Dam and below the Thermalito Afterbay Outlet

American Shad

American shad life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed in Section 1.1.4 for the Sacramento River. American shad spawning in the lower Feather River occurs from April through June (DWR 2007). American shad juvenile rearing reportedly occurs in the Feather River below Yuba City (USFWS 1995). Because American shad juvenile rearing can occur in the Sacramento River year-round, juvenile rearing in the lower Feather River is also evaluated year-round.

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on American shad in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and spawning (April through June)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River

- Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

- ❑ Juvenile rearing and downstream movement (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

Striped Bass

Striped bass life history periodicities and habitat requirements in the lower Feather River are similar to those previously discussed in Section 1.1.4 for the Sacramento River. Striped bass spawning in the lower Feather River extends from April through June (DWR 2007).

Comparisons of modeling output for the Folsom WCM alternatives, relative to the basis of comparison, were conducted by USACE to identify the effects of the alternatives on striped bass in the Feather River for each of the following lifestages, life history periodicities, and modeled locations:

- ❑ Adult immigration and spawning (April through June)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

- ❑ Juvenile rearing (year-round)
  - Flows below the Thermalito Afterbay Outlet and at the mouth of the Feather River
  - Water temperatures below the Thermalito Afterbay Outlet and at the mouth of the Feather River

1.1.5.5 Sutter Bypass

Within the Sutter National Wildlife Refuge (NWR), native anadromous fish include steelhead and four distinct runs of Chinook salmon (USFWS 2009). Encompassing an area of about 2,600 acres, the Sutter NWR is located about 50 miles north of Sacramento, 10 miles southwest of Yuba City, and 5 miles south of Sutter, California. About 80 percent of the Sutter NWR is located within the Sutter Bypass, which is west of Yuba City, California (USFWS 2009). The east and west Sutter Bypass canals are part of lower Butte Creek and are tributary to the larger Sacramento River system.

During periods of high flows in the Sutter Bypass, large numbers of Chinook salmon and steelhead can use the Sutter NWR (USFWS 2009). When inundated, the relatively warmer waters of the floodplain become very productive and produce an abundance of prey, resulting in rapid growth rates and relatively large sizes of juvenile anadromous salmonids outmigrating to the Delta and the Pacific Ocean.

During periods of flooding, the Sutter NWR provides high-value rearing habitat for migrating juvenile Chinook salmon. Water enters the Sutter Bypass in several ways. First, Butte Creek, a non-SWP/CVP tributary of the Sacramento River, spills into Sutter Bypass via Butte Slough (Feyer et al. 2006). Second, when Sacramento River flows exceed between 90,000 and 100,000 cfs at Ord Ferry, water flows naturally over the banks into the Butte Basin. In addition to the Sacramento River overbank flows at Ord Ferry, the

Sutter Bypass receives inflow at weirs along the Sacramento River during high-flow events. Water enters Sutter Bypass at Tisdale Weir when Sacramento River flow exceeds 21,012 cfs, at Moulton Weir when flow exceeds 44,990 cfs, and at Colusa Weir when flow exceeds 65,014 cfs (Feyer et al. 2006).

Changed operations of the SWP/CVP could cause changes in flow in the Feather River associated with the Folsom WCM alternatives. Given the minor changes in the mean monthly flow modeling for the Far-Field, it is unlikely that high-flow events would exceed the weir overflow thresholds. Therefore, although USACE recognizes that the Sutter Bypass provides important habitat during high-flow events, USACE did not specifically evaluate spills into the Sutter Bypass for this Draft Technical Report.

1.1.5.6 Yolo Bypass

Several special-status fish species are reported to use the Yolo Bypass for adult immigration, spawning, and/or juvenile rearing. In particular, the Yolo Bypass provides high-quality rearing habitat as a result of high nutrient and invertebrate production when it is inundated (Sommer et al. 2001; Sommer et al. 2005).

To evaluate changes in rearing habitat in the Yolo Bypass, USACE used simulated changes in mean monthly flow out of the bypass as an indicator of floodplain inundation and changes in Yolo Bypass flow with the Folsom WCM alternatives, relative to the basis of comparison. Applicable lifestages of fish species of focused evaluation were evaluated in the Yolo Bypass during their respective lifestage periodicities, restricted to the months during which the Yolo Bypass generally floods. Spills from the Sacramento River into the Yolo Bypass generally occur during November through May. Therefore, changes in mean monthly Yolo Bypass outflow were evaluated only for November through May.

For anadromous fish, including runs of Chinook salmon, steelhead, and green and white sturgeon, Yolo Bypass outflow was evaluated during the Sacramento River juvenile rearing and downstream movement period (restricted to the November through May evaluation period). Delta smelt were evaluated during the reported period of adult rearing in the Yolo Bypass, and Sacramento splittail were evaluated during both the reported spawning and embryo incubation lifestage and the juvenile rearing and downstream movement lifestage (restricted to the November through May evaluation period). Floodplain habitat in the Yolo Bypass is particularly important to Sacramento splittail, which is discussed in more detail below in this section.

During winter and spring, adult splittail move upstream onto floodplains to forage and spawn (Meng and Moyle 1995; Sommer et al. 1997). Splittail spawn generally between late February and early July (Moyle 2002), laying their eggs on submerged vegetation. Age-0 splittail abundance has been significantly correlated to mean Delta outflow during February through May and to the number of days of Yolo Bypass floodplain inundation (Meng and Moyle 1995; Sommer et al. 1997). USACE's evaluation of floodplain habitat availability in the Yolo Bypass addresses all splittail lifestages because floodplain habitat is important to all lifestages.

Flows through the Yolo Bypass of about 10,000 cfs reportedly could provide the greatest area of shallow habitat in the Yolo Bypass (Moyle et al. 2004, Sommer et al. 2004, Harrell and Sommer 2003, and Harrell et al. 2009, all as cited in Fleenor et al. 2010). It has been reported that 30 days is the estimated minimum time required for the development of splittail eggs to emigrating juveniles, based on estimated values reported in the literature (e.g., Feyrer et al. 2004, Feyrer et al. 2006, Moyle et al. 2004, and Sommer et al.

2007, all as cited in ICF 2013). Year-class abundance of splittail is reportedly determined primarily by floodplain spawning and rearing habitat conditions during February 1 through June 30 (Sommer et al. 1997). SWRCB (2010) and CDFG (2010) recommend that the Yolo Bypass be inundated for at least 30 consecutive days between late February and May of wet and above-normal water years to benefit splittail spawning and recruitment.

The availability of splittail floodplain habitat was evaluated by USACE by comparing CalSim II–simulated mean monthly Yolo Bypass flow (downstream of Fremont and Sacramento Weirs) with the Folsom WCM alternatives, relative to the basis of comparison, during February through May of wet and above-normal water years. Although CalSim II–simulated mean monthly flows do not necessarily indicate the duration of inundation of the Yolo Bypass, the frequency of inundation is indicated. Additionally, although NMFS (2009) stated that the floodplain is fully activated at 8,000 cfs, USACE assumes that increases in inundation frequency, regardless of flow volume in the bypass, would provide additional habitat for splittail even if the floodplain were not fully activated. Therefore, USACE's analysis of Yolo Bypass flows with the Folsom WCM alternatives, relative to the basis of comparison, does not specifically focus on flows above 8,000 cfs.

EVALUATION SPECIES

Yolo Bypass outflow was evaluated by USACE for the following species and lifestage-specific periods (restricted to the November through May evaluation period):

- ❑ Sacramento River winter-run Chinook salmon
    - Juvenile rearing and downstream movement (November through March)
- ❑ Central Valley spring-run Chinook salmon
    - Juvenile rearing and downstream movement (year-round)
- ❑ Central Valley fall-run Chinook salmon
    - Juvenile rearing and downstream movement (December through May)
- ❑ Central Valley late fall-run Chinook salmon
    - Juvenile rearing and downstream movement (November through May)
- ❑ Central Valley steelhead
    - Juvenile rearing and downstream movement (November through May)
- ❑ Green sturgeon
    - Juvenile rearing and downstream movement (November through May)
- ❑ White sturgeon
    - Juvenile rearing and downstream movement (April and May)
- ❑ Delta smelt

- Adult rearing (December through May)

- ❑ Sacramento splittail
  - Spawning and embryo incubation (February through May)
  - Juvenile rearing and downstream movement (April and May)

1.1.5.7 Sacramento–San Joaquin Delta

The Folsom WCM alternatives could influence aquatic habitat conditions by altering Delta inflow and water export operations. Therefore, USACE evaluated aquatic habitat conditions and export operations (e.g., fish salvage operations) to identify effects on Delta species of focused evaluation.

1.1.5.7.1 Evaluation Species

The current assemblages of fish in the Delta and watersheds upstream include a mixture of native and introduced species. Although there is limited knowledge of the ecology of native fish in the past, the historical assemblages of fish upstream of and in the Delta were different from the current assemblages (Moyle 2002). For example, the Sacramento perch, once abundant in sloughs off main channels, was extirpated from the Delta (Rutter 1908). Conversely, a large number of nonnative species of fish have been either intentionally (e.g., striped bass, channel catfish, American shad, threadfin shad, and largemouth bass) or unintentionally (e.g., goldfish) introduced into the system.

Although many fish species inhabit the Delta for all or part of their lifecycles, the following species of focused evaluation are considered for detailed evaluation in the Delta because they are Federally or state listed as threatened or endangered, are proposed for Federal or state listing as threatened or endangered, are species classified as candidates for future Federal or state listing, are state species of special concern, or are considered commercially or recreationally important.

Table 6. Fish Species of Focused Evaluation in the Sacramento–San Joaquin Delta.

Common Name	Status
• Sacramento River winter-run Chinook salmon ESU	Federally and state endangered
• Central Valley spring-run Chinook salmon ESU	Federally and state threatened
• Central Valley fall-/late fall-run Chinook salmon ESU	Federal species of concern State species of special concern Recreational and/or commercial importance
• Central Valley steelhead DPS	Federally threatened Recreational and/or commercial importance
• Delta smelt	Federally threatened State endangered
• Longfin smelt	Federal candidate State threatened
• American shad	Recreational and/or commercial importance
• Striped bass	Recreational and/or commercial importance

The habitat requirements and distribution for the above species are largely representative of the habitat requirements and distribution of other Delta fish species. Therefore, USACE's analysis of effects on the above species covers the range of effects on other Delta fishery resources.

SPECIES EXCLUDED FROM EVALUATION

Hardhead

Hardhead, a California species of special concern, is widely distributed throughout the Sacramento–San Joaquin River system, although it is absent from the valley reaches of the San Joaquin River (Moyle 2002). Hardheads generally occur in large, undisturbed, low- to mid-elevation rivers and streams of the region (Moyle 2002). The precise historical distribution and abundance patterns of hardheads are unknown, but the presence of their remains in Indian middens (mounds or deposits containing shells, animal bones, and other refuse) suggests that they were common in the general Delta region when the Delta was still a largely undisturbed intertidal swamp (The Bay Institute 1998).

However, based on USACE's evaluation of recent and historical fish surveys in the Delta, it is unlikely that hardheads occur in appreciable numbers in the Delta. Specifically, very few hardheads were reported in salvage data collected at the SWP and CVP fish salvage facilities. For example, from April 1, 2000, through March 31, 2003, the average annual salvage of hardheads at the Tracy Fish Facility was four individuals. Between 1993 and 2000, only 38 hardheads were counted at the SWP and CVP fish salvage facilities (BDAT 2010). Therefore, USACE anticipates that water operations would not substantively affect hardheads in the Delta. Thus, no further evaluation of hardheads in the Delta was conducted by USACE.

Northern Anchovy and Starry Flounder

Northern anchovy and starry flounder are managed as "monitored species" by the Coastal Pelagic Species Fishery Management Plan and the Pacific Coast Groundfish Fishery Management Plan of the Pacific Fishery Management Council (PFMC), respectively, and are subject to Essential Fish Habitat consultation as a result (PFMC 1998a and 1998c as cited in Reclamation 2008).

Northern Anchovy

Northern anchovies occur from British Columbia to Baja California (Reclamation 2008) and are reported to be common in surveys of the lower tidal portions of the Sacramento and San Joaquin Rivers (Herrgesell 1994 as cited in Reclamation 2008). However, because of their salinity requirements, northern anchovies have not been recorded above brackish water within these systems. This species typically is found from seawater to mesohaline waters (moderately brackish with salinity range of 5 to 18 parts per thousand [ppt]) and occasionally in oligohaline areas (brackish water with low salinity range of 0.5 to 5 ppt) (Reclamation 2008).

Reclamation (2008) determined that, because the northern anchovy is primarily a marine species and because integrated SWP/CVP operations have little effect on marine conditions, it is unlikely that changes in SWP/CVP operations would affect the northern anchovy. Northern anchovies made up less than 1 percent of the total fish captured by otter trawl and beach seine in Suisun Marsh between 1979 and 1999 (Matern et al. 2002 as cited in Reclamation 2008). However, this species was the fourth most common fish larvae collected in a 1991 survey of Suisun Bay, and northern anchovies also are common in San Pablo Bay (Herrgesell 1994 as cited in Reclamation 2008). Reclamation (2008) also reported that there are no records of northern anchovy salvage at the SWP/CVP fish salvage facilities. Therefore, USACE anticipates that water operations would not substantively affect northern anchovies in the Delta. Thus, no further detailed evaluation of northern anchovies in the Delta was conducted by USACE.

Starry Flounder

Starry flounders are known to occur in coastal waters of the Pacific and Arctic Oceans and connecting seas. In the eastern Pacific Ocean, the southern limit of its range is the mouth of the Santa Ynez River (Santa Barbara County, California) to as far north as the Alaskan Peninsula (Reclamation 2008). In northern California, this species can occur as far east as Suisun Bay and the lower portion of the San Joaquin River in the Delta. Further, Reclamation (2008) considered starry flounder primarily a marine and estuarine species.

Starry flounder is one of the most common flatfish in the San Francisco Bay and Delta and is an important component of the nearshore (inner continental shelf and shallow sublittoral) communities (Haugen and Thomas 2001 as cited in Reclamation 2008). The distribution of starry flounders tends to shift with growth. Younger juveniles are typically found in fresh or brackish water of Suisun Bay, Suisun Marsh, and the Delta, while older juveniles range from brackish to marine waters in Suisun and San Pablo Bays. Adults tend to live in shallow marine waters within and outside San Francisco Bay before returning to estuaries to spawn (Goals Project 2000 as cited in Reclamation 2008).

Starry flounders are not targeted by central California commercial fisheries. Most individuals are taken as incidental catch by bottom trawls, gill nets, and trammel nets. Recreational catch typically occurs by hook-and-line methods from piers, boats, and shore in estuarine and rocky areas (Reclamation 2008).

Salvage of starry flounders has been documented at the SWP and CVP fish salvage facilities in the Delta. Specifically, it has been reported that fish salvage records for the Sacramento–San Joaquin Delta between 1981 and 2002 indicated average monthly salvage of 187 fish per month at CVP and 77 at SWP (Foss 2003 as cited in Reclamation 2008). Recent salvage data indicate that substantially fewer starry flounders have been salvaged.

Specifically, salvage data obtained from the CDFG Salvage FTP (file-transfer) website during 2010 showed that, from 1995 through 2006, most starry flounder salvage at both facilities occurred during May, June, and July. CDFG salvage data indicate that most starry flounder salvage during 2008 and 2009 occurred during April and May. At the time the data were retrieved, data for 2007 were unavailable. The average monthly starry flounder salvage at the SWP and CVP facilities combined from 1995 through 2006 was 51 fish during May, 79 fish during June, and 30 fish during July (CDFG, no date).

From 2008 through 2009, the average combined SWP and CVP starry flounder salvage was 10 and 12 fish during April and May, respectively. Additionally, the next-highest average salvage estimate was four fish salvaged during March, April, and August. However, the highest single month salvage estimate occurred during June 1997 with an average of 427 fish salvaged at both facilities combined. The highest single-month starry flounder salvage at either facility was 696 fish at the CVP facility during May 1997.

Because starry flounders are not listed as threatened or endangered under the Federal or state ESAs, are not listed as species of special concern by CDFW or as species of concern by the U.S. Fish and Wildlife Service (USFWS), are not targeted by commercial fisheries, do not support a large recreational fishery, and are generally salvaged in relatively low numbers, no further evaluation of starry flounders in the Delta was conducted by USACE.

1.1.5.7.2 Fish Salvage and Entrainment Loss

In order to determine whether the Folsom WCM alternatives could cause substantial changes in fish salvage and entrainment, relative to the basis of comparison, at the Skinner Fish Protection Facility (part of the SWP) and the Tracy Fish Collection Facility (part of the CVP), USACE compared mean monthly total fish export volumes from these two facilities. USACE conducted further detailed evaluation of fish salvage and entrainment loss for fish species of focused evaluation if substantial changes in exports would occur with the alternatives, relative to the basis of comparison.

1.1.5.7.3 Species-Specific Analytical Approach

DELTA SMELT

Delta smelt are endemic to the San Francisco Bay/Sacramento–San Joaquin Delta (Bay-Delta) estuary (Moyle 2002). Delta smelt are primarily found downstream of Isleton on the Sacramento River, downstream of Mossdale on the San Joaquin River, and in Suisun Bay and Suisun Marsh. Delta smelt adults occur primarily in the tidally influenced low-salinity region of Suisun Bay and the freshwater regions of the Delta and the Sacramento and San Joaquin Rivers (Moyle 2002). The downstream location of the low-salinity habitat for delta smelt is typically located in Suisun Bay, extending farther to the west in response to high Delta outflows and farther to the east in response to low Delta outflows. Delta smelt have been collected in Carquinez Strait, in the Napa River, and even as far downstream as San Pablo Bay in wet years (Moyle 2002).

During September or October, adults begin upstream movement toward the freshwater sloughs and channels of the western Delta to spawn. Spawning takes place between February and July but appears to be greatest during mid-April and May (Bennett 2005). Spawning can occur in the Sacramento River as far upstream as Sacramento, the Mokelumne River system, and the Cache Slough region (Moyle 2002). Since 1982, the center of adult delta smelt abundance in the fall has been the northwestern Delta in the channel of the Sacramento River near Decker Island. In any month, two or more lifestages (adult, larvae, and juveniles) of delta smelt can be present in Suisun Bay (DWR and Reclamation 1994; Moyle 2002; Wang 1991). Delta smelt are also found seasonally in Suisun Marsh.

Eggs and Embryos

Based on reported delta smelt spawning timing, USACE evaluated the effects of the Folsom WCM alternatives on delta smelt eggs and embryos for the period of February through May (Moyle 2002; USFWS 2008).

Water Temperature

Water temperature reportedly is an important factor in the development of eggs and newly hatched delta smelt (Bennett 2005; Swanson and Cech 1995). Recent studies show that optimal delta smelt hatching success and larval survival in aquaculture occurs at 15°C to 17°C (B. Baskerville-Bridges, pers. comm, no date, as cited in Bennett 2005). Although incubation temperatures below 15°C have generally lower hatching success, water temperatures exceeding 20°C decrease the egg incubation period, mean hatch length, and time to first feeding as well as larval feeding success, resulting in higher mortality (B. Baskerville-Bridges, pers. comm., no date, as cited in Bennett 2005). Therefore, delta smelt spawning success might be variable when temperatures fall below 15°C, but can be more sharply limited by water temperatures that are above 20°C (Bennett 2005). Temperatures above 20°C during spring can also lead to higher mortality of newly spawned larvae (Bennett 2005).

Although water temperature is an important factor in the egg development and hatching success of delta smelt, the Folsom WCM alternatives have limited opportunity to affect water temperatures in the Delta. However, changes in SWP and CVP reservoir releases and operations at the South Delta pumping facilities could alter Delta inflow and outflow in the Sacramento River, which could alter residence times and water temperatures in delta smelt spawning areas.

USACE simulated monthly Sacramento River water temperatures at Freeport with the Folsom WCM alternatives and with the basis of comparison using Reclamation’s average monthly water temperature model. For the purpose of conducting an impact assessment on delta smelt eggs and embryos, USACE evaluated average monthly water temperatures at Freeport for the period of February through May (Moyle 2002; USFWS 2008) with the Folsom WCM alternatives, relative to the basis of comparison. Specifically, because egg and embryo hatching success and survival decreases below 15°C (59°F) and above 20°C (68°F), exceedance probability distributions were used to calculate the proportion of time that simulated water temperatures occur within this range with the Folsom WCM alternatives, relative to the basis of comparison.

Larvae

Based on the reported onset of delta smelt spawning and embryo incubation durations, USACE evaluated the effects of the Folsom WCM alternatives on delta smelt larvae for the period of March through June (Moyle 2002; USFWS 2008).

Water Temperature

Similar to the egg and embryo lifestage, delta smelt larval survival reportedly is optimized when water temperatures are within the range of about 15°C to 20°C (Bennett 2005) and decreases when temperatures rise above 20°C (Bennett 2005; Swanson and Cech 1995). Different parts of the Delta experience different water temperature conditions, with water temperatures increasing in the central and south Delta more than they do in the northern Delta or Suisun Bay. Because the Delta has a large water surface area and covers a large geographic extent, water temperature is influenced by ambient weather and climatic conditions more than by the operation of the SWP and CVP facilities.

For this reason, it is unlikely that the Folsom WCM alternatives would influence water temperatures in the Delta substantially during the March through June analytical period. However, changes in flows caused by the Folsom WCM alternatives and operations at the South Delta pumping facilities could alter Delta inflow and outflow in the Sacramento River, which could alter Delta water residence times and temperatures, which could alter Delta water temperatures and affect delta smelt larvae.

USACE simulated monthly Sacramento River water temperatures at Freeport with the Folsom WCM alternatives and with the basis of comparison using Reclamation's average monthly water temperature model. For the purpose of conducting an impact assessment on delta smelt larvae, USACE evaluated average monthly water temperatures at Freeport for the period of March through June (Moyle 2002; USFWS 2008) with the Folsom WCM alternatives, relative to the basis of comparison. Specifically, because embryo hatching success and survival decreases below 15°C (59°F) and above 20°C (68°F), exceedance probability distributions were used to calculate the proportion of time that simulated water temperatures occur within this range with the Folsom WCM alternatives, relative to the basis of comparison.

Entrainment

Larval delta smelt are considered weak swimmers that reportedly exercise some control of their position in the Delta through vertical migrations in the water column (Bennett 2005). Their initial distribution in the Delta depends on the location of spawning. Larval delta smelt are generally observed in the Delta between March and June, with a peak during April and May (Bennett 2005; Moyle 2002). The fish screens associated with the fish salvage facilities are not effective for fish less than 20 millimeters (mm) in length, and any screened larval delta smelt likely suffer high rates of mortality during the collection, handling, transport, and release phases of the salvage process. Therefore, larval delta smelt entrained at the SWP and CVP facilities are generally presumed by USACE to be killed.

Old and Middle River (OMR) Flows

SWRCB (2010) and CDFG (2010) recommended that OMR flows be more positive than –1,500 cfs during March through June of dry and critically dry years to protect the delta smelt population from entrainment at the SWP and CVP export facilities during years with relatively low Delta outflow. Therefore, for the purpose of assessing the effects of the Folsom WCM alternatives, flows less than (i.e., more negative than) –1,500 cfs were used as an impact indicator for delta smelt. Specifically, USACE evaluated the percentage of time from March through June when OMR flows are less than –1,500 cfs during dry and critical years with the Folsom WCM alternatives, relative to the basis of comparison.

Transport Flows

Larval delta smelt might rely on flow patterns to facilitate their movement from one area to another when conditions in their existing location become unsuitable. The geographic distribution of larval and early juvenile lifestages of delta smelt reportedly appears to be influenced by freshwater inflows to the Delta during the late winter and spring.

It has been hypothesized that higher Delta inflows result in faster larval planktonic transport rates from the upstream spawning habitat to the downstream estuarine portions of the Delta. Specifically, this movement occurs from the Delta downstream to the low-salinity zone, generally located downstream of the confluence of the Sacramento and San Joaquin Rivers or in Suisun Bay (Bennett 2005).

The importance of transport flows for larval delta smelt depends on the distribution of larvae in the Delta and ambient water temperature and food supply conditions. If water temperatures are suitable and food supply is sufficient to provide adequate nourishment during the period when delta smelt first begin feeding (5 to 8 days after hatching), transport flows would likely be unimportant. However, when water temperatures become too warm (i.e., exceed 22°C [about 72°F]) or when food supplies in the area where delta smelt hatch are inadequate, transport flows likely are more important. Because food quantity is generally higher in the low-salinity zone compared to upstream areas, USACE expects that delta smelt would be in more suitable conditions if they move into this region before exogenous feeding begins.

Additionally, although there is no known positive correlation between Delta outflow and delta smelt abundance, Delta outflow does reportedly have significant positive effects on several measures of delta smelt habitat (Kimmerer et al. 2009 as cited in SWRCB 2010), and spring outflow is positively correlated with spring abundance of the calanoid copepod *Eurytemora affinis* (Kimmerer 2002a as cited in SWRCB 2010), an important delta smelt prey item. Therefore, changes in Delta outflow from the Folsom WCM alternatives could affect delta smelt.

Effects on the downstream transport of larval delta smelt were estimated by USACE by evaluating simulated average monthly Delta outflow during the latter portion (May and June) of the larval delta smelt evaluation period when water temperatures in the Central and South Delta begin to warm. Higher Delta outflow is generally assumed to be a result of greater inflow and increased movement of water through the Delta, thus resulting in increased transport and survival of larval delta smelt.

Food Availability

Production of larval and juvenile delta smelt reportedly is presently food limited in the Delta, and food limitation during these lifestages is an important contributing cause of the species' recent declines and is an impediment to its recovery (Sommer et al. 2007). Suppressed food supply during late spring and early summer (roughly May through June) might be contributing to reduced growth rates of larval and juvenile delta smelt, which have declined in connection with recent declines in the abundance of key copepod species (Bennett 2005; Sweetnam 1999).

In recent decades, significant changes have been reported in the composition of the phytoplankton community within Suisun Bay and the interior Delta (Brown 2009). Diatoms of the genus *Thalassiosira*, which are important in the diet of calanoid copepods (an important food item of delta smelt), have declined substantially, while the abundance of less beneficial phytoplankton, such as flagellates, green algae, and cyanobacteria, have increased. Smaller, slower-growing smelt reportedly are generally subject to higher rates of predation and are ultimately less fecund as adults.

USACE does not anticipate that changes in SWP and CVP operations associated with the Folsom WCM alternatives would substantially affect food availability because the alternatives would generally cause insubstantial changes in Delta outflow.

Juveniles

USACE evaluated the effects of the Folsom WCM alternatives on delta smelt juveniles for the period of May through July (Moyle 2002; USFWS 2008).

Water Temperature

Water temperature tolerance thresholds for juvenile delta smelt are not commonly reported in readily available literature. However, survival of newly spawned larvae and older delta smelt appears to decrease at temperatures over 20°C (68°F) (Bennett 2005; Swanson and Cech 1995). Additionally, delta smelt of all sizes are found in the main channels of the Delta and Suisun Marsh and the open waters of Suisun Bay, where the waters are well-oxygenated and temperatures are relatively cool, usually lower than 20°C to 22°C (68°F to about 72°F) in summer. Specifically, over 90 percent of juvenile and pre-adult delta smelt caught in the CDFG Summer Townet Survey and CDFG Fall Mid-Water Trawl Survey were collected at water temperatures lower than 20°C (68°F) (Bennett 2005). Additionally, water temperatures over about 25°C (77°F) are reportedly lethal for delta smelt and can constrain delta smelt habitat, particularly during summer and early fall (Swanson et al. 2000 as cited in Bennett 2005).

USACE simulated monthly Sacramento River water temperatures at Freeport with the Folsom WCM alternatives and with basis of comparison using Reclamation's average monthly water temperature model. For the purpose of conducting an impact assessment on delta smelt juveniles, USACE evaluated average monthly water temperatures at Freeport for the period of May through July (Moyle 2002; USFWS 2008) with the Folsom WCM alternatives, relative to the basis of comparison. Specifically, because egg and embryo hatching success and survival decreases below 15°C (59°F), USACE assumed that juvenile growth and survival would also be reduced. Additionally, because over 90 percent of juvenile delta smelt are found in CDFW surveys at water temperatures below 20°C (68°F), exceedance probability distributions were used to calculate the proportion of time that simulated water temperatures occur within this range with the Folsom WCM alternatives, relative to the basis of comparison.

Food Availability

Refer to the discussion of Food Availability for delta smelt larvae, above.

Rearing Habitat

The suitability of delta smelt rearing habitat increases when the location of the low-salinity zone during the fall is downstream of the confluence of the Sacramento and San Joaquin Rivers (SWRCB 2010). This corresponds to Delta outflow being greater than about 7,500 cfs between September and November, which would have to be achieved by releasing water from upstream reservoirs during most years (SWRCB 2008). USFWS (2008) recommended that the low-salinity zone be maintained in Suisun Bay during the fall of above-normal and wet water years. Specifically, the USFWS (2008) RPA Action 4 prescribed an X2 location of 74 river kilometers (RKm) during wet water years and an X2 location of 81 RKm during above-normal water years. (The term *X2* is used to define the distance from the Golden Gate Bridge upstream to the location in the Delta or the Sacramento River where salinity near the bottom of the water column is about 2 ppt.) This action was restricted to wetter water years to ensure that sufficient coldwater pool availability remained for steelhead and salmon during drier water years (USFWS 2008). Presumably based on USFWS (2008), CDFG (2010) recommended that X2 be maintained in between 74 RKm and 81 RKm between September and November during wet and above-normal water year types.

Because X2 is considered an indicator of delta smelt habitat availability, USACE evaluated changes in X2 with the Folsom WCM alternatives, relative to the basis of comparison. Specifically, Feyrer et al. (2010)

concluded that, as X2 increases, predicted delta smelt habitat declines, but the association is nonlinear. Information presented in Feyrer et al. (2010) indicates that changes in X2 might particularly affect delta smelt habitat suitability between about RKm 65 and RKm 80. Therefore, USACE evaluated changes in X2 of 0.5 kilometer (km) or more specifically between RKm 65 and RKm 80 with the Folsom WCM alternatives, relative to the basis of comparison.

Adults

USACE evaluated the effects of the Folsom WCM alternatives on delta smelt adults for the period of December through May (Moyle 2002; USFWS 2008).

Water Temperature

Delta smelt of all sizes are found in the main channels of the Delta and Suisun Marsh and the open waters of Suisun Bay, where the waters are well-oxygenated and temperatures are relatively cool, usually lower than 20°C to 22°C (68°F to about 72°F) in summer. Additionally, delta smelt spawning success appears to be confined to water temperatures between about 15°C to 20°C (59°F to 68°F) (Bennett 2005), and over 90 percent of delta smelt caught in the CDFG Summer Townet Survey and CDFG Fall Mid-Water Trawl Survey were collected at water temperatures lower than 20°C (68°F) (Bennett 2005). Water temperatures over about 25°C are reportedly lethal for delta smelt and can constrain delta smelt habitat, particularly during summer and early fall (Swanson et al. 2000 as cited in Bennett 2005). Sommer and Meija (2013) report that 25°C (77°F) is used as a general guideline to assess the upper limits for delta smelt habitat (Wagner et al. 2011 and Cloern et al. 2011 as cited in Sommer and Meija 2013).

USACE simulated monthly Sacramento River water temperatures at Freeport with the Folsom WCM alternatives and with the basis of comparison using Reclamation's average monthly water temperature model. For the purpose of conducting an impact assessment on delta smelt adults, USACE evaluated average monthly water temperatures at Freeport for the period of December through May (Moyle 2002; USFWS 2008) with the Folsom WCM alternatives, relative to the basis of comparison. Because delta smelt spawning success reportedly appears to be confined to water temperatures between about 15°C to 20°C (59°F to 68°F) (Bennett 2005), exceedance probability distributions were used to calculate the proportion of time that simulated water temperatures occur within this range with the Folsom WCM alternatives, relative to the basis of comparison.

OMR Flows

In addition to analyzing adult delta smelt salvage, USACE also evaluated OMR flows. The USFWS (2008) *Biological Opinion on the Proposed Coordinated Operations of the Central Valley Project and State Water Project* provides net negative OMR flow restrictions to protect spawning adult delta smelt. The USFWS (2008) RPA Action 1 restricts OMR flow during the fall to –2,000 cfs for 14 days when a turbidity or salvage trigger has been met; both triggers have previously been correlated with the upstream movement of spawning adult delta smelt. RPA Action 2 is initiated immediately after Action 1 to protect adult delta smelt after migration, but prior to spawning, by restricting net OMR flows to between –1,250 and –5,000 cfs, based on the recommendations of the Smelt Working Group (USFWS 2008).

SWRCB (2010) and CDFG (2010) recommended that OMR flows be more positive than –5,000 cfs between December and February of all water year types to protect upstream migrating adult delta smelt.

Therefore, for the purpose of assessing the effects of the Folsom WCM alternatives, flows less than (i.e., more negative than) –5,000 cfs were used as an impact indicator for migrating adult delta smelt. Specifically, USACE evaluated the percentage of time from December through February when OMR flows would be less than –5,000 cfs with the Folsom WCM alternatives, relative to the basis of comparison.

Food Availability

Refer to the discussion of Food Availability for delta smelt larvae, above.

Longfin Smelt

Populations of longfin smelt occur along the Pacific Coast of North America, from Hinchinbrook Island, Prince William Sound, Alaska to the San Francisco estuary. Although individual longfin smelt have been caught in Monterey Bay (Moyle 2002), available data suggest that the Bay-Delta population is the southernmost, and also the largest, spawning population in California.

Longfin smelt larvae have a widespread distribution in the San Francisco estuary and are detected each year in the western Delta, Suisun Bay, and Suisun Marsh (Baxter et al. 1999). Larval longfin smelt are also frequently caught in San Pablo Bay, and they are sometimes caught in the Central and South Bays and in the eastern and southern Delta (Baxter et al. 1999). In many years, longfin smelt are caught in the Napa River estuary as well. Larval sampling in the South Bay is not extensive enough to characterize the presence or abundance (if any) of larval longfin smelt.

Longfin smelt are widespread within the Delta and, historically, they were found seasonally in all of its major open-water habitats and Suisun Marsh. Longfin smelt are believed to spawn at the transition zone between freshwater and saltwater, but exact spawning locations and conditions that support egg deposition and incubation are unknown. Spawning almost certainly occurs in the Sacramento River mainstem, probably near Rio Vista and downstream.

Eggs and Embryos

Spawning longfin smelt scatter adhesive eggs on sand substrates from December through May (CDFG 2010).

Water Temperature

Studies are not readily available that document a relationship between hatching success and developmental rate with water temperature, dissolved oxygen, or salinity for the longfin smelt population of the San Francisco estuary. The only known study on this topic (Lake Washington population) found that longfin smelt eggs hatched in about 42 days at about 45°F (Dryfoos 1965). Because the San Francisco estuary population is at the southern edge of the species' range, this population might have evolved a tolerance for warmer temperatures than have populations farther north.

Because reputable information regarding longfin smelt egg and embryo water temperature tolerances is not readily available, USACE used water temperature ranges for delta smelt eggs and embryos as impact indicators. Specifically, because delta smelt egg and embryo hatching success and survival decrease below 15°C (59°F) and above 20°C (68°F), exceedance probability distributions were used to calculate the proportion of time that simulated water temperatures occur within this range with the Folsom WCM alternatives, relative to the basis of comparison. These exceedance probability distributions were evaluated from December through April.

Larvae and Juveniles

Water Temperature

Juvenile longfin smelt reportedly attempt to migrate to avoid water temperatures greater than 20°C (68°F) (Baxter et al. 2009). The distribution of larval smelt (and the subsequent distribution of juveniles) is generally associated with the position of X2. Larval smelt are frequently caught in San Pablo Bay, and during high-outflow years they appear in the Central and South Bays (Rosenfield 2010).

Because reputable information regarding longfin smelt larvae and juvenile water temperature tolerances is not readily available, USACE used the upper limit of the water temperature range for delta smelt larvae and juveniles as an impact indicator. Specifically, because delta smelt larval survival reportedly is optimized when water temperatures are within the range of about 15°C to 20°C (59°F to 68°F), exceedance probability distributions were used to calculate the proportion of time that simulated water temperatures occur below 20°C (68°F) with the Folsom WCM alternatives, relative to the basis of comparison. These exceedance probability distributions were evaluated from December through June.

Entrainment – SWP/CVP

Young longfin smelt are thought to be influenced by tidal and net currents while migrating downstream. Larval longfin smelt, which are less than 20 mm, pass through the louvers at the SWP or CVP export facilities and are not counted or salvaged (CDFG 2010; SWRCB 2010). Entrainment of larval longfin smelt is reported to likely be greatest during March and April (The Bay Institute 2010). High export pumping rates can cause reverse OMR flows, which can passively move all age groups of longfin smelt, particularly larvae, toward the export facilities (SWRCB 2010).

Young longfin smelt are most vulnerable to entrainment during drier water years with low Delta outflow and high net negative OMR flows (CDFG 2010; SWRCB 2010). CDFG's (2009) particle-tracking modeling for larval longfin smelt predicted that larval entrainment at the SWP might be 2 percent to 10 percent during the relatively low outflow conditions that were modeled, assuming that input data approximated actual longfin smelt hatching densities and that the particle-tracking modeling with surface-oriented particles roughly represented movement of longfin smelt larvae (CDFG 2009).

However, CDFG (2009) reports that such a high percentage of larvae entrained would be expected only during periods of low downstream transport flows during which Qwest (a broad indication of the net direction and quantity of flow in the San Joaquin River at Jersey Point) was generally negative (i.e., the net direction and quantity of flow in the San Joaquin River at Jersey Point was upstream). Despite a high negative net OMR flow, particle entrainment substantially decreased when the Sacramento River flows at Rio Vista increased above about 40,000 cfs (CDFG 2009b as cited in CDFG 2010). Entrainment of particles was generally low at flows of 55,000, despite very high exports and negative OMR flows (CDFG 2009). If these high-flow conditions were to occur throughout the primary hatching period of January through March, the expected percentage of larvae entrained at the SWP would be less than 1 percent, given the assumed relative San Joaquin River spawning densities (CDFG 2009).

CDFG (2009) reportedly identified a significant relationship between spring (April through June) net negative OMR flows and total SWP and CVP juvenile longfin smelt salvage. Juvenile longfin smelt salvage reportedly increased rapidly as OMR flows became more negative than –2,000 cfs (CDFG 2009). However, as winter and spring, or only spring, outflows increased (shifting X2 downstream), the salvage of juvenile longfin smelt reportedly decreased significantly. Grimaldo (no date, as cited in CDFG 2009) found that the best models explaining inter-annual winter (December through March) salvage of longfin smelt included combining Old and Middle River flows. Plotting combined salvage on average December-through-March OMR flows indicates rapidly increasing salvage of OMR flows approaching, and more negative than, –5000 cfs (CDFG 2009).

CDFG (2009) suggests that the pelagic nature of larval and juvenile longfin smelt and their similar responses to outflows and OMR flows indicate that similar actions would benefit both lifestages, including periodic pulse flows through the central Delta during January through June to transport larvae and juveniles away from the region of entrainment risk, and less-negative OMR flows.

CDFG (2010) recommends the following OMR flow criteria to benefit longfin smelt:

- At no time should OMR flows be more negative than –5,000 cfs during December through March.
- During April and May of dry and critical water years, OMR flows should be more positive than –1,500 cfs when the longfin smelt Fall Midwinter Trawl Survey (FMWT) index is more than 500, and should be positive when the longfin smelt FMWT index is less than 500.

Therefore, USACE evaluated changes in the frequency with which mean monthly OMR flows are greater than –5,000 cfs during December through March with the Folsom WCM alternatives, relative to the basis of comparison. In addition, changes in the frequency with which mean monthly OMR flows are greater than –1,500 cfs and greater than 0 cfs were evaluated during April and May of dry and critical water years with the Folsom WCM alternatives, relative to the basis of comparison.

Transport Flows

Longfin smelt abundance has been reported to be positively correlated with Delta outflow (as measured by X2 position) (Kimmerer et al. 2009; Rosenfeld and Baxter 2007; Sommer et al. 2007). Kimmerer et al. (2009) related the log of the longfin smelt annual abundance index for each of three surveys (i.e., Fall Midwater Trawl, Bay Midwater Trawl, and Bay Otter Trawl) to X2 position averaged over several spring months when longfin smelt are most vulnerable to freshwater flow effects. Increased habitat quantity associated with increased Delta outflow might contribute to an increase in longfin smelt abundance; however, the primary mechanism for the positive relationship between longfin smelt abundance and Delta outflow is not well understood (Kimmerer et al. 2009). Kimmerer et al. (2009) hypothesize that it might be related to the shift by young longfin smelt toward greater depth at higher salinity, possibly implying a retention mechanism.

The effects of transport flows (i.e., Delta outflow) on larval longfin smelt were estimated by USACE by evaluating changes in simulated X2. CDFG (2010) recommends that X2 be maintained between 64 km and 75 km during January through June in order to provide longfin smelt with low-salinity habitat within or downstream of Suisun Bay.

USACE evaluated simulated mean monthly X2 location exceedance probability distributions during January through June to examine the change in frequency with which mean monthly X2 would be maintained at or downstream of 75 RKm during January through June with the Folsom WCM alternatives, relative to the basis of comparison. Exceedance probability distributions were evaluated over the entire simulation period and specifically over the lowest 25 percent of the cumulative probability distribution (i.e., low-flow conditions).

Although CDFG (2009b as cited in CDFG 2010) describes the longfin smelt larvae evaluation period as December through May, CDFG (2010) provides X2 recommendations during January through June to protect multiple lifestages of longfin smelt including larvae, juveniles, and adults.

Food Availability

Food limitation for longfin smelt in the estuary is reportedly an important contributing cause of their recent declines and also is thought of as a substantial impediment to their recovery (Sommer et al. 2007). Rosenfield and Baxter (2007) observed that the response of both age-1 and age-2 longfin smelt to Delta outflow was muted after the Corbula clam introduction. Orsi and Mecum (1996) noted that the primary prey species for juvenile longfin smelt (*Neomysis mercedis*) had been similarly affected by the clam introduction as a result of the clam's grazing on phytoplankton and copepods. Because changes in Delta outflow with the Folsom WCM alternatives would be generally insubstantial, USACE does not anticipate that changes in SWP and CVP operations with the Folsom WCM alternatives, relative to the basis of comparison, would substantially affect food availability.

Adults

Based on the identified presence of newly hatched larvae and an assumed 25-day incubation period, CDFG (2009b as cited in CDFG 2010) estimated that longfin smelt likely spawn during November through April, with a peak in January.

Water Temperature

Longfin smelt spawning is believed to occur in the Sacramento River mainstem near Rio Vista and downstream (The Bay Institute 2007). As water temperatures drop below 18°C (about 64°F) during the fall, maturing adult longfin smelt migrate from the lower estuary to the Low Salinity Zone and congregate prior to spawning (CDFG 2009). Spawning reportedly starts when water temperatures drop below 16°C (about 61°F) and becomes consistent when water temperatures drop below 13°C (about 55°F) (CDFG, no date, as cited in CDFG 2009). Moyle (2002) states that longfin smelt inhabiting the Bay-Delta estuary are thought to spawn in freshwater or slightly brackish water over sandy or gravel substrates at temperatures ranging from 7°C to 14.5°C (about 45°F to 58°F).

Movement patterns based on catches in CDFW fishery sampling suggest that longfin smelt actively avoid water temperatures greater than 22°C (about 72°F). In addition, sampling data suggest that longfin smelt do not occupy areas with temperatures greater than 22°C (about 72°F) in combination with salinities greater than 26 ppt. Therefore, USACE used water temperature exceedance probability distributions to calculate the proportion of time that simulated water temperatures exceed 72°F with the Folsom WCM alternatives, relative to the basis of comparison, during November through April.

Entrainment

As discussed above in this section, CDFG (2010) recommended that OMR flows be no more negative than –5,000 cfs at any time during January through March in order to protect adult and juvenile longfin smelt from being entrained. The frequency with which OMR flows are –5,000 cfs or higher during December through March were compared by USACE with the Folsom WCM alternatives, relative to the basis of comparison.

Food Availability

Adult longfin smelt prey primarily on the small shrimp *Neomysis mercedis* (Moyle 2002). As discussed above in this section, food availability might be a limiting factor for the longfin smelt population in the estuary. However, because changes in Delta outflow with the Folsom WCM alternatives would be generally insubstantial, USACE does not anticipate that changes in water operations with the Folsom WCM alternatives, relative to the basis of comparison, would substantially affect food availability.

WINTER-RUN CHINOOK SALMON

Fry and Juveniles

Rearing of juvenile winter-run Chinook salmon in the Delta reportedly occurs primarily from November through early May (NMFS 2014). Therefore, USACE evaluated winter-run Chinook salmon in the Delta during November through May.

Delta Emigration and Rearing Habitat

The assessment of changes in winter-run Chinook salmon rearing habitat in the Delta includes USACE's evaluation of changes in seasonal flows in the lower Sacramento River (at Rio Vista), Delta outflow, and OMR flows.

USACE compared long-term average flows, average flows by water year type, and monthly exceedance probability distributions (November through May) of simulated Sacramento River flow at Rio Vista with the Folsom WCM alternatives, relative to the basis of comparison.

Hydrodynamic conditions in the interior Delta likely affect the quality and availability of juvenile salmonid rearing habitat. Two general indicators of habitat conditions within the interior Delta were used to assess changes in habitat conditions for juvenile salmonid rearing: Delta outflow and OMR reverse flows. Decreased flows through the Delta might decrease the migration rate of juvenile salmonids moving downstream, thereby increasing their exposure time to unsuitable water temperatures, entrainment into the interior Delta, entrainment in water diversions, contaminants, and predation (CDFG 2010).

USACE evaluated changes in CalSim II–simulated mean monthly Delta outflow during November through May with the Folsom WCM alternatives, relative to the basis of comparison. USACE assumes that an increase in Delta outflow might contribute to improved rearing conditions and survival of juvenile

Chinook salmon in the Delta and Suisun Bay. Monthly probability-of-exceedance distributions of Delta outflow were compared with the Folsom WCM alternatives, relative to the basis of comparison.

The behavioral response and effects of reducing OMR reverse flows on juvenile winter-run Chinook salmon migration, rearing, survival, and growth are not clearly known. However, for this analysis, USACE assumes that a reduction in OMR reverse flows might contribute to improved rearing and emigration conditions for juvenile winter-run Chinook salmon in the interior Delta. Specifically, it is likely that recommendations to reduce the effects of negative and low OMR flows on San Joaquin River Chinook salmon also would reduce effects on winter-run Chinook salmon.

Specifically, to reduce the risk of juvenile Chinook salmon entrainment and straying into the central Delta, CDFG (2010) recommends that OMR flows be greater than 2,500 cfs during November through June. However, because there is no specific OMR flow recommendation for winter-run Chinook salmon, USACE compared probability-of-exceedance distributions of CalSim II–simulated mean monthly OMR reverse flows with the Folsom WCM alternatives and evaluated them relative to the basis of comparison. Simulated mean monthly changes in the magnitude of OMR reverse flows were compared with the Folsom WCM alternatives, relative to the basis of comparison, during November through May.

Adults

Seasonal Flows – Attraction

Adult winter-run Chinook salmon migrate upstream through the Delta on spawning migrations. The Folsom WCM alternatives might change the proportion of water reaching the Delta that originates in the Sacramento River, relative to the San Joaquin River watershed. Quantitative information on the relationship between Sacramento and San Joaquin river flow and adult steelhead attraction and upstream migration is not available. Therefore, in the absence of quantitative relationships for adult winter-run Chinook salmon, USACE conducted a qualitative assessment based on the magnitude of flow changes estimated to occur in the lower Sacramento River during the migration period.

SPRING-RUN CHINOOK SALMON

Fry and Juveniles

Most juvenile spring-run Chinook salmon emigrate through the Delta during November to early May (NMFS 2009), but juveniles have reportedly been found at Chipps Island primarily during December through June. Therefore, USACE evaluated juvenile spring-run Chinook salmon in the Delta during November through June.

Delta Emigration and Rearing Habitat

The assessment of changes in spring-run Chinook salmon rearing habitat in the Delta includes the same evaluations as described for winter-run Chinook salmon, including changes in seasonal flows in the lower Sacramento River (at Rio Vista), Delta outflow, and OMR flows.

USACE compared long-term average flows, average flows by water year type, and monthly exceedance probability distributions (November through June) of simulated Sacramento River flow at Rio Vista with the Folsom WCM alternatives, relative to the basis of comparison.

Similar to the methods described for winter-run Chinook salmon, USACE evaluated changes in CalSim II–simulated mean monthly Delta outflow during November through June with the Folsom WCM alternatives, relative to the basis of comparison. Simulated mean monthly changes in the magnitude of OMR reverse flows also were compared with the Folsom WCM alternatives, relative to the basis of comparison, during November through June.

Adults

Seasonal Flows – Attraction

Adult spring-run Chinook salmon migrate upstream through the Delta on spawning migrations. As described for winter-run Chinook salmon, USACE conducted a qualitative assessment regarding the effects of the Folsom WCM alternatives on adult attraction flows for spring-run Chinook salmon based on the magnitude of flow changes estimated to occur in the lower Sacramento River during the upstream migration period.

FALL AND LATE FALL-RUN CHINOOK SALMON

Fry and Juveniles

In general, fall and late fall-run Chinook salmon juveniles occur primarily in the Delta during November through June (ICF International 2013). Therefore, USACE evaluated juvenile fall-run and late fall-run Chinook salmon in the Delta during November through June.

Delta Emigration and Rearing Habitat

The assessment of changes in fall- and late fall-run Chinook salmon rearing habitat in the Delta includes the same evaluations as for winter-run Chinook salmon, including changes in seasonal flows in the lower Sacramento River (at Rio Vista), Delta outflow, and OMR flows.

USACE compared long-term average flows, average flows by water year type, and monthly exceedance probability distributions (November through June) of simulated Sacramento River flow at Rio Vista with the Folsom WCM alternatives, relative to the basis of comparison.

Similar to the methods described for winter-run Chinook salmon, USACE evaluated changes in CalSim II–simulated mean monthly Delta outflow during November through June with the Folsom WCM alternatives, relative to the basis of comparison. Simulated mean monthly changes in the magnitude of OMR reverse flows also were compared with the Folsom WCM alternatives, relative to the basis of comparison, during November through June.

Adults (Sacramento River Basin)

Seasonal Flows – Attraction

Adult fall- and late fall-run Chinook salmon migrate upstream through the Delta on spawning migrations. As described for winter-run Chinook salmon, USACE conducted a qualitative assessment regarding the effects of the Folsom WCM alternatives on adult attraction flows for fall and late fall-run Chinook salmon to the Sacramento River based on the magnitude of flow changes estimated to occur in the lower Sacramento River during the upstream migration period.

Adults (San Joaquin River Basin)

OMR Flows

USACE evaluated simulated mean monthly changes in the magnitude of OMR reverse flows with the Folsom WCM alternatives, relative to the basis of comparison, during December through February. To prevent straying of adult San Joaquin basin Chinook salmon, CDFG (2010) recommends that OMR flows be greater than –5,000 cfs during December through February. USACE evaluated exceedance probability distributions to identify changes in OMR flows with the Folsom WCM alternatives. Specifically, USACE evaluated the percentage of time from December through February when OMR flows would be less than –5,000 cfs with the Folsom WCM alternatives, relative to the basis of comparison.

STEELHEAD

Juveniles

Steelhead outmigration and rearing in the Delta were evaluated by USACE during October through July (NMFS 2009).

Delta Emigration and Rearing Habitat

The assessment of changes in steelhead rearing habitat in the Delta includes evaluation of changes in seasonal flows in the lower Sacramento River (at Rio Vista), Delta outflow, and OMR flows.

USACE compared long-term average flows, average flows by water year type, and monthly exceedance probability distributions (October through July) of simulated Sacramento River flow at Rio Vista with the Folsom WCM alternatives, relative to the basis of comparison.

Hydrodynamic conditions in the interior Delta likely affect the quality and availability of juvenile salmonid rearing habitat. Two general indicators of habitat conditions within the interior Delta were used to assess changes in habitat conditions for juvenile salmonid rearing: Delta outflow and OMR reverse flows. Decreased flows through the Delta might decrease the migration rate of juvenile salmonids moving downstream, thereby increasing their exposure time to unsuitable water temperatures, entrainment into the interior Delta, entrainment in water diversions, contaminants, and predation (CDFG 2010).

USACE evaluated changes in CalSim II–simulated mean monthly Delta outflow during October through July with the Folsom WCM alternatives, relative to the basis of comparison. Although there are no known statistical relationships between Delta outflow and juvenile steelhead survival or adult abundance, USACE assumes that an increase in Delta outflow might contribute to improved rearing conditions and survival of juvenile steelhead in the Delta and Suisun Bay. Monthly probability-of-exceedance distributions of Delta outflow were compared with the Folsom WCM alternatives, relative to the basis of comparison.

The behavioral response and effects of reducing OMR reverse flows on juvenile steelhead migration, rearing, survival, and growth are not clearly known. However, for this analysis, USACE assumes that a reduction in OMR reverse flows might contribute to improved rearing and emigration conditions for juvenile steelhead in the interior Delta. Specifically, it is likely that recommendations to reduce the effects of negative and low OMR flows on Chinook salmon also would reduce effects on Central Valley steelhead.

Specifically, to reduce the risk of juvenile Chinook salmon entrainment and straying into the central Delta, CDFG (2010) recommends that OMR flows be greater than 2,500 cfs during November through June. However, because there is no specific OMR flow recommendation for steelhead, USACE compared probability-of-exceedance distributions of CalSim II–simulated mean monthly OMR reverse flows with the Folsom WCM alternatives and evaluated them relative to the basis of comparison. Simulated mean monthly changes in the magnitude of OMR reverse flows were compared with the Folsom WCM alternatives, relative to the basis of comparison, during October through July.

Adults

Seasonal Flows – Attraction

Adult steelhead migrate upstream through the Delta on spawning migrations. The Folsom WCM alternatives might change the proportion of water reaching the Delta that originates in the Sacramento River, relative to the San Joaquin River watershed. Quantitative information on the relationship between Sacramento and San Joaquin river flow and adult steelhead attraction and upstream migration is not available. Therefore, in the absence of quantitative relationships for adult steelhead, USACE conducted a qualitative assessment based on the magnitude of flow changes estimated to occur in the lower Sacramento River during the migration period.

AMERICAN SHAD

Although salinity is an important habitat component for many species within the Delta, changes in salinity that could occur with the Folsom WCM alternatives likely would not adversely affect American shad. Specifically, adult American shad enter the Delta from San Francisco Bay via Suisun and Honker Bays on spawning migrations and return to the ocean after spawning in freshwater. During this portion of their lifecycle, individual fish can tolerate a wide range of salinities. Therefore, changes in Delta salinity with Folsom WCM alternatives likely would not adversely affect adult American shad.

Juvenile American shad are reported to sometimes rear for extended periods in the Delta. However, little information exists regarding the distribution of juvenile American shad in the Delta throughout the extended rearing duration. Curing their extended Delta rearing period, juvenile American shad grow and endure osmoregulatory and salinity tolerance changes that allow them to select appropriate habitat. For this reason, it is not likely that salinity is a limiting habitat component for juvenile American shad. Therefore, changes in salinity with the Folsom WCM alternatives are not likely to adversely affect rearing juvenile shad habitat availability and are not further evaluated.

Eggs and Larvae

X2

CDFG (2010) recommended an X2 location from RKm 75 to RKm 64 (approximately equivalent to a net Delta outflow of 11,400 to 29,200 cfs) from April through June of all water years to support American shad egg and larval survival. Because the Folsom WCM alternatives have little ability to limit flows at the high end of the recommended range (i.e., Delta outflow could be above 29,200 cfs regardless of project operations), USACE evaluated the effects of the Folsom WCM alternatives on American shad by evaluating the frequency with which the average monthly X2 position would be maintained at or downstream of RKm 75 during April through June with the Folsom WCM alternatives, relative to the basis of comparison.

STRIPED BASS

Most larvae and fry are transported from the spawning areas to the Delta within days of spawning. Mortality due to entrainment and reduced rearing habitat availability has been associated with SWP and CVP project-related effects on Delta hydrodynamics (Sommer et al. 2005).

Eggs and Larvae

X2

USACE compared changes in the upstream or downstream movement of simulated mean monthly X2 location year-round with the Folsom WCM alternatives, relative to the basis of comparison. Simulated changes in X2 were used to qualitatively estimate the effects on striped bass survival and distribution within the Delta with the Folsom WCM alternatives, relative to the basis of comparison.

1.1.6 References

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Appendix 7C

1.1 Water Temperature Index Value Selection Rationale and Justification

1.1.1 Introduction

Water temperature is one of the most important environmental parameters affecting the distribution, growth, and survival of fish populations. Lethal water temperatures control fish populations by directly reducing population size, while sub-lethal water temperatures affect fish populations via indirect physiologic influences. Water temperatures can particularly regulate fish populations that are near their latitudinal distributional extremes, because environmental conditions (e.g., water temperature) at distributional extremes also can be near the boundaries of conditions that allow the populations to persist. For example, California's Central Valley is at the southern limit of Chinook salmon distribution, and studies have demonstrated that direct effects of high water temperatures are an important source of juvenile Chinook salmon mortality in the Central Valley (Baker et al. 1995).

Technical evaluation guidelines have been developed to assess the effects of water diversion and water-use projects in a consistent and effective manner. In order to successfully evaluate the effects of water temperature regimes on a given lifestage, it is necessary to gain a broad understanding of how fish species respond to water temperature regimes. This appendix presents the results of a literature review that was conducted by the U.S. Army Corps of Engineers (USACE) to: (1) interpret the available literature on the effects of water temperature on the various lifestages of fish species of focused evaluation, (2) consider the effects of short-term and long-term exposure to constant or fluctuating temperatures, and (3) establish biologically defensible water temperature index (WTI) values to be used as guidelines for assessing the effects of the Folsom Water Control Manual (WCM) Project alternatives.

1.1.2 Methods

To the extent that literature describing thermal tolerances for each species was available, USACE established WTI values from a comprehensive literature review. The types of literature examined included scientific journals, master's theses and PhD dissertations, literature reviews, and agency publications. With respect to water temperature, the primary concern in the Central Valley relates to water temperatures that can exceed upper water temperature tolerance limits rather than lower limits; therefore, USACE established index values only for water temperatures at and above the warmer tolerance or optimal zone for each species. For non-salmonid species, USACE assumes that sufficient warmwater habitat is available in Central Valley waterbodies such that effects resulting from exposure to cold water likely would not occur.

To the extent that information was available, USACE determined WTI values by emphasizing the results of laboratory experiments that examined how water temperature affects fish in Central Valley watersheds being evaluated as well as by considering field studies documenting habitat use and regulatory documents such as biological opinions.

When local studies were not available, USACE used studies on fish from outside the Central Valley to establish index values. To avoid unwarranted specificity, only whole integers were selected as index values; thus, support for index values was, in some cases, partially derived from literature supporting a water temperature that varied from the resulting index value by several tenths of a degree. For example, Combs and Burrows (1957) reported that constant incubation temperatures between 42.5 degrees Fahrenheit (°F) and 57.5°F resulted in normal development of Chinook salmon eggs, and their report was referenced as support for a WTI value of 58°F. Rounding for the purpose of selecting index values is appropriate because the daily variation of experimental treatment temperatures is often high. For example, temperature treatments in Marine (1997) consisted of control (55.4°F to 60.8°F), intermediate (62.6°F to 68.0°F), and extreme (69.8°F to 75.2°F) treatments that varied daily by whole degrees.

USACE's inspection of the available literature on the effects of water temperature on fish species of focused evaluation revealed the need to interpret each document with caution and to verify the appropriateness of statements supported by references to other literature. Often source studies are cited incorrectly and sometimes repeatedly. For example, Hinze (1959) actually examines the effects of water temperature on incubating Chinook salmon eggs, yet Hinze (1959) is cited in Boles et al. (1988); Marine (1992); and NMFS (1997) in statements regarding the effects of water temperature on holding Chinook salmon adults. Boles et al. (1988) and Marine (1992) were then further cited by McCullough et al. (2001) in support of a section detailing how water temperature affects the viability of gametes developing in adults.

Most of the literature on water temperature requirements refers to "stressful," "tolerable," "preferred," or "optimal" water temperatures or water temperature ranges. Spence et al. (1996) defined the tolerable water temperature range as the range at which fish can survive indefinitely. Thermal stress to fish is any water temperature change that alters the biological functions of the fish and that decreases the probability of survival (McCullough 1999). Optimal water temperatures provide for feeding activity, normal physiological response, and behavior void of thermal stress symptoms (McCullough 1999). Preferred water temperature ranges are those that are most frequently selected by fish when they are allowed to freely choose locations along a thermal gradient (McCullough 1999).

For Chinook salmon and steelhead, USACE took WTI values from Bratovich et al. (2012). Bratovich et al. (2012) evaluated water temperature suitabilities associated with the reintroduction of spring-run Chinook salmon and steelhead into the upper Yuba River Basin and describe development of the upper optimum (UO) WTI values and upper tolerance (UT) WTI values. Bratovich et al. (2012) is the most recent, comprehensive literature review available and particularly emphasizes the Central Valley. Therefore, the lifestage-specific UO and UT WTI values identified by Bratovich et al. (2012) were used by USACE for all runs of Chinook salmon and steelhead in this evaluation (Table 1).

Chinook salmon holding WTI values were applied only to the holding of winter-run and spring-run Chinook salmon, because fall-run Chinook salmon generally enter freshwater in a sexually mature state and reportedly spawn soon after reaching freshwater spawning grounds. The Chinook salmon smolt emigration WTI values were applied only to spring-run Chinook salmon, because fall-run and winter-run Chinook salmon generally emigrate from Central Valley rivers as young-of-the-year (Kimmerer and Brown 2006). Refer to Appendix A in Bratovich et al. (2012) for a detailed literature review of Chinook salmon and steelhead water temperature preferences and tolerances.

Table 1. Lifestage-specific Upper Optimum and Upper Tolerance WTI Values for Chinook Salmon and Steelhead.

Chinook Salmon			Steelhead		
Lifestage	**Upper Optimum WTI**	**Upper Tolerance WTI**	**Lifestage**	**Upper Optimum WTI**	**Upper Tolerance WTI**
Adult immigration	64°F	68°F	Adult immigration	64°F	68°F
Adult holding	61°F	65°F	Adult holding	61°F	65°F
Spawning	56°F	58°F	Spawning	54°F	57°F
Embryo incubation	56°F	58°F	Embryo incubation	54°F	57°F
Juv. rearing & outmigration	61°F	65°F	Juv. rearing & outmigration	65°F	68°F
Smolt emigration	63°F	68°F	Smolt emigration	52°F	55°F

For the remaining fish species of focused evaluation, USACE developed lifestage-specific water temperature impact indicator values or ranges to be used as evaluation guidelines, the basis of which are described in this appendix. For some species and lifestages, water temperature ranges were developed instead of individual values when water temperature suitabilities or tolerances were reported as a range, and not in terms of particular values.

The WTI values and ranges are not meant to serve as significance thresholds, but instead serve as a mechanism by which to compare the Folsom WCM alternatives to a baseline condition. Differences in the frequency of exceeding a particular WTI value between a Folsom WCM alternative and the baseline condition do not necessarily constitute an impact. Impact determinations will be based on USACE's consideration of all evaluated impact indicators for all lifestages for a particular species.

1.1.3 Results

1.1.3.1 North American Green Sturgeon

1.1.3.1.1 Adult Immigration and Holding

The habitat requirements of North American green sturgeon are not well known. In the Klamath River, the water temperature tolerance of immigrating adult green sturgeon reportedly ranges from 44.4°F to 60.8°F. Reportedly, no green sturgeon were found in areas of the river outside this surface water temperature range (USFWS 1995). Additionally, water temperatures ranging from 61°F to 66°F are reportedly tolerable (Mayfield and Cech 2004 and NMFS 2006, both as cited in NMFS 2009). Therefore, a WTI value of 61°F is used to evaluate green sturgeon adult immigration and holding in this evaluation.

1.1.3.1.2 Spawning and Embryo Incubation

Green sturgeon reportedly spawn in water temperatures ranging from about 50°F to 70°F (CDFG 2001). Suitable water temperatures for green sturgeon during spawning and egg incubation have been reported to range between 46°F to 57°F (74 Federal Register 52300), while water temperatures ranging from 57°F to 65°F are reported as tolerable (Mayfield and Cech 2004 and NMFS 2006, both as cited in NMFS 2009). Similarly, suitable water temperatures for egg incubation in green sturgeon were reported by Van Eenennaam et al. (2005) to be between 52°F and 63°F, with the upper limit of optimal water temperatures ranging from 63°F to 64°F. Further, Van Eenennaam et al. (2005) reported that water temperatures greater than about 73°F led to complete mortality of embryos prior to hatching.

Water temperatures not exceeding 62.6°F have been reported to permit normal North American green sturgeon larval development (Van Eenennaam et al. 2005). Werner et al. (2007) suggest that temperatures remain below 68°F for larval development. Temperatures of about 59°F are believed to be optimal for larval growth, whereas temperatures below about 52°F or above about 66°F might be detrimental for growth (Cech et al. 2000). Water temperatures above 68°F are reportedly lethal to North American green sturgeon embryos (Beamesderfer and Webb 2002; Cech et al. 2000).

In addition to available literature evaluating empirical studies, USACE reviewed the Sacramento River Ecological Flow Tool (SacEFT) Record of Design (v.2.00) (ESSA Technologies, Ltd. 2011) to identify water temperature thresholds used by the California Department of Water Resources (DWR), The Nature Conservancy, and others for evaluating effects on green sturgeon eggs in the Sacramento River. The SacEFT Record of Design states, “The best information we were able to use is based on in vitro studies (Cech et al. 2000) of larval development, which we adapted to create a quasi-mortality model in which larvae experience no mortality at temperatures below 17°C [degrees Celsius] and complete mortality at temperatures at and above 20°C.” These temperatures correspond to 62.6°F and 68°F, respectively.

Because available literature is not entirely in agreement regarding appropriate thermal tolerances for North American green sturgeon, USACE used a bulk-of-evidence approach to identify an appropriate index value to be used for evaluating water temperature effects on green sturgeon spawning and embryo incubation. Based on the above literature, USACE selected a WTI value of 63°F.

1.1.3.1.3 Juvenile Rearing and Downstream Movement

The National Marine Fisheries Service (NMFS) (74 Federal Register 52300) reports optimal water temperatures for the development of green sturgeon egg, larval, and juvenile lifestages ranging between 52°F and 66°F. Growth of juvenile green sturgeon is reportedly optimal at 59°F and is reduced at both 51.8°F and 66.2°F (Cech et al. 2000). According to NMFS (74 Federal Register 52300), suitable water temperatures for juvenile green sturgeon should be below about 75°F. At temperatures above about 75°F, juvenile green sturgeon exhibit decreased swimming performance (Mayfield and Cech 2004 as cited in NMFS 2009) and increased cellular stress (Allen et al. 2006).

Optimum water temperatures for green sturgeon larvae reportedly are less than about 63°F (Israel and Klimley 2008). Reproductive success and young-of-the-year recruitment might be negatively affected when larvae are exposed to water temperatures greater than 68°F (Israel and Klimley 2008). Optimal juvenile green sturgeon water temperatures reportedly range from 59°F to 66°F (Israel and Klimley

2008). Because several sources report that optimal green sturgeon larvae and juvenile growth occurs below about 66°F, it was selected by USACE as a WTI value for evaluating green sturgeon juvenile rearing and downstream movement.

1.1.3.2 White Sturgeon

1.1.3.2.1 Adult Immigration and Holding

Similar to North American green sturgeon, little detailed information exists regarding thermal tolerances in white sturgeon. In fact, very little is known about adult white sturgeon habitat in the Sacramento River or in the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta), though they are present throughout the river and delta during the spring, fall, and winter (Gleason et al. 2008 as cited in Israel et al. 2011). However, recent publication of the Delta Regional Ecosystem Regional Implementation Plan (DRERIP) conceptual model for white sturgeon (www.dfg.ca.gov/ERP/conceptual_models.asp) indicated that, although adult white sturgeon begin to show signs of stress at temperatures above 68°F (20°C) (Cech et al. 1984 and Geist et al. 2005, both as cited in Israel et al. 2011), the upper limit of suitable water temperatures for adult white sturgeon is reportedly 25°C (77°F) (Israel et al. 2011). Therefore, USACE used a WTI value of 77°F for evaluating white sturgeon adult immigration and holding.

1.1.3.2.2 Spawning and Embryo Incubation

White sturgeon spawning occurs from mid-February to late May when water temperatures are between 46°F and 72°F, with peak spawning activity occurring during March and April (Kohlhorst 1976 and Kohlhorst and Cech 2001, both as cited in Israel et al. 2011).

Incubation length and success in white sturgeon is largely temperature-dependent. Field studies have found eggs when water temperatures appear optimal for egg incubation on the Sacramento River (14°C to 16°C) (Kohlhorst 1976 as cited in Israel et al. 2011). Additionally, white sturgeon egg incubation occurs between 11°C and 20°C (about 52°F to 68°F), with optimal egg incubation occurring at water temperatures ranging from 14°C to 16°C (about 57°F to 61°F) (Wang et al. 1987 as cited in Israel et al. 2011, Table 1). Incubation water temperatures above 17°C (about 63°F) reportedly result in premature hatching and higher mortality (Wang et al. 1985, 1987, both as cited in Israel et al. 2011). Wang (1985 as cited in Israel et al. 2011) showed that the size of a white sturgeon larva was inversely related to water temperature during egg incubation in experiments. In experiments, incubation temperatures above 17°C resulted in premature hatching with higher mortality and no hatching at temperatures above 20°C (Wang et al. 1985, 1987, both as cited in Israel et al. 2011).

Because the upper end of optimal embryo incubation for white sturgeon is reported to be 61°F (Wang et al. 1987 as cited in Israel et al. 2011), USACE selected a WTI value of 61°F for this lifestage.

1.1.3.2.3 Juvenile Rearing and Downstream Movement

Cech et al. (1984 as cited in Israel et al. 2011) observed slow growth and some mortality in juvenile white sturgeon kept in water temperatures above 20°C (68°F), while larger juveniles were reported to show signs of stress above 19°C (about 66°F) (Geist et al. 2005 as cited in Israel et al. 2011). Additionally, in experiments reported by Cech et al. (1984 as cited in Israel et al. 2011), young juvenile white sturgeon (0.5 gram to 0.6 gram) grew significantly greater at 20°C than at 15°C. However, no growth difference was observed between 20°C and 25°C, though increased temperatures led to increased activity in juvenile white sturgeon (Cech et al. 1984 as cited in Israel et al. 2011). Temperatures higher than 25°C are not tolerated by juvenile white sturgeon, and stress is observed near 20°C (Cech et al. 1984 and Geist et al. 2005, both as cited in Israel et al. 2011).

Because stress is observed in white sturgeon juveniles above about 66°F (19°C), USACE selected this temperature as a WTI value for evaluation.

1.1.3.3 River Lamprey and Pacific Lamprey

Generally, lamprey biology is less well studied and understood than that of other fish in the Central Valley. However, where literature is available and specifically is available for California streams and rivers, the majority of information available is for Pacific lamprey. Specifically, Moyle (2002) stated that the biology of river lamprey has not been studied in California. However, Pacific and river lamprey use similar habitats for spawning and ammocoete rearing in the Sacramento River system and have similar lifestage periodicities for spawning and ammocoete rearing, which indicates that their habitat requirements are likely similar. Therefore, for the purpose of evaluating water temperatures for Pacific lamprey and river lamprey, USACE used the same WTI values.

1.1.3.3.1 Adult Immigration

Little information is available regarding water temperature preferences and tolerances of adult lampreys. However, reported water temperature extremes in which migrating adult Pacific lampreys can survive range from 41.9°F to 59.9°F, as observed under laboratory conditions (Close 2001). Therefore, USACE used a range of 42°F to 60°F to evaluate river and Pacific lamprey adult immigration.

1.1.3.3.2 Spawning and Embryo Incubation

River lampreys are reported to spawn at water temperatures ranging from 55.4°F to 56.3°F (Wang 1986). However, it is not likely that the species requires a water temperature range of 1.1°F. Therefore, USACE did not rely on these water temperatures to develop WTI values for evaluation.

Pacific lampreys reportedly spawn where water temperatures are typically 12°C to 18°C (53.6°F to 64.4°F) (Moyle 2002). Additionally, Moyle (2002) reported that Pacific lamprey embryos hatch in about 19 days at 15°C (59°F). Pacific lamprey laboratory studies and analyses in the Columbia River basin suggest that consistently high survival and low occurrence of embryonic developmental abnormalities occur as water temperatures increase from 10°C to 18°C (50°F to 64.4°F), with a significant decrease in survival and increase in developmental abnormalities at 22°C (about 72°F) (Meeuwig et al. 2002; Meeuwig et al. 2005).

Therefore, USACE used a range of 50°F to 64°F to evaluate river and Pacific lamprey spawning and embryo incubation.

1.1.3.3.3 Ammocoete Rearing and Downstream Movement

Meeuwig et al. (2002) and Meeuwig et al. (2005) found a significant decrease in survival and increase in developmental abnormalities of Pacific lamprey larvae at 22°C (71.6°F) in a laboratory setting.

Laboratory studies and analyses suggest that consistently high survival and low occurrence of embryonic developmental abnormalities occur in Pacific lamprey and western brook lamprey at water temperatures ranging from 50°F to 64.4°F, with a significant decrease in survival and increase in developmental abnormalities at 71.6°F (Meeuwig et al. 2002; Meeuwig et al. 2005), which could indicate similar water temperature effects on river lamprey. Meeuwig et al. (2002) and Meeuwig et al. (2005) identified 64.4°F as the most beneficial temperature for survival of Pacific and western brook lampreys, which is similar to the thermal optima reported for survival of sea lampreys (Meeuwig et al. 2002; Meeuwig et. al 2005).

Moyle et al. (1995) indicate that river lamprey eggs and ammocoetes might require water temperatures that do not exceed 25°C (77°F). However, the effect of temperatures exceeding this threshold on river lamprey eggs is unknown. The effects on this species are likely similar to and, for the purpose of this evaluation, are assumed to be similar to those for Pacific lamprey when water temperatures exceed 22°C (71.6°F) as described by Meeuwig et al. (2002) and Meeuwig et al. (2005).

Therefore, in consideration of available information, USACE used a WTI value of 72°F to evaluate river and Pacific lamprey ammocoete rearing and downstream movement.

1.1.3.4 Hardhead

1.1.3.4.1 Spawning

Little is known about the lifestage-specific water temperature requirements of hardhead. Furthermore, hardhead spawning has not been documented, and documentation regarding water temperatures associated with hardhead spawning is not widely available. However, Wang (1986) reported that temperatures for hardhead spawning range from 59°F to 64.4°F. Therefore, USACE used a range of 59°F to 64°F to evaluate hardhead spawning.

1.1.3.4.2 Adults and Other Lifestages

Using samples of hardheads taken at 10 locations within water bodies of the San Joaquin drainage, USACE determined that adults prefer water temperatures of 68°F (Brown and Moyle 1993 as cited in Moyle 2002). Hardheads are reportedly found in streams with summer water temperatures above 20°C (68°F) (Moyle 2002), while water temperatures ranging from 65°F (about 18°C) to 75°F (about 24°C) are believed to be suitable (Cech et al. 1990). Under laboratory conditions, juvenile hardheads preferred water temperatures ranging from 75.2°F to 82.4°F (24°C to 28°C) (Knight 1985 as cited in Moyle 2002). Baltz et al. (1987 as cited in Moyle 2002) stated that hardhead generally selected water temperatures of 17°C to 21°C (62.6°F to 69.8°F) in a thermal plume in the Pit River.

In a recent laboratory study on the thermal preferences and tolerances of juvenile and adult hardheads, Thompson et al. (2012) found that hardheads perform well (behaviorally and physiologically) at moderate temperatures (i.e., above 16°C [60.8°F] and below 25°C [77.0°F]). In their thermal preference experiments, Thompson et al. (2012) found that, regardless of thermal acclimation history, adult hardheads tended to prefer an overall mean water temperature of 20.5°C (68.9°F), and juvenile hardheads preferred a mean water temperature of 19.5°C (67.1°F). Overall, hardheads appear to be particularly well suited to water temperatures below 25°C (77.0°F) and clearly avoided water temperatures above 26°C (78.8°F) (Thompson et al. 2012).

Based on the lowest and highest water temperatures reported in the body of literature related to hardhead, USACE used a water temperature range of 61°F to 77°F to evaluate hardhead adults and other lifestages.

1.1.3.5 Sacramento Splittail

1.1.3.5.1 Spawning

Floodplain inundation during March and April appears to be the primary factor contributing to splittail abundance (DWR 2004). Moyle et al. (2003) report that moderate-to-strong year classes of splittail develop when floodplains are inundated for 6 to 10 weeks between late February and late April.

Although floodplain inundation is the dominant factor in splittail spawning success, a literature review of thermal tolerance studies and field observations conducted by DWR (2004) suggests that water temperatures between 45°F and 75°F are considered to constitute the range of suitable splittail spawning water temperatures.

For the purpose of this evaluation, USACE evaluated Sacramento splittail primarily in the Yolo Bypass because of the dominant effect of Yolo Bypass hydrologic conditions on the population of Sacramento splittail. Because the suitable water temperature range for splittail is so large, and because USACE does not expect water temperatures to occur outside of this range with increased frequency with the Folsom WCM alternatives, relative to the basis of comparison, water temperatures are not further evaluated for Sacramento splittail.

1.1.3.6 American Shad

1.1.3.6.1 Adult Immigration and Spawning

Water temperature is an important factor influencing the timing of spawning. American shad are reported to spawn at water temperatures ranging from about 46°F to 79°F (USFWS 1967), although optimal spawning temperatures are reported to range from about 60°F to 70°F (Bell 1986; CDFG 1980; Leggett and Whitney 1972; Painter et al. 1979; Rich 1987). The optimal water temperature for egg development is reported to occur at 62°F (16.7°C). At this temperature, eggs hatch in 6 to 8 days; at water temperatures near 75°F, eggs would hatch in 3 days (MacKenzie et al. 1985 as cited in Moyle 2002).

Based on the available information, USACE used a water temperature range 60°F to 70°F to evaluate American shad adult immigration and spawning.

1.1.3.6.2 Juvenile Rearing and Downstream Movement

Juvenile American shad have reportedly been found in water temperatures ranging from 10°C to 31°C (50.0°F to 87.8°F), although only one fish was found at 31°C (Marcy et al. 1972 as cited in Stier and Crance 1985). In the Sacramento River, juvenile American shad reportedly prefer water temperatures between 62.6°F and 77°F (17°C and 25°C) (Moyle 2002).

Based on the available information, USACE used a water temperature range 63°F to 77°F to evaluate American shad juvenile rearing and downstream movement.

1.1.3.7 Striped Bass

1.1.3.7.1 Adult Immigration and Spawning

Adult striped bass are present in Central Valley rivers throughout the year, with peak abundance occurring during the spring. Adult and juvenile striped bass can survive temperatures as high as 34°C (93.2°F) for short periods, although they are under stress after temperatures exceed 25°C (77°F), and temperatures over 30°C (86°F) are usually lethal (Moyle 2002). Spawning reportedly does not occur until water temperatures reach 14°C (57.2°F), while optimal water temperatures for striped bass spawning are reported to range from about 15°C to 20°C (59°F to 68°F), and spawning ceases above 21°C (69.8°F) (Moyle 2002).

Based on the available information, USACE used a water temperature range 59°F to 68°F to evaluate striped bass adult immigration and spawning.

1.1.3.7.2 Juvenile Rearing

Regan et al. (1968 as cited in Fay et al. 1983, Table 7) reported that striped bass larvae can tolerate water temperatures from 12°C to 23°C (53.6°F to 73.4°F), while optimum water temperatures range from 16°C to 19°C (60.8°F to 66.2°F). Davies (1970 as cited in Fay et al. 1983, Table 7) reported that striped bass larvae can tolerate water temperatures from 10°C to 25°C (50°F to 77°F), while optimum water temperatures range from 15°C to 22°C (59°F to 71.6°F). Rogers et al. (1977 as cited in Fay et al. 1983, Table 7) also reported a larval striped bass tolerance range of 10°C to 25°C (50°F to 77°F) but an optimum water temperature tolerance range of 18°C to 21°C (64.4°F to 69.8°F). Bogdanov et al. (1967 as cited in Fay et al. 1983, Table 8) reported that juvenile striped bass can tolerate water temperatures from 10°C to 27°C (50°F to 80.6°F), while optimum water temperatures range from 16°C to 19°C (60.8°F to 66.2°F). Optimal water temperatures for juvenile striped bass rearing also have been reported to range from about 16°C to 22°C (61°F to 71°F) (Fay et al. 1983).

Based on the available information, USACE used a water temperature range 61°F to 71°F to evaluate striped bass juvenile rearing.

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Appendix 7D

1.1 Analysis of Spawning Weighted Usable Area for Upper Sacramento River and Feather River Salmonids

The *term flow-dependent habitat availability* refers to the quantity and quality of habitat available to individual species and lifestages for a particular instream flow. Typically, the relationship between instream flow and the quantity and quality of instream habitat is expressed in terms of weighted usable area (WUA) produced at a particular flow level.

For the Chinook salmon and steelhead adult spawning lifestages, the term *flow-dependent habitat availability* refers to the amount of appropriate spawning habitat, including the suitable water depths, velocities, and substrate for successful spawning that is, in part, contingent on stream flow. Salmonids typically deposit eggs within a range of depths and velocities that ensure adequate exchange of water between surface and substrate interstices to maintain high oxygen levels and remove metabolic wastes from the redd. Stream flow directly affects the availability of appropriate spawning habitat (SWRI 2002). In general, the amount of habitat suitable for spawning increases as flows increase from very low flows up to a certain flow, and then the amount of suitable spawning habitat generally decreases as flows increase because of excessive velocities, depths, etc. In addition, excessive stream flows can cause scouring of the substrate, resulting in mortality to developing eggs and embryos (Spence et al. 1996).

The physical habitat simulation (PHABSIM) system is a commonly used method to express indices of the quantity and quality of habitat associated with specific flows. PHABSIM is the combination of hydraulic and habitat models, the output of which is expressed as WUA and is used to predict the relationship between instream flow and the quantity and quality of habitat for various lifestages of one or more species of fish.

1.1.1 Scaled Composite Annual Spawning WUA Indices

In the upper Sacramento and Feather Rivers, available spawning habitat for Chinook salmon and steelhead is expressed by scaled composite WUA indices that correspond to the spawning habitat available to the species under simulated monthly flows occurring during their spawning seasons. In general, the scaled composite WUA annual index $CWUA_Y$) is calculated as the sum of the WUAs that correspond to the monthly flows during the species' spawning season at the sampled reaches within the species' spawning area, multiplied by a temporal weighting coefficient that represents the expected relative spawning intensity in the particular month of the spawning season, divided by the maximum WUA for the sum of the sampled spawning reaches, over the flow range for which the WUA-flow relationship was developed.

The U.S. Army Corps of Engineers (USACE) used four different formulae to calculate the scaled composite WUA annual indices for Chinook salmon and steelhead spawning in the upper Sacramento and Feather Rivers.

For winter-run Chinook salmon, late fall-run Chinook salmon, and steelhead spawning in the upper Sacramento River, the scaled composite annual spawning WUA index ($CWUA_Y$) is expressed by the following formula:

$$CWUA_Y = \frac{\sum_{m=1}^{K} w_m \times \left(\sum_{h=1}^{3} WUA_h \left(Q_{m,Y} \right) \right)}{\max \left(\sum_{h=1}^{3} WUA_h \left(Q \right) \right)} \tag{1}$$

where $WUA_h\,(Q_{m,Y})$ is the WUA of reach h at the monthly Keswick flow release $Q_{m,Y}$ obtained from the WUA-flow relationships developed for the three species by the most recent Instream Flow Incremental Methodology (IFIM) studies (Gard 2003) performed at three sampled spawning reaches extending from Keswick Dam (river mile [RM] 301) through the confluence with Battle Creek (RM 271). The denominator of the equation that serves to scale the expression is the maximum achievable WUA for all three spawning reaches combined over the flow range for which the WUA-flow relationships were developed. Finally, w_m are the temporal weighting coefficients for winter-run Chinook salmon, late fall-run Chinook salmon, or steelhead for each of the months in the K-month spawning periods of the species.

For fall-run Chinook salmon spawning in the upper Sacramento River, the scaled composite annual spawning WUA index has a slightly more complex formula:

$$CWUA_Y = \frac{\sum_{m=1}^{K} w_m \times \left(\sum_{h=1}^{3} WUA_h \left(Q_{m,Y} \right) + \sum_{l=1}^{2} WUA_l \left(Q_{m,Y} \right) \right)}{\max \left(\sum_{h=1}^{3} WUA_h \left(Q \right) \right) + \max \left(\sum_{l=1}^{2} WUA_l \left(Q \right) \right)}. \tag{2}$$

For Sacramento River fall-run Chinook salmon, the WUA-flow relationships developed in a more recent IFIM study (Gard 2005) for two additional spawning reaches extending from the confluence with Battle Creek (RM 270) through the confluence with Deer Creek (RM 220) were included by USACE with the WUA-flow relationships developed in Gard (2003). In formula 2, $WUA_l\,(Q_{m,Y})$ is the WUA for these additional reaches at monthly flow $Q_{m,Y}$. This monthly flow corresponds to simulated monthly flows in the Sacramento River immediately downstream of the confluence with Battle Creek. As in the previous equation, w_m are the temporal weighting coefficients for fall-run Chinook salmon for each of the months in the K-month spawning periods of the species.

For steelhead spawning in the Feather River, the scaled composite annual spawning WUA index is computed as:

$$CWUA_Y = \frac{\sum_{m=1}^{K} w_m \times \left(WUA_h\left(Q_{m,Y}\right) + WUA_l\left(Q_{m,Y}\right)\right)}{\max\left(WUA_h\left(Q\right)\right) + \max\left(WUA_l\left(Q\right)\right)} \tag{3}$$

where $WUA_l\,(Q_{m,Y})$ is the WUA for steelhead spawning in the Feather River Low Flow Channel (LFC) (i.e., the reach extending from the Fish Barrier Dam [RM 67.3] to the Thermalito Afterbay Outlet [RM 59]) at the simulated monthly flow $Q_{m,Y}$ measured at the Fish Barrier Dam. Similarly, $WUA_h\,(Q_{m,Y})$ is the WUA for steelhead spawning in the Feather River High Flow Channel (HFC) (i.e., the reach extending from the Thermalito Afterbay Outlet to the confluence with Honcut Creek [RM 44]) at the simulated monthly flow $Q_{m,Y}$ measured below the Thermalito Afterbay Outlet. The denominator of the equation that serves to scale the expression is the sum of the maximum achievable WUAs in the Feather River LFC (max($WUA_l\,(Q)$)) and in the Feather River HFC (max($WUA_h(Q)$)) resulting from the WUA-flow relationships for the two Feather River reaches, developed by the California Department of Water Resources (DWR 2004). The w_m are the temporal weighting coefficients for steelhead spawning.

For spring-run and fall-run Chinook salmon in the Feather River, the scaled composite annual spawning WUA index is computed as:

$$CWUA_Y = w_h \times \left[\sum_{m=1}^{K} w_m \times \frac{WUA_h\left(Q_{m,Y}\right)}{\max\left(WUA_h\left(Q\right)\right)}\right] + w_l \times \left[\sum_{m=1}^{K} w_m \times \frac{WUA_l\left(Q_{m,Y}\right)}{\max\left(WUA_l\left(Q\right)\right)}\right] \tag{4}$$

where $WUA_l\,(Q_{m,Y})$, $WUA_h\,(Q_{m,Y})$, max($WUA_l\,(Q)$) and max($WUA_h(Q)$) are defined as previously identified with respect to the WUA-flow relationships developed for Chinook salmon spawning in the Feather River (DWR 2004). The coefficients w_l and w_h are spatial weighting coefficients for the LFC and HFC that integrate both the relative importance of the reach in terms of maximum achievable WUA and the relative use of the reach by the species as the average proportion of carcasses found in the reach during the DWR 2000–2014 carcass surveys (DWR, no date). Details on the calculation of these spatial weighting coefficients are provided in Section E-5.

Table 1 summarizes the calculation of annual spawning habitat availability in the upper Sacramento and Feather Rivers by species. The table lists the months and river reaches over which the scaled composite annual spawning WUA index was calculated.

Table 1. Summary of Calculations of Annual Spawning Habitat Availability Indices in the Upper Sacramento and Feather Rivers.

River	Species	WUA Equation	Months (*k*)	Reaches
Upper Sacramento River	Winter-run Chinook salmon	1	8 (Mar – Aug)	3 (from RM 301 through RM 271)
	Fall-run Chinook salmon	2	3 (Oct – Dec)	3 (from RM 301 through RM 271) plus 2 (from RM 270 through RM 220)
	Late fall-run Chinook salmon	1	4 (Jan – Apr)	3 (from RM 301 through RM 271)
	Steelhead	1	7 (Nov – May)	3 (from RM 301 through RM 271)
Feather River	Spring-run Chinook salmon	3	2 (Sep – Oct)	2 (from RM 67.3 through RM 59, and from RM 59 through RM 44)
	Fall-run Chinook salmon	3	3 (Oct – Dec)	2 (from RM 67.3 through RM 59, and from RM 59 through RM 44)
	Steelhead	3	4 (Jan – Apr)	2 (from RM 67.3 through RM 59, and from RM 59 through RM 44)

RM – River Mile

The following sections describe the data and calculations that USACE used to develop the main components of $CWUA_Y$ in formulae 1, 2, 3, and 4:

- Spawning WUA-flow relationships by river and species/run ($WUA_k(Q)$)
- Temporal weighting coefficients (w_m)
- Spatial weighting coefficients (w_l and w_h)

1.1.2 Upper Sacramento River WUA-Flow Relationships

To describe the habitat available to winter-run, fall-run, and late fall-run Chinook salmon and steelhead spawning in the upper Sacramento River, this analysis uses the spawning WUA-flow relationships that were developed by two recent IFIM studies (Gard 2003, 2005).

In the first IFIM study (Gard 2003), the Physical Habitat Simulation (PHABSIM) component of the IFIM was used to model WUA for the three uppermost reaches of the studied area (reaches 6 through 4; **Table 2**). Gard (2003) reported two spawning WUA-flow relationships per species for the uppermost reach (reach 6). One corresponds to the period when the Anderson-Cottonwood Irrigation District (ACID) dam boards are installed (approximately April through October), and the other corresponds to the period when the ACID dam boards are removed (approximately from November 1 through March). The dates of installation and removal of the boards can vary depending on hydrologic conditions.

Table 2. Summary of the Upper Sacramento River Reaches with WUA-Flow Relationships for Spawning Salmonids Developed by Gard (2003, 2005) and Locations of the Modeled Flows Used in the Analysis of Spawning WUA.

Reach Number	Reach Description	Upper Limit (RM)	Lower Limit (RM)	Flow Site Location (CALSIM II node)
6	Keswick Dam to Anderson-Cottonwood Irrigation District (ACID) Dam	301	298	Below Keswick Dam (C 5)
5	ACID Dam to the confluence with Cow Creek	297.5	280	Below Keswick Dam (C 5)
4	Confluence with Cow Creek to the confluence with Battle Creek	279.1	271	Below Keswick Dam (C 5)
3	Confluence with Battle Creek to above Lake Red Bluff	270.3	258	Battle Creek confluence (C 108)
2	Red Bluff Diversion Dam to the confluence with Deer Creek	242	220	Battle Creek confluence (C 108)

By contrast with the Gard (2003) IFIM study that used PHABSIM, the second IFIM study (Gard 2005) used a two-dimensional hydraulic and habitat model (RIVER2D) to model spawning WUA in the two lowermost reaches (reaches 3 and 2; Table 2) of the study area for fall-run Chinook salmon. Gard (2003) reported the spawning WUA-flow relationships for the three uppermost reaches (reaches 6, 5, and 4) for steelhead and for fall-run, late fall-run, and winter-run Chinook salmon, while Gard (2005) reported the spawning WUA-flow relationships in the two lower most reaches (reaches 3 and 2) only for fall-run Chinook salmon.

No spawning WUA-flow relationship has been produced in any analysis for spring-run Chinook salmon in the Sacramento River, primarily because: (1) very few Chinook salmon redds were catalogued as spring-run redds during the 1989–1994 California Department of Fish and Wildlife (CDFW) aerial redd counts; (2) fish identified as spring-run Chinook salmon in the mainstem Sacramento River are considered hybrids that display the migration timing of both spring-run and fall-run Chinook salmon; (3) spring-run Chinook salmon are thought to be primarily tributary spawners, and it has not been feasible to differentiate potential spring-run Chinook salmon that do spawn in the mainstem Sacramento River from fall-run Chinook salmon; and (4) spring-run Chinook salmon habitat suitability criteria are not available from streams similar to the Sacramento River (Gard 2003).

Given the availability of WUA-flow relationships for salmonids spawning in the upper Sacramento River described in the previous paragraphs, the evaluation of habitat availability for flows modeled with the Folsom Water Control Manual (WCM) Project alternatives and basis-of-comparison scenarios are based on the following assumptions:

1. The steelhead spawning WUA-flow relationships for reaches 6, 5, and 4 (Gard 2003) were applied to modeled flows downstream of Keswick Dam to assess the habitat availability for steelhead spawning in the upper Sacramento River.
2. The winter-run Chinook salmon spawning WUA-flow relationships for reaches 6, 5, and 4 (Gard 2003) were applied to modeled flows downstream of Keswick Dam to assess the habitat availability for winter-run Chinook salmon spawning in the upper Sacramento River.
3. The late fall-run Chinook salmon spawning WUA-flow relationships for reaches 6, 5, and 4 (Gard 2003) were applied to modeled flows downstream of Keswick Dam to assess the habitat availability for late fall-run Chinook salmon spawning in the upper Sacramento River.
4. The fall-run Chinook salmon WUA-flow relationships for reaches 6, 5, and 4 (Gard 2003) were applied to modeled flows downstream of Keswick Dam, and the fall-run Chinook salmon spawning WUA-flow relationships for reaches 3 and 2 (Gard 2005) were applied to modeled flows downstream of the confluence with Battle Creek to assess the habitat availability for fall-run Chinook salmon spawning in the upper Sacramento River.
5. The spawning habitat availability of spring-run Chinook salmon was not evaluated in the upper Sacramento River.

For each species/run, the spawning WUA values of each of the five study reaches at a particular monthly flow $Q_{m,Y}$ were obtained from the WUA-flow relationships developed by the two IFIM studies and were summed to calculate composite values ($\sum_{h=1}^{3} WUA_h\left(Q_{m.Y}\right)$ and $\sum_{l=1}^{2} WUA_l\left(Q_{m.Y}\right)$ in formulae 1 and 2). For $\sum_{h=1}^{3} WUA_h\left(Q_{m.Y}\right)$ that combines the values for reaches 6, 5, and 4, the monthly flow $Q_{m,Y}$ is the flow modeled with the Folsom WCM alternatives and the bases of comparison for the particular month *m* and year for a location immediately below Keswick Dam, the uppermost boundary of the five study reaches (CALSIM II node C5). For $\sum_{l=1}^{2} WUA_l\left(Q_{m.Y}\right)$ that combines the values for reaches 3 and 2, the monthly flow $Q_{m,Y}$ is the modeled flow for a location downstream of the confluence with Battle Creek that constitutes the limit between reaches 4 and 3 (CALSIM II node C108).

Because the WUA-flow relationships developed by the most recent IFIM studies present WUA values within particular flow ranges at particular variable steps (e.g., in the upper Sacramento River the WUA-flow relationships were developed for a flow range of 3,250 cubic feet per second [cfs] to 31,000 cfs, with increasing steps of 250 cfs, 500 cfs, 1,000 cfs, and 2,000 cfs), the modeled monthly flow $Q_{m,Y}$ for which the composite WUA needs to be computed often falls between two flows for which there are WUA values in the WUA-flow relationships. Therefore, the composite WUA value was determined by linear interpolation between the available WUA values for the flows immediately below and above the target flow $Q_{m,Y}$. In those cases when the target flow $Q_{m,Y}$ was lower than the lowest flow value in the WUA-flow relationship (3,250 cfs) or higher than the highest flow value in the WUA-flow relationship (31,000 cfs), series of extrapolated WUA values were generated from fitting a polynomial and a power or exponential function to the closest WUA and flow values in the available WUA-flow relationships, as summarized below.

A polynomial function was fitted to the WUA values for the 12 lowest flows in the available WUA-flow relationship (Q = 3,250 cfs, 3,500 cfs, 3,750 cfs, 4,000 cfs, 4,250 cfs, 4,500 cfs, 4,750 cfs, 5,000 cfs, 5,250 cfs, 5,500 cfs, 6,000 cfs, and 6,500 cfs) to generate 33 extrapolated WUA values for flows ranging from Q = 0 cfs to Q = 3,200 cfs in increasing steps of 100 cfs.

Power and exponential functions were fitted to the WUA values for the eight or 10 highest flows in the available WUA-flow relationships (Q = 17,000 cfs, 19,000 cfs, 21,000 cfs, 23,000 cfs, 25,000 cfs, 27,000 cfs, 29,000 cfs, and 31,000 cfs for winter-run and fall-run Chinook salmon, with the addition of Q = 14,000 cfs and Q = 15,000 cfs for steelhead and late fall-run Chinook salmon). The fitted function that produced a better fit was then used to generate 49 extrapolated WUA values for Q ranging from 32,000 cfs through 80,000 cfs in increasing steps of 1,000 cfs.

Details of the extrapolation procedure and available WUA-flow relationships for winter-run, fall-run, and late fall-run Chinook salmon and steelhead spawning in the upper Sacramento River are provided in the following sections.

1.1.2.1 Winter-run Chinook Salmon

Figure 1 shows the WUA-flow relationships for winter-run Chinook salmon spawning in the upper Sacramento River (Gard 2003). Figure 1 shows the WUA-flow relationships for the three uppermost study reaches extending from Keswick Dam to the confluence with Battle Creek (reaches 6, 5, and 4 in Table 2) as connected colored circles. The WUA-flow relationship for reach 6 with ACID dam boards installed was applied because the ACID dam boards are installed approximately from April through October, a period that covers most of winter-run Chinook salmon spawning (March through August).

The composite WUA-flow relationship, resulting from the sum of the three reach specific relationships, is indicated as a black line in Figure 1. The maximum WUA value for this composite line is 1,718,329 square feet (ft^2) corresponding to a flow Q = 9,000 cfs. This maximum WUA value corresponds to the denominator $\max\left(\sum_{h=1}^{3} WUA_h\left(Q\right)\right)$ in formula 1 that is used to scale the composite annual spawning WUA index. The composite WUA curve has 30 data points corresponding to flows ranging from 3,250 cfs through 31,000 cfs that were used for the direct linear interpolation of simulated flows $Q_{m,Y}$ downstream of Keswick Dam between 3,250 cfs and 31,000 cfs with the Folsom WCM alternatives and the bases of comparison during the entire simulation period.

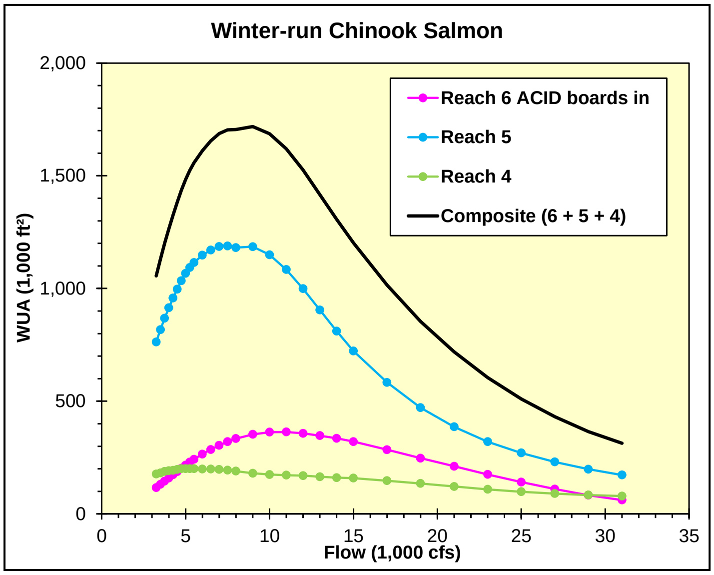

Figure 1. Relationship between Winter-run Chinook Salmon Spawning WUA and Flow for the Three Upper Study Reaches in the Upper Sacramento River Extending from Keswick Dam to the Confluence with Battle Creek and for the Composite of the Three Reaches.

To interpolate target monthly flows lower than 3,250 cfs, a polynomial function was first fitted to the WUA values for the 12 lowest flows in the composite WUA-flow relationship (Q = 3,250 cfs, 3,500 cfs, 3,750 cfs, 4,000 cfs, 4,250 cfs, 4,500 cfs, 4,750 cfs, 5,000 cfs, 5,250 cfs, 5,500 cfs, 6,000 cfs, and 6,500 cfs). The equation of the fitted polynomial was $WUA = 243.307 \times Q + 0.063593 \times Q^2 - 1.42 \times 10^{-5} \times Q^3 + 7.20 \times 10^{-10} \times Q^4$, which had a coefficient of determination R^2 = 0.999998. The polynomial equation was used to generate 33 extrapolated WUA values for flows ranging from Q = 0 cfs to Q = 3,200 cfs in increasing steps of 100 cfs that were in turn used to interpolate target monthly flows lower than 3,250 cfs. These extrapolated WUA values were plotted in **Figure 2**.

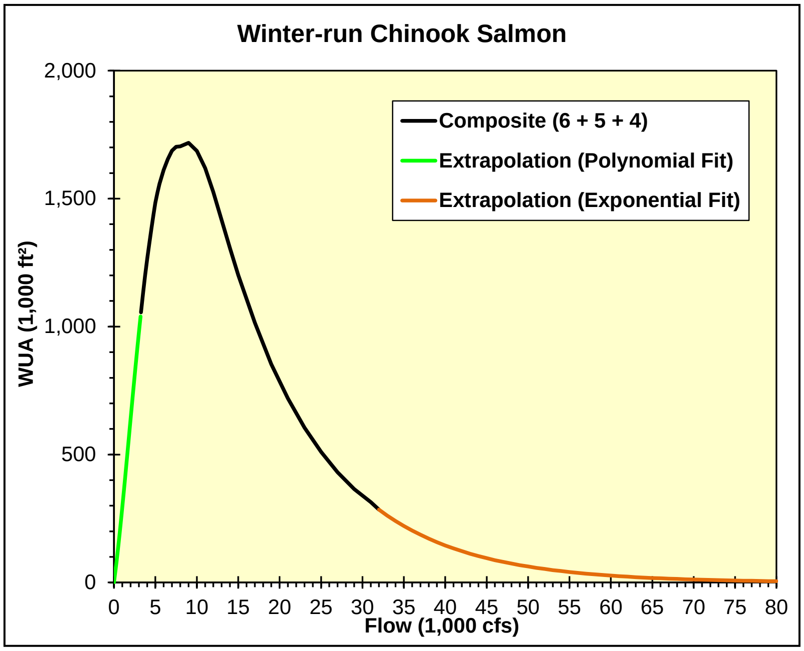

Figure 2. Final Relationship between the Composite WUA and Flow for Winter-run Chinook Salmon Spawning in the Upper Sacramento River.

To interpolate WUA values at simulated flows higher than 31,000 cfs, an exponential function was fitted to the WUA values for the eight highest flows in the composite WUA-flow relationship (*Q* = 17,000 cfs, 19,000 cfs, 21,000 cfs, 23,000 cfs, 25,000 cfs, 27,000 cfs, 29,000 cfs, and 31,000 cfs). The fitted exponential function was $\ln(WUA) = 15.258 - 0.000084 \times Q$, which had a coefficient of determination $R^2 = 0.999707$. The regression equation was used to generate 49 extrapolated WUA values for *Q* ranging from 32,000 cfs through 80,000 cfs in increasing steps of 1,000 cfs that were in turn used to interpolate target monthly flows greater than 31,000 cfs (Figure 2).

The 33 WUA values extrapolated from the fitted polynomial and the 49 WUA values extrapolated from the fitted exponential function were combined with the 30 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for monthly flows below Keswick Dam generated with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 3**).

Table 3. Extrapolated Composite Spawning WUA-Flow Relationship for Winter-run Chinook Salmon in the Upper Sacramento River.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,800	912,297	19,000	853,248	53,000	48,368
100	24,952	2,900	944,932	21,000	719,101	54,000	44,455
200	51,093	3,000	977,095	23,000	604,650	55,000	40,858
300	78,338	3,100	1,008,751	25,000	509,956	56,000	37,553
400	106,607	3,200	1,039,868	27,000	431,024	57,000	34,515
500	135,821	3,250	1,055,578	29,000	365,165	58,000	31,722
600	165,903	3,500	1,130,004	31,000	313,612	59,000	29,156
700	196,776	3,750	1,201,239	32,000	284,444	60,000	26,797
800	228,368	4,000	1,265,116	33,000	261,431	61,000	24,629
900	260,604	4,250	1,324,175	34,000	240,280	62,000	22,636
1,000	293,416	4,500	1,382,024	35,000	220,840	63,000	20,805
1,100	326,734	4,750	1,437,000	36,000	202,973	64,000	19,122
1,200	360,491	5,000	1,484,122	37,000	186,551	65,000	17,575
1,300	394,622	5,250	1,522,893	38,000	171,458	66,000	16,153
1,400	429,063	5,500	1,557,427	39,000	157,586	67,000	14,846
1,500	463,753	6,000	1,611,679	40,000	144,837	68,000	13,645
1,600	498,630	6,500	1,654,507	41,000	133,119	69,000	12,541
1,700	533,638	7,000	1,687,002	42,000	122,349	70,000	11,526
1,800	568,718	7,500	1,703,166	43,000	112,450	71,000	10,594
1,900	603,816	8,000	1,704,798	44,000	103,352	72,000	9,737
2,000	638,879	9,000	1,718,329	45,000	94,990	73,000	8,949
2,100	673,855	10,000	1,686,744	46,000	87,305	74,000	8,225
2,200	708,695	11,000	1,619,130	47,000	80,242	75,000	7,559
2,300	743,350	12,000	1,525,890	48,000	73,750	76,000	6,948
2,400	777,775	13,000	1,416,716	49,000	67,783	77,000	6,386
2,500	811,923	14,000	1,307,088	50,000	62,299	78,000	5,869
2,600	845,754	15,000	1,201,694	51,000	57,259	79,000	5,394
2,700	879,225	17,000	1,015,402	52,000	52,626	80,000	4,958

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using an exponential function (see text for details).

1.1.2.2 Fall-run Chinook Salmon

Figure 3 shows the WUA-flow relationships for fall-run Chinook salmon spawning in the upper Sacramento River developed by Gard (2003, 2005). Figure 3 shows the WUA-flow relationships for the three uppermost studied reaches extending from Keswick Dam to the confluence with Battle Creek (reaches 6, 5, and 4) as connected colored circles. The WUA-flow relationship for reach 6 with ACID dam boards removed was preferred over the relationship for reach 6 with ACID boards installed, because the ACID boards are removed approximately from November through March, a period that covers most of the fall-run Chinook salmon spawning period (October through December). Figure 3 also displays the WUA-flow relationships for the two lower reaches (reaches 3 and 2), presented in Gard (2005), that extend from the confluence with Battle Creek to the confluence with Deer Creek.

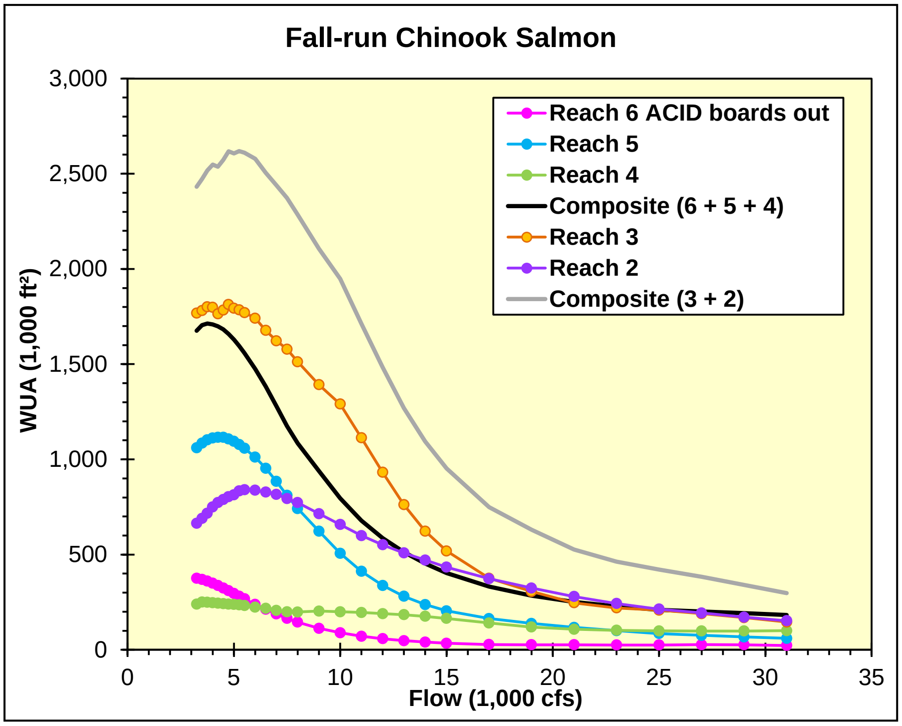

Figure 3. Relationship between Fall-run Chinook Salmon Spawning WUA and Flow for the Three Upper Study Reaches in the Upper Sacramento River Extending from Keswick Dam to the Confluence with Battle Creek (Reaches 6, 5, and 4) and for the Two Lowermost Reaches Extending from the Confluence with Battle Creek to the Confluence with Deer Creek (Reaches 3 and 2), and the Corresponding Composite Relationships.

For the purpose of this analysis, the individual reach-specific WUA-flow relationships were combined into two composite relationships. One composite WUA-flow relationship, resulting from the sum of the relationships for reaches 6, 5, and 4, is indicated as a black line in Figure 3. The maximum WUA value for this composite line is 1,713,275 ft² corresponding to a flow Q = 3,750 cfs. This maximum WUA value corresponds to the denominator $\max\left(\sum_{h=1}^{3} WUA_h\left(Q\right)\right)$ in formula 2 that is used to scale the composite annual spawning WUA index. This composite WUA relationship has 30 data points corresponding to flows ranging from 3,250 cfs through 31,000 cfs that were used for the direct linear interpolation of WUA values at simulated flows $Q_{m,Y}$ downstream of Keswick Dam between 3,250 cfs and 31,000 cfs with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

The second composite annual spawning WUA-flow relationship, resulting from the sum of the relationships for reaches 3 and 2, is indicated as a gray line in Figure 3. The maximum WUA value for this composite line is 2,619,093 ft² corresponding to a flow Q = 5,250 cfs. This maximum WUA value corresponds to the denominator $\max\left(\sum_{l=1}^{2} WUA_l\left(Q\right)\right)$ in formula 2 that is also used to scale the composite WUA index. This second composite WUA-flow relationship also was used for the direct linear interpolation of WUA values at simulated flows $Q_{m,Y}$ downstream of the confluence with Battle Creek.

To interpolate WUA values at simulated monthly flows lower than 3,250 cfs, two polynomial functions were first fitted to the WUA values for the 12 lowest flows of each composite WUA-flow relationship (*Q* = 3,250 cfs, 3,500 cfs, 3,750 cfs, 4,000 cfs, 4,250 cfs, 4,500 cfs, 4,750 cfs, 5,000 cfs, 5,250 cfs, 5,500 cfs, 6,000 cfs, and 6,500 cfs).

For Composite (6 + 5 + 4), the equation of the fitted polynomial was $WUA = 1{,}042.313 \times Q - 0.195906 \times Q^2 + 1.06 \times 10^{-5} \times Q^3 - 1.25 \times 10^{-11} \times Q^4$, which had a coefficient of determination $R^2 = 0.9999978$. For Composite (3 + 2), the equation of the fitted polynomial was $WUA = 1{,}820.780 \times Q - 0.530362 \times Q^2 + 7.58 \times 10^{-5} \times Q^3 - 4.33 \times 10^{-9} \times Q^4$, which had a coefficient of determination $R^2 = 0.9999827$. Both polynomial equations were used to generate 33 extrapolated WUA values for flows ranging from *Q* = 0 cfs to *Q* = 3,200 cfs in increasing steps of 100 cfs that were in turn used to interpolate WUA values at simulated monthly flows lower than 3,250 cfs. These extrapolated WUA values were plotted in **Figure 4**.

To interpolate WUA values at simulated flows higher than 31,000 cfs, two power functions were fitted to the WUA values for the eight highest flows in the composite WUA-flow relationships (*Q* = 17,000 cfs, 19,000 cfs, 21,000 cfs, 23,000 cfs, 25,000 cfs, 27,000 cfs, 29,000 cfs, and 31,000 cfs). For Composite (6 + 5 + 4), the fitted function was $\ln(WUA) = 22.145 - 0.972993 \times \ln(Q)$, which had a coefficient of determination $R^2 = 0.9756057$. For Composite (3 + 2), the fitted function was $\ln(WUA) = 27.917 - 1.478628 \times \ln(Q)$, which had a coefficient of determination $R^2 = 0.9958651$.

The regression equations were used to generate 49 extrapolated WUA values for *Q* ranging from 32,000 cfs through 80,000 cfs in increasing steps of 1,000 cfs (Figure 4) that were in turn used to interpolate WUA values at simulated monthly flows greater than 31,000 cfs.

The 33 WUA values extrapolated from the fitted polynomial and the 49 WUA values extrapolated from the fitted power function were combined with the 30 values of the Composite (6 +5 +4) WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for simulated monthly flows below Keswick Dam with the Folsom WCM alternatives and the bases of comparison (**Table 4**). **Table 5** displays the comparable look-up table used for the linear interpolation of WUA values for monthly flows downstream of the confluence with Battle Creek with the Folsom WCM alternatives and the bases of comparison.

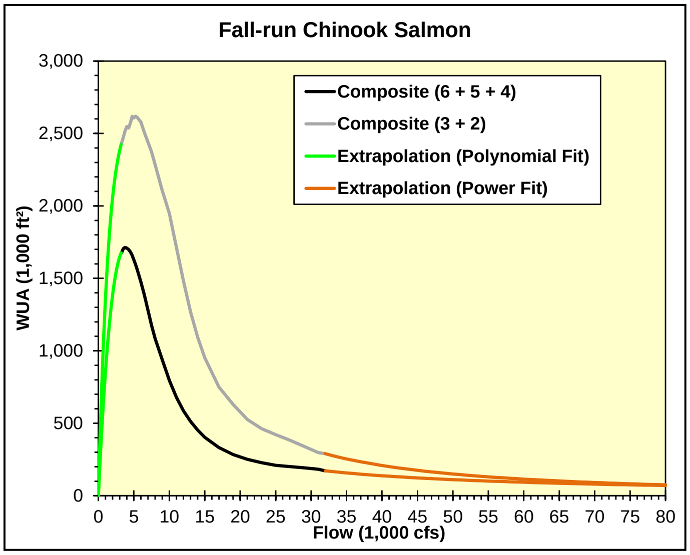

Figure 4. Final Relationships between the Composite WUA and Flow for Fall-run Chinook Salmon Spawning in the Upper Sacramento River Downstream of Keswick Dam, Composite (6 + 5 + 4), and Downstream of the Confluence with Battle Creek, Composite (3 + 2).

Table 4. Extrapolated Composite Spawning WUA-Flow Relationship for Fall-run Chinook Salmon in the Upper Sacramento River between Keswick Dam and the Confluence with Battle Creek.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,800	1,614,269	19,000	284,576	53,000	104,879
100	102,283	2,900	1,632,525	21,000	251,595	54,000	102,989
200	200,711	3,000	1,648,693	23,000	227,845	55,000	101,167
300	295,348	3,100	1,662,836	25,000	209,999	56,000	99,409
400	386,258	3,200	1,675,016	27,000	201,205	57,000	97,711
500	473,503	3,250	1,675,371	29,000	192,657	58,000	96,072
600	557,147	3,500	1,705,121	31,000	183,143	59,000	94,487
700	637,254	3,750	1,713,275	32,000	171,356	60,000	92,954
800	713,887	4,000	1,709,027	33,000	166,301	61,000	91,471
900	787,109	4,250	1,698,553	34,000	161,540	62,000	90,036
1,000	856,984	4,500	1,682,514	35,000	157,048	63,000	88,645
1,100	923,574	4,750	1,658,083	36,000	152,801	64,000	87,297
1,200	986,944	5,000	1,628,690	37,000	148,782	65,000	85,990
1,300	1,047,155	5,250	1,595,354	38,000	144,971	66,000	84,722
1,400	1,104,272	5,500	1,557,715	39,000	141,353	67,000	83,491
1,500	1,158,357	6,000	1,474,361	40,000	137,913	68,000	82,296
1,600	1,209,474	6,500	1,382,883	41,000	134,639	69,000	81,136
1,700	1,257,686	7,000	1,278,772	42,000	131,519	70,000	80,008
1,800	1,303,055	7,500	1,174,572	43,000	128,542	71,000	78,911
1,900	1,345,645	8,000	1,084,717	44,000	125,699	72,000	77,844
2,000	1,385,519	9,000	938,728	45,000	122,980	73,000	76,807
2,100	1,422,739	10,000	795,801	46,000	120,378	74,000	75,797
2,200	1,457,369	11,000	678,263	47,000	117,885	75,000	74,813
2,300	1,489,471	12,000	585,960	48,000	115,495	76,000	73,855
2,400	1,519,109	13,000	512,660	49,000	113,201	77,000	72,922
2,500	1,546,345	14,000	453,412	50,000	110,997	78,000	72,012
2,600	1,571,242	15,000	403,338	51,000	108,879	79,000	71,125
2,700	1,593,862	17,000	332,231	52,000	106,841	80,000	70,260

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

Table 5. Extrapolated Composite Spawning WUA-Flow Relationship for Fall-run Chinook Salmon in the Upper Sacramento River between the Confluence with Battle Creek and the Confluence with Dry Creek.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,800	2,337,177	19,000	630,753	53,000	137,601
100	176,850	2,900	2,361,474	21,000	526,365	54,000	133,850
200	343,541	3,000	2,383,976	23,000	462,509	55,000	130,267
300	500,512	3,100	2,404,829	25,000	421,614	56,000	126,843
400	648,192	3,200	2,424,171	27,000	382,837	57,000	123,566
500	787,000	3,250	2,432,159	29,000	340,721	58,000	120,429
600	917,343	3,500	2,472,408	31,000	298,265	59,000	117,423
700	1,039,618	3,750	2,517,107	32,000	290,154	60,000	114,541
800	1,154,212	4,000	2,548,379	33,000	277,248	61,000	111,775
900	1,261,503	4,250	2,537,270	34,000	265,276	62,000	109,120
1,000	1,361,856	4,500	2,572,156	35,000	254,146	63,000	106,569
1,100	1,455,627	4,750	2,617,635	36,000	243,777	64,000	104,116
1,200	1,543,162	5,000	2,607,065	37,000	234,098	65,000	101,756
1,300	1,624,796	5,250	2,619,093	38,000	225,047	66,000	99,485
1,400	1,700,853	5,500	2,610,395	39,000	216,567	67,000	97,297
1,500	1,771,648	6,000	2,578,633	40,000	208,610	68,000	95,189
1,600	1,837,485	6,500	2,504,604	41,000	201,130	69,000	93,156
1,700	1,898,656	7,000	2,438,632	42,000	194,090	70,000	91,195
1,800	1,955,446	7,500	2,372,848	43,000	187,453	71,000	89,302
1,900	2,008,126	8,000	2,285,308	44,000	181,188	72,000	87,474
2,000	2,056,959	9,000	2,106,590	45,000	175,266	73,000	85,708
2,100	2,102,198	10,000	1,948,099	46,000	169,662	74,000	84,001
2,200	2,144,082	11,000	1,712,607	47,000	164,352	75,000	82,351
2,300	2,182,844	12,000	1,483,279	48,000	159,314	76,000	80,754
2,400	2,218,704	13,000	1,269,818	49,000	154,530	77,000	79,208
2,500	2,251,873	14,000	1,094,316	50,000	149,982	78,000	77,711
2,600	2,282,550	15,000	952,887	51,000	145,655	79,000	76,261
2,700	2,310,925	17,000	749,112	52,000	141,532	80,000	74,855

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

1.1.2.3 Late Fall-run Chinook Salmon

Figure 5 shows the WUA-flow relationships for late fall-run Chinook salmon spawning in the upper Sacramento River developed by Gard (2003). Figure 5 shows the WUA-flow relationships for the three uppermost studied reaches extending from Keswick Dam to the confluence with Battle Creek (reaches 6, 5, and 4) as connected colored circles. The WUA-flow relationship for reach 6 with ACID dam boards removed was preferred over the relationship for reach 6 with ACID dam boards installed, because the ACID dam boards are removed approximately from November through March, a period that encompasses most of late fall-run Chinook salmon spawning (January through April).

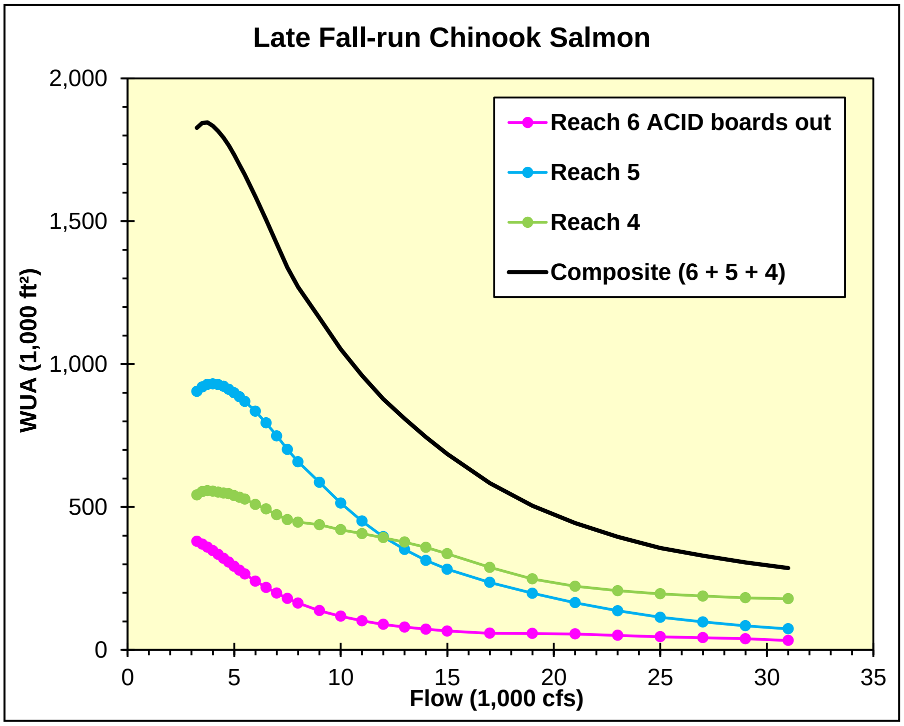

Figure 5. Relationship between Late Fall-run Chinook Salmon Spawning WUA and Flow for the Three Upper Study Reaches in the Upper Sacramento River Extending from Keswick Dam to the Confluence with Battle Creek and for the Composite of the Three Reaches.

The composite spawning WUA-flow relationship resulting from the sum of the three reach-specific relationships is indicated as a black line in Figure 5. The maximum WUA value for this composite line is 1,845,325 ft² corresponding to a flow Q = 3.750 cfs. This maximum WUA value corresponds to the denominator $\max\left(\sum_{h=1}^{3} WUA_h(Q)\right)$ in formula 1 that is used to scale the composite WUA annual index.

The composite WUA curve has 30 data points corresponding to flows ranging from 3,250 cfs through 31,000 cfs, which were used for the direct linear interpolation of WUA values at simulated monthly flows $Q_{m,Y}$ downstream of Keswick Dam between 3,250 cfs and 31,000 cfs with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

To interpolate WUA values at monthly flows lower than 3,250 cfs, a polynomial function was first fitted to the WUA values for the 12 lowest flows in the composite WUA-flow relationship (Q = 3,250 cfs, 3,500 cfs, 3,750 cfs, 4,000 cfs, 4,250 cfs, 4,500 cfs, 4,750 cfs, 5,000 cfs, 5,250 cfs, 5,500 cfs, 6,000 cfs, and 6,500 cfs). The equation of the fitted polynomial was $WUA = 1,281.425 \times Q - 0.296674 \times Q^2 + 2.58 \times 10^{-5} \times Q^3 - 7.67 \times 10^{-10} \times Q^4$, which had a coefficient of determination R^2 = 0.9999985. The polynomial equation was used to generate 33 extrapolated WUA values for flows ranging from Q = 0 cfs to Q = 3,200 cfs in increasing steps of 100 cfs that were in turn used to interpolate WUA values at simulated monthly flows lower than 3,250 cfs. These extrapolated WUA values were displayed as a green line in **Figure 6**.

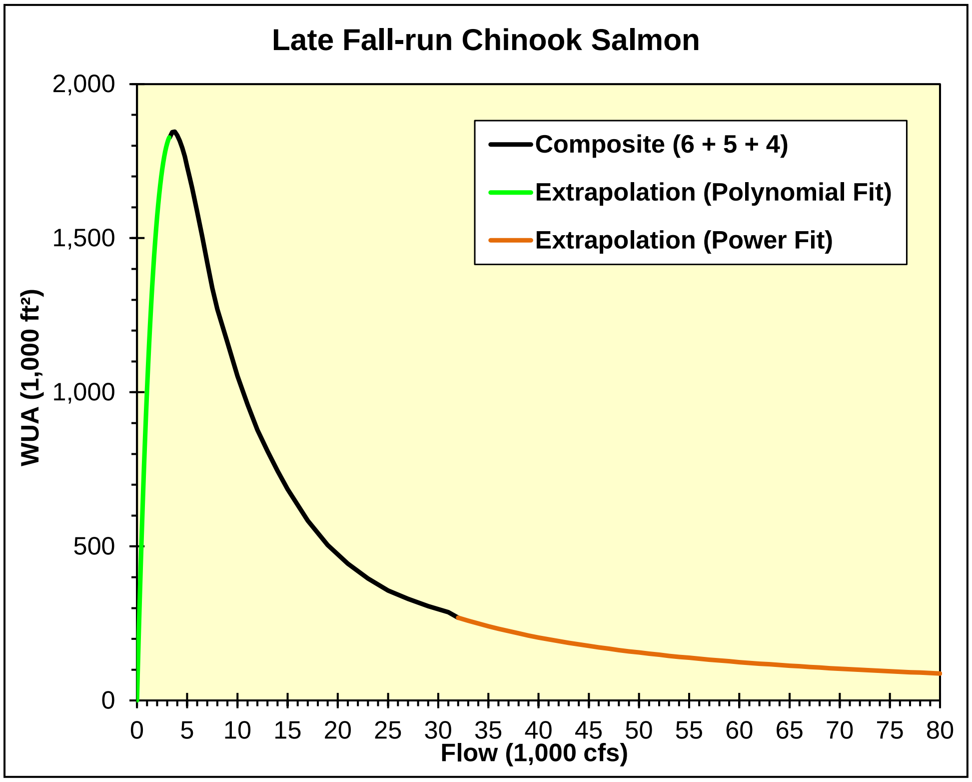

Figure 6. Final Relationship between the Composite Spawning WUA and Flow for Late Fall-run Chinook Salmon in the Upper Sacramento River.

To interpolate WUA values at simulated monthly flows higher than 31,000 cfs, a power function was fitted to the WUA values for the 10 highest flows in the composite WUA-flow relationship (Q = 14,000 cfs, 15,000 cfs, 17,000 cfs, 19,000 cfs, 21,000 cfs, 23,000 cfs, 25,000 cfs, 27,000 cfs, 29,000 cfs, and 31,000 cfs). The fitted power function was $\ln(WUA) = 25.176 - 1.221799 \times \ln(Q)$, which had a coefficient of determination $R^2 = 0.9983288$. The regression equation was used to generate 49 extrapolated WUA values for Q ranging from 32,000 cfs through 80,000 cfs in increasing steps of 1,000 cfs, which were used to interpolate WUA values at simulated monthly flows greater than 31,000 cfs (orange line in Figure 6). The 33 WUA values extrapolated from the fitted polynomial and the 49 WUA values extrapolated from the fitted power function were combined with the 30 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for monthly flows below Keswick Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 6**).

Table 6. Extrapolated Composite Spawning WUA-Flow Relationship for Late Fall-run Chinook Salmon in the Upper Sacramento River between Keswick Dam and the Confluence with Battle Creek.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,800	1,780,891	19,000	504,202	53,000	145,058
100	125,201	2,900	1,795,657	21,000	444,296	54,000	141,782
200	244,623	3,000	1,808,202	23,000	395,583	55,000	138,639
300	358,417	3,100	1,818,625	25,000	356,862	56,000	135,620
400	466,732	3,200	1,827,026	27,000	329,502	57,000	132,719
500	569,719	3,250	1,826,424	29,000	306,142	58,000	129,929
600	667,522	3,500	1,843,894	31,000	286,239	59,000	127,243
700	760,286	3,750	1,845,325	32,000	268,701	60,000	124,657
800	848,154	4,000	1,833,079	33,000	258,786	61,000	122,165
900	931,268	4,250	1,814,978	34,000	249,517	62,000	119,761
1,000	1,009,765	4,500	1,792,412	35,000	240,834	63,000	117,443
1,100	1,083,784	4,750	1,764,982	36,000	232,686	64,000	115,205
1,200	1,153,460	5,000	1,732,190	37,000	225,026	65,000	113,043
1,300	1,218,925	5,250	1,698,171	38,000	217,812	66,000	110,954
1,400	1,280,312	5,500	1,662,923	39,000	211,008	67,000	108,934
1,500	1,337,751	6,000	1,584,827	40,000	204,580	68,000	106,980
1,600	1,391,370	6,500	1,505,518	41,000	198,501	69,000	105,089
1,700	1,441,294	7,000	1,420,648	42,000	192,741	70,000	103,257
1,800	1,487,649	7,500	1,337,801	43,000	187,279	71,000	101,483
1,900	1,530,556	8,000	1,269,219	44,000	182,092	72,000	99,764
2,000	1,570,137	9,000	1,162,217	45,000	177,160	73,000	98,096
2,100	1,606,510	10,000	1,052,319	46,000	172,466	74,000	96,479
2,200	1,639,792	11,000	960,010	47,000	167,993	75,000	94,910
2,300	1,670,098	12,000	878,320	48,000	163,727	76,000	93,386
2,400	1,697,541	13,000	809,172	49,000	159,654	77,000	91,907
2,500	1,722,234	14,000	745,047	50,000	155,761	78,000	90,469
2,600	1,744,285	15,000	685,114	51,000	152,038	79,000	89,072
2,700	1,763,802	17,000	583,594	52,000	148,473	80,000	87,713

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

1.1.2.4 Steelhead

Figure 7 shows the spawning WUA-flow relationships for steelhead in the upper Sacramento River developed by Gard (2003). Figure 7 shows the WUA-flow relationships for the three uppermost studied reaches extending from Keswick Dam to the confluence with Battle Creek (reaches 6, 5, and 4) as connected colored circles. The WUA-flow relationship for reach 6 with ACID dam boards removed was preferred over the relationship for reach 6 with ACID dam boards installed, because the ACID dam boards are removed approximately from November through March, a period that encompasses most of the expected steelhead spawning period (November through April).

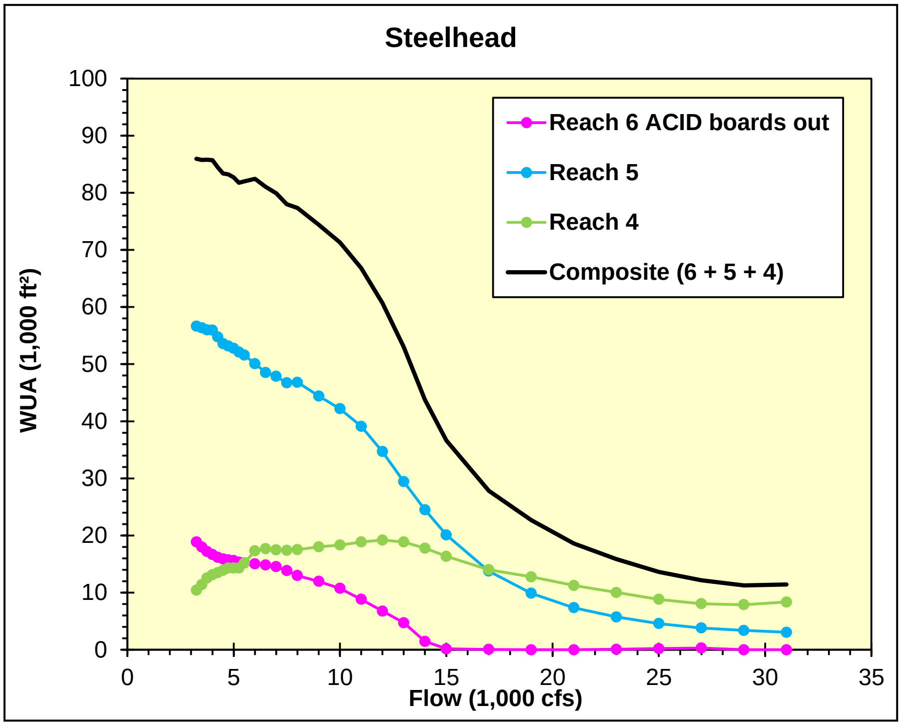

Figure 7. Relationship between Steelhead Spawning WUA and Flow for the Three Upper Study Reaches in the Upper Sacramento River Extending from Keswick Dam to the Confluence with Battle Creek and for the Composite of the Three Reaches.

The steelhead composite spawning WUA-flow relationship resulting from the sum of the three reach-specific relationships is indicated as a black line in Figure 7. The maximum WUA value for this composite line is 85,953 ft² corresponding to a flow Q = 3.250 cfs. This maximum WUA value corresponds to the denominator $\max\left(\sum_{h=1}^{3} WUA_h(Q)\right)$ in formula 1 that is used to scale the composite annual spawning WUA index. To interpolate WUA values at simulated monthly flows lower than 3,250 cfs, a polynomial function was first fitted to the WUA values for the 12 lowest flows in the composite WUA-flow relationship (Q = 3,250 cfs, 3,500 cfs, 3,750 cfs, 4,000 cfs, 4,250 cfs, 4,500 cfs, 4,750 cfs, 5,000 cfs, 5,250 cfs, 5,500 cfs, 6,000 cfs, and 6,500 cfs). The equation of the fitted polynomial was $WUA = 76.538 \times Q - 0.024229 \times Q^2 + 3.23 \times 10^{-6} \times Q^3 - 1.56 \times 10^{-10} \times Q^4$, which had a coefficient of determination R^2 = 0.9999785. The polynomial equation was used to generate 33 extrapolated WUA values for flows ranging from Q = 0 cfs to Q = 3,200 cfs in increasing steps of 100 cfs which were used to interpolate WUA values at simulated monthly flows lower than 3,250 cfs. These extrapolated WUA values were plotted in **Figure 8**.

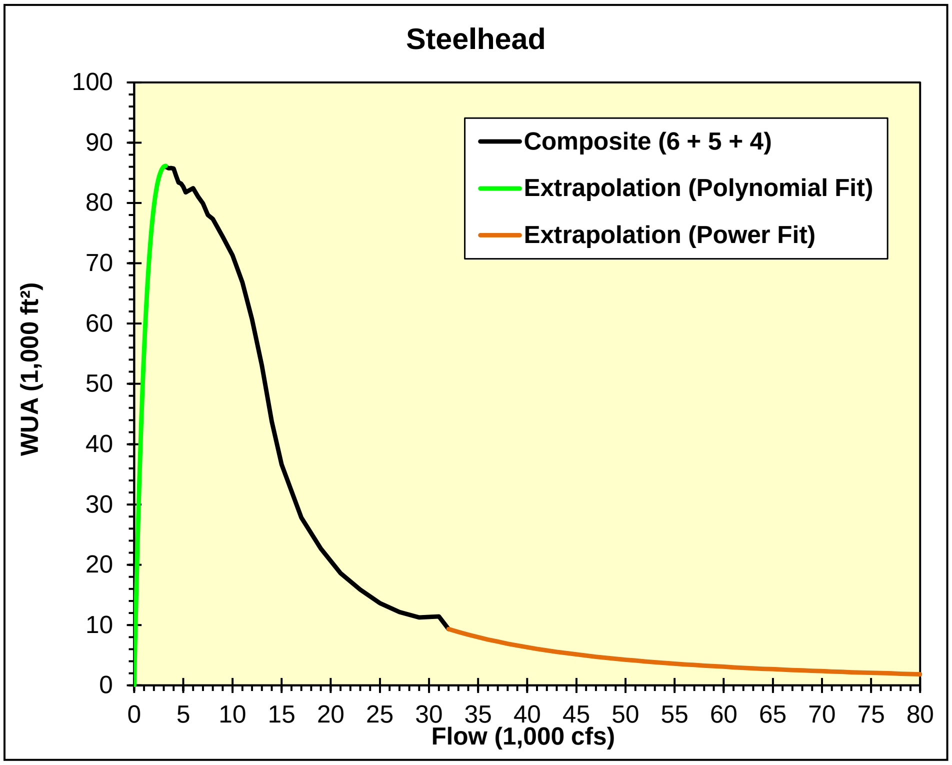

Figure 8. Final Relationship between the Composite WUA and Flow for Steelhead Spawning in the Upper Sacramento River.

To interpolate WUA values at simulated monthly flows higher than 31,000 cfs, a power function was fitted to the WUA values for the 10 highest flows in the composite WUA-flow relationship (Q = 14,000 cfs, 15,000 cfs, 17,000 cfs, 19,000 cfs, 21,000 cfs, 23,000 cfs, 25,000 cfs, 27,000 cfs, 29,000 cfs, and 31,000 cfs). The fitted power function was $\ln(WUA) = 27.424 - 1.762036 \times \ln(Q)$, which had a coefficient of determination $R^2 = 0.9808943$. The 33 WUA values extrapolated from the fitted polynomial and the 49 WUA values extrapolated from the fitted power function were combined with the 30 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for simulated monthly flows below Keswick Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 7**).

Table 7. Extrapolated Composite Spawning WUA-Flow Relationships for Steelhead in the Upper Sacramento River between Keswick Dam and the Confluence with Battle Creek.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,800	85,576	19,000	22,675	53,000	3,852
100	7,415	2,900	85,836	21,000	18,629	54,000	3,728
200	14,364	3,000	86,016	23,000	15,877	55,000	3,609
300	20,867	3,100	86,123	25,000	13,630	56,000	3,496
400	26,941	3,200	86,165	27,000	12,183	57,000	3,389
500	32,605	3,250	85,953	29,000	11,286	58,000	3,287
600	37,877	3,500	85,759	31,000	11,436	59,000	3,189
700	42,773	3,750	85,787	32,000	9,372	60,000	3,096
800	47,312	4,000	85,714	33,000	8,878	61,000	3,007
900	51,508	4,250	84,469	34,000	8,423	62,000	2,922
1,000	55,379	4,500	83,395	35,000	8,003	63,000	2,841
1,100	58,940	4,750	83,237	36,000	7,616	64,000	2,763
1,200	62,207	5,000	82,692	37,000	7,257	65,000	2,689
1,300	65,194	5,250	81,755	38,000	6,924	66,000	2,617
1,400	67,917	5,500	81,982	39,000	6,614	67,000	2,549
1,500	70,389	6,000	82,440	40,000	6,325	68,000	2,483
1,600	72,625	6,500	81,071	41,000	6,056	69,000	2,420
1,700	74,638	7,000	79,903	42,000	5,804	70,000	2,360
1,800	76,442	7,500	78,000	43,000	5,569	71,000	2,301
1,900	78,048	8,000	77,362	44,000	5,347	72,000	2,245
2,000	79,470	9,000	74,421	45,000	5,140	73,000	2,191
2,100	80,720	10,000	71,289	46,000	4,945	74,000	2,140
2,200	81,809	11,000	66,808	47,000	4,761	75,000	2,090
2,300	82,749	12,000	60,684	48,000	4,587	76,000	2,041
2,400	83,550	13,000	53,053	49,000	4,424	77,000	1,995
2,500	84,224	14,000	43,771	50,000	4,269	78,000	1,950
2,600	84,779	15,000	36,637	51,000	4,123	79,000	1,907
2,700	85,227	17,000	27,844	52,000	3,984	80,000	1,865

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

1.1.3 Feather River Spawning WUA Flow Relationships

The spawning WUA-flow relationships developed for the salmonid species spawning in the lower Feather River were obtained from DWR (2004). This IFIM study for the lower Feather River generated WUA-flow relationships for two reaches: (1) reach 1, typically referred to as the Feather River LFC; and (2) reach 2, typically referred to as the Feather River HFC (**Table 8**).

Table 8. Summary Description of the Feather River Reaches with WUA-Flow Relationships for Spawning Salmonids Developed by DWR (2004) and Locations for the Modeled Flows used in the Analysis of Spawning Habitat Availability.

Reach Number	Reach Description	Upper Limit (RM)	Lower Limit (RM)	Flow Site Location (CALSIM II node)
1	LFC from Fish Barrier Dam to Thermalito Afterbay Outlet	67.25	59	Feather River at Fish Barrier Dam (C200-A)
2	HFC from Thermalito Afterbay Outlet to the confluence with Honcut Creek	59	44	Feather River below Thermalito Afterbay (C203)

The WUA-flow relationships developed by DWR (2004) were based on the merging of IFIM data collected by DWR in 1992 and reviewed in TRPA (2002), with new depth, velocity, substrate, and cover data collected along supplemental PHABSIM cross-section transects in 2002 and 2003, the calibration of revised PHABSIM computer models, and the updating of habitat suitability index (HSI) curves for spawning Chinook salmon and steelhead.

1.1.3.1 Chinook Salmon

The WUA-flow relationships developed for spawning Chinook salmon (**Figure 9**) were based on HSI curves obtained from depth and velocity data collected on 212 Chinook salmon redds measured in October 1991, and on 205 Chinook salmon redds measured in the fall of 1995, and an additional 200 measurements of depth and velocity taken at “unoccupied” locations to represent the “availability” of habitat conditions that were not chosen by spawners. Substrate habitat suitability criteria for the analysis were created from the October 1991 data because substrate data were not collected in 1995. Because DWR (2004) did not presented separate WUA-flow relationships for spawning fall-run and spring-run Chinook salmon, the current assessment of flow-dependent spawning habitat availability used the WUA-flow relationships in Figure 9 for both fall-run and spring-run Chinook salmon spawning in the lower Feather River.

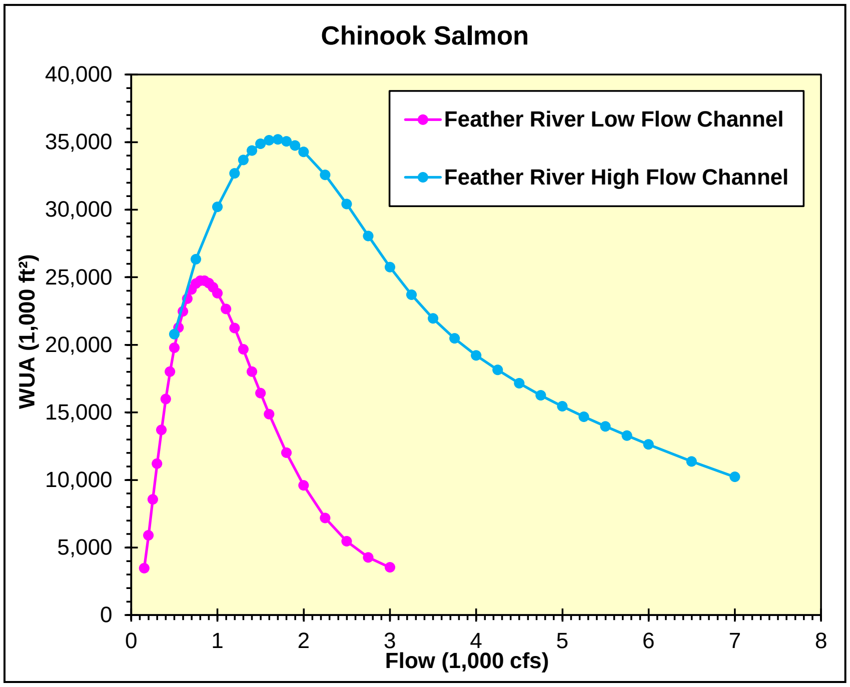

Figure 9. Relationship between Chinook Salmon Spawning WUA and Flow for the Two Study Reaches in the Lower Feather River Extending from the Fish Barrier Dam to the Confluence with Honcut Creek.

The WUA-flow relationship developed for the LFC, indicated as connected pink circles in Figure 9, has a maximum WUA value of 24,741,090 ft² corresponding to a flow Q = 850 cfs. This maximum WUA value corresponds to the denominator $\max\left(WUA_l\left(Q\right)\right)$ in formula 4 that is used to scale the composite annual spawning WUA index. The WUA-flow relationship has 30 data points corresponding to flows ranging from 150 cfs through 3,000 cfs at increasing steps of 50 cfs, 100 cfs, 200 cfs, and 250 cfs. These data points were used for the direct linear interpolation of WUA values at simulated monthly flows $Q_{m,Y}$ immediately downstream of the Fish Barrier Dam (CALSIM II node C203) with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

The WUA-flow relationship developed for the HFC, indicated as connected blue circles in Figure 9, has a maximum WUA value of 35,198,090 ft² corresponding to a flow Q = 1,700 cfs. This maximum WUA value corresponds to the denominator $\max\left(WUA_h\left(Q\right)\right)$ in formula 4 and is also used to scale the composite annual spawning WUA index. The HFC WUA-flow relationship also has 30 data points corresponding to flows ranging from 500 cfs through 7,000 cfs at increasing steps of 100 cfs, 200 cfs, 250 cfs, and 500 cfs. These data points were used for the direct linear interpolation of WUA values at simulated monthly flows $Q_{m,Y}$ immediately downstream of the Thermalito Afterbay (CALSIM II node C200-A) with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

To interpolate WUA values at simulated monthly flows lower than 150 cfs in the LFC and lower than 500 cfs in the HFC, two polynomial functions were fitted to some of the WUA values of the WUA-flow relationships illustrated in Figure 9. To interpolate WUA values at simulated monthly flows lower than

150 cfs in the LFC, the polynomial function was fitted to the 14 lowest flows in the LFC WUA-flow relationship (the flows ranging from Q = 150 cfs to Q = 800 cfs). The equation of the fitted polynomial was $WUA = -1.618 \times Q + 0.223482 \times Q^2 - 3.70 \times 10^{-4} \times Q^3 + 1.77 \times 10^{-7} \times Q^4$, which had a coefficient of determination $R^2 = 0.9999756$. The polynomial equation was used to generate 15 extrapolated WUA values for flows ranging from Q = 0 cfs to Q = 140 cfs in increasing steps of 10 cfs, which were used to interpolate WUA values at simulated monthly flows lower than 150 cfs. These extrapolated WUA values are plotted as a green line in **Figure 10**.

To interpolate WUA values at simulated monthly flows lower than 500 cfs in the HFC, the polynomial function was fitted to the 14 lowest flows in the HFC WUA-flow relationship (the flows ranging from Q = 500 cfs through Q = 2,500 cfs). The equation of the fitted polynomial was $WUA = 54.074 \times Q - 0.030685 \times Q^2 + 8.41 \times 10^{-6} \times Q^3 - 1.14 \times 10^{-9} \times Q^4$, which had a coefficient of determination $R^2 = 0.9999505$. The polynomial equation was used to generate 50 extrapolated WUA values for flows ranging from Q = 0 cfs to Q = 490 cfs in increasing steps of 10 cfs, which were used to interpolate WUA values at simulated monthly flows lower than 500 cfs. These extrapolated WUA values also are plotted as a green line in Figure 10.

Because flows in the LFC rarely exceed 800 cfs, it was not necessary for this analysis to obtain WUA values for flows greater than the 3,000-cfs upper limit of the LFC WUA-flow relationship. By contrast, flows in the HFC do exceed the upper limit of the HFC WUA-flow relationship. To interpolate WUA values at simulated monthly flows higher than 7,000 cfs in the HFC, an exponential function was fitted to the WUA values for the 10 highest flows in the HFC WUA-flow relationship (the flows ranging from Q = 4,250 cfs to Q = 7,000 cfs). The fitted exponential function was $\ln(WUA) = 10.680 - 0.000207 \times Q$, which had a coefficient of determination $R^2 = 0.9998532$. The regression equation was then used to generate 70 extrapolated WUA values for Q ranging from 7,500 cfs through 42,000 cfs in increasing steps of 500 cfs, which were used to interpolate WUA values at simulated monthly flows greater than 31,000 cfs (orange line in Figure 10).

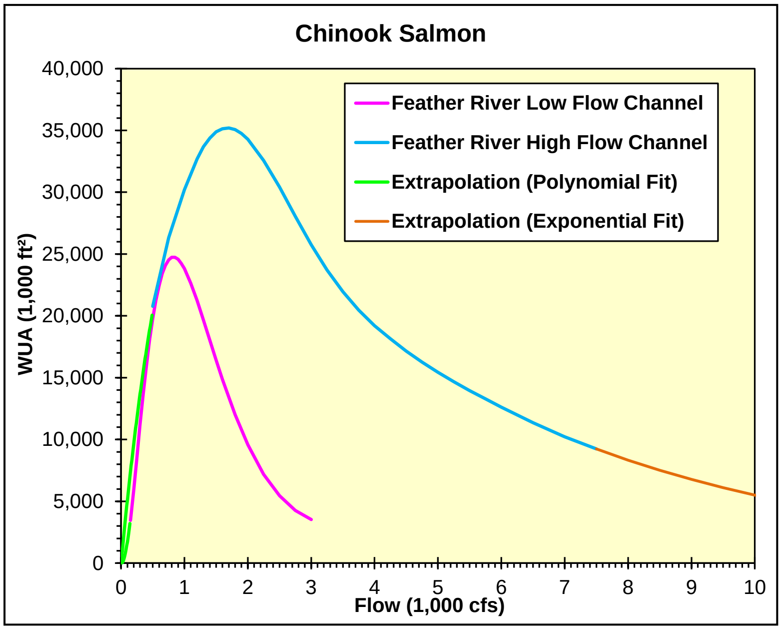

Figure 10. Final Relationship between the Composite WUA and Flow for Chinook Salmon Spawning in the LFC and HFC of the Lower Feather River.

The 15 WUA values extrapolated from the fitted polynomial were combined with the 30 values of the original LFC WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for simulated monthly flows immediately downstream of the Fish Barrier Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 9**). Similarly, the 50 WUA values extrapolated from the fitted polynomial and the 70 WUA values extrapolated from the fitted exponential function were combined with the 30 values of the original HFC WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for simulated monthly flows immediately downstream of the Thermalito Afterbay with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 10**).

Table 9. Extrapolated Spawning WUA-Flow Relationships for Chinook Salmon in the Lower Feather River between the Fish Barrier Dam and the Thermalito Afterbay Outlet.

Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)
0	0	150	3,460.980	900	24,567.120
10	5.799	200	5,903.400	950	24,248.470
20	54.098	250	8,565.240	1,000	23,821.070
30	142.743	300	11,197.250	1,100	22,655.140
40	269.619	350	13,691.620	1,200	21,237.340
50	432.654	400	15,979.160	1,300	19,662.700
60	629.821	450	18,011.420	1,400	18,012.660
70	859.132	500	19,778.950	1,500	16,416.190
80	1,118.644	550	21,271.740	1,600	14,861.290
90	1,406.456	600	22,472.430	1,800	12,004.900
100	1,720.710	650	23,416.740	2,000	9,588.350
110	2,059.588	700	24,090.230	2,250	7,178.580
120	2,421.317	750	24,525.810	2,500	5,454.150
130	2,804.166	800	24,736.140	2,750	4,264.050
140	3,206.446	850	24,741.090	3,000	3,523.410

WUA values obtained through extrapolation using a polynomial function (see text for details).

Table 10. Extrapolated Spawning WUA-Flow Relationships for Chinook Salmon in the Lower Feather River between the Thermalito Afterbay Outlet and the Confluence with Honcut Creek.

Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)
0	0	380	16,555.081	5,750	13,282.640	24,500	275.529
10	537.682	390	16,894.352	6,000	12,622.640	25,000	248.488
20	1,069.277	400	17,229.246	6,500	11,366.810	25,500	224.101
30	1,594.835	410	17,559.803	7,000	10,224.170	26,000	202.107
40	2,114.406	420	17,886.062	7,500	9,235.643	26,500	182.272
50	2,628.041	430	18,208.062	8,000	8,329.240	27,000	164.384
60	3,135.787	440	18,525.842	8,500	7,511.793	27,500	148.251
70	3,637.694	450	18,839.440	9,000	6,774.572	28,000	133.701
80	4,133.811	460	19,148.896	9,500	6,109.703	28,500	120.579
90	4,624.185	470	19,454.246	10,000	5,510.085	29,000	108.746
100	5,108.866	480	19,755.529	10,500	4,969.315	29,500	98.073
110	5,587.901	490	20,052.782	11,000	4,481.617	30,000	88.448
120	6,061.338	500	20,780.100	11,500	4,041.783	30,500	79.768
130	6,529.223	750	26,322.670	12,000	3,645.115	31,000	71.939
140	6,991.605	1,000	30,204.290	12,500	3,287.377	31,500	64.879
150	7,448.529	1,200	32,691.770	13,000	2,964.748	32,000	58.511
160	7,900.042	1,300	33,679.540	13,500	2,673.782	32,500	52.769
170	8,346.192	1,400	34,378.390	14,000	2,411.372	33,000	47.590
180	8,787.022	1,500	34,878.890	14,500	2,174.716	33,500	42.920
190	9,222.580	1,600	35,137.160	15,000	1,961.285	34,000	38.707
200	9,652.910	1,700	35,198.090	15,500	1,768.801	34,500	34.909
210	10,078.058	1,800	35,058.990	16,000	1,595.207	35,000	31.483
220	10,498.068	1,900	34,748.930	16,500	1,438.651	35,500	28.393
230	10,912.986	2,000	34,278.830	17,000	1,297.459	36,000	25.606
240	11,322.855	2,250	32,571.050	17,500	1,170.124	36,500	23.093
250	11,727.719	2,500	30,408.820	18,000	1,055.286	37,000	20.827
260	12,127.623	2,750	28,051.660	18,500	951.718	37,500	18.783
270	12,522.610	3,000	25,750.770	19,000	858.315	38,000	16.939
280	12,912.722	3,250	23,704.410	19,500	774.078	38,500	15.277
290	13,298.003	3,500	21,947.580	20,000	698.109	39,000	13.778
300	13,678.496	3,750	20,471.850	20,500	629.595	39,500	12.426
310	14,054.242	4,000	19,214.760	21,000	567.805	40,000	11.206
320	14,425.285	4,250	18,140.940	21,500	512.080	40,500	10.106
330	14,791.665	4,500	17,155.790	22,000	461.823	41,000	9.114
340	15,153.425	4,750	16,256.150	22,500	416.499	41,500	8.220
350	15,510.606	5,000	15,441.510	23,000	375.623	42,000	7.413
360	15,863.248	5,250	14,676.420	23,500	338.759		
370	16,211.393	5,500	13,960.600	24,000	305.512		

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using an exponential function (see text for details).

1.1.3.2 Steelhead

The spawning WUA-flow relationships developed for steelhead (**Figure 11**) were based on HSI curves obtained from depth, velocity, and substrate data collected on 76 steelhead redds in the late winter of 2002 (DWR 2003).

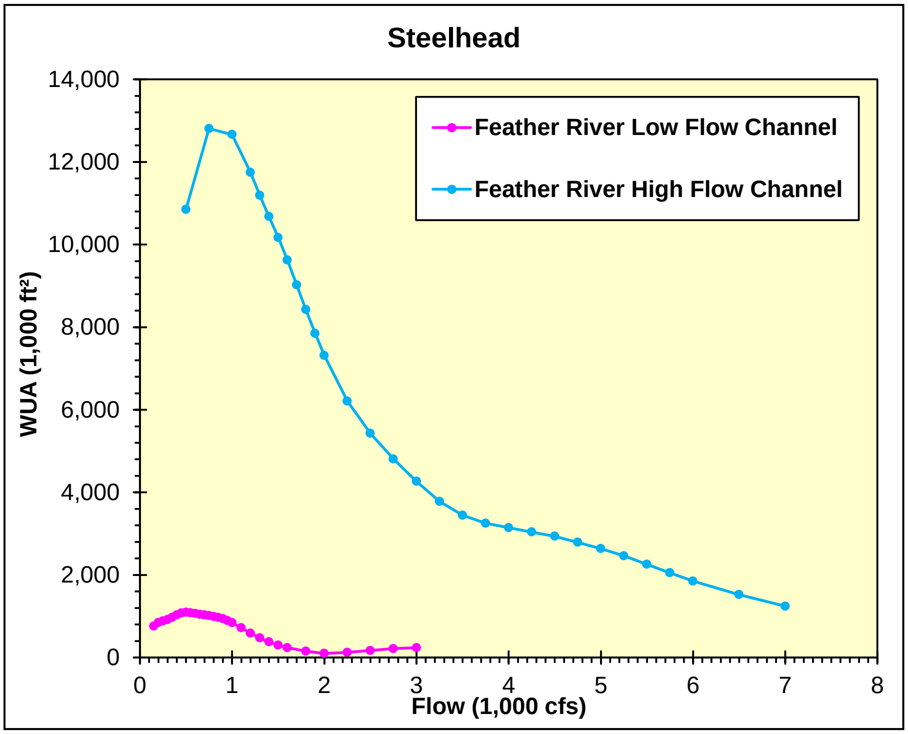

Figure 11. Relationship between Steelhead Spawning Habitat Availability (Expressed as WUA) and Flow for the Two Study Reaches in the Lower Feather River Extending from the Fish Barrier Dam to the Confluence with Honcut Creek.

The spawning WUA-flow relationship developed for the LFC (indicated as connected pink circles in Figure 11) has a maximum WUA value of 1,092,780 ft², corresponding to a flow Q = 500 cfs. The WUA-flow relationship has 30 data points corresponding to flows ranging from 150 cfs through 3,000 cfs at increasing steps of 50 cfs, 100 cfs, 200 cfs, and 250 cfs. These data points were used for the direct linear interpolation of WUA values at simulated monthly flows $Q_{m,Y}$ immediately downstream of the Fish Barrier Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

The WUA-flow relationship developed for the HFC (indicated as connected blue circles in Figure 11) has a maximum WUA value of 12,808,710 ft², corresponding to a flow Q = 750 cfs. The HFC WUA-flow relationship also has 30 data points corresponding to flows ranging from 500 cfs through 7,000 cfs at increasing steps of 100 cfs, 200 cfs, 250 cfs, and 500 cfs. These data points were used for the direct linear interpolation of WUA values at simulated monthly flows $Q_{m,Y}$ immediately downstream of the Thermalito After Bay with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

To interpolate WUA values at simulated monthly flows lower than 150 cfs in the LFC and lower than 500 cfs in the HFC, two polynomial functions were fitted to some of the WUA values of the WUA-flow relationships illustrated in Figure 11. To interpolate WUA values at simulated monthly flows lower than 150 cfs in the LFC, the polynomial function was fitted to the eight lowest flows in the LFC WUA-flow relationship (the flows ranging from Q = 150 cfs to Q = 500 cfs). The equation of the fitted polynomial was $WUA = 9.915 \times Q - 0.044882 \times Q^2 + 9.61 \times 10^{-5} \times Q^3 - 7.44 \times 10^{-8} \times Q^4$, which had a coefficient of determination $R^2 = 0.9999744$. The polynomial equation was used to generate 15 extrapolated WUA values for flows ranging from $Q = 0$ cfs to $Q = 140$ cfs in increasing steps of 10 cfs, which were used to interpolate target monthly flows lower than 150 cfs. These extrapolated WUA values are plotted as a green line in **Figure 12**.

To interpolate WUA values at simulated monthly flows lower than 500 cfs in the HFC, the polynomial function was fitted to the 14 lowest flows in the HFC WUA-flow relationship (the flows ranging from $Q = 500$ cfs through $Q = 2{,}500$ cfs). The equation of the fitted polynomial was $WUA = 36.317 \times Q - 0.033980 \times Q^2 + 1.16 \times 10^{-5} \times Q^3 - 1.40 \times 10^{-9} \times Q^4$, which had a coefficient of determination $R^2 = 0.9998986$. The polynomial equation was used to generate 50 extrapolated WUA values for flows ranging from $Q = 0$ cfs to $Q = 490$ cfs in increasing steps of 10 cfs, which were used to interpolate WUA values at target monthly flows lower than 500 cfs. These extrapolated WUA values also are plotted as a green line in Figure 12.

To interpolate WUA values at simulated monthly flows higher than 7,000 cfs in the HFC, an exponential function was fitted to the WUA values for the six highest flows in the HFC WUA-flow relationship (the flows ranging from $Q = 5{,}250$ cfs to $Q = 7{,}000$ cfs). The fitted exponential function was $\ln(WUA) = 9.879 - 0.000393 \times Q$, which had a coefficient of determination $R^2 = 0.9996391$. The regression equation was then used to generate 70 extrapolated WUA values for Q ranging from 7,500 cfs through 42,000 cfs in increasing steps of 500 cfs, which were used to interpolate target monthly flows greater than 31,000 cfs (orange line in Figure 12).

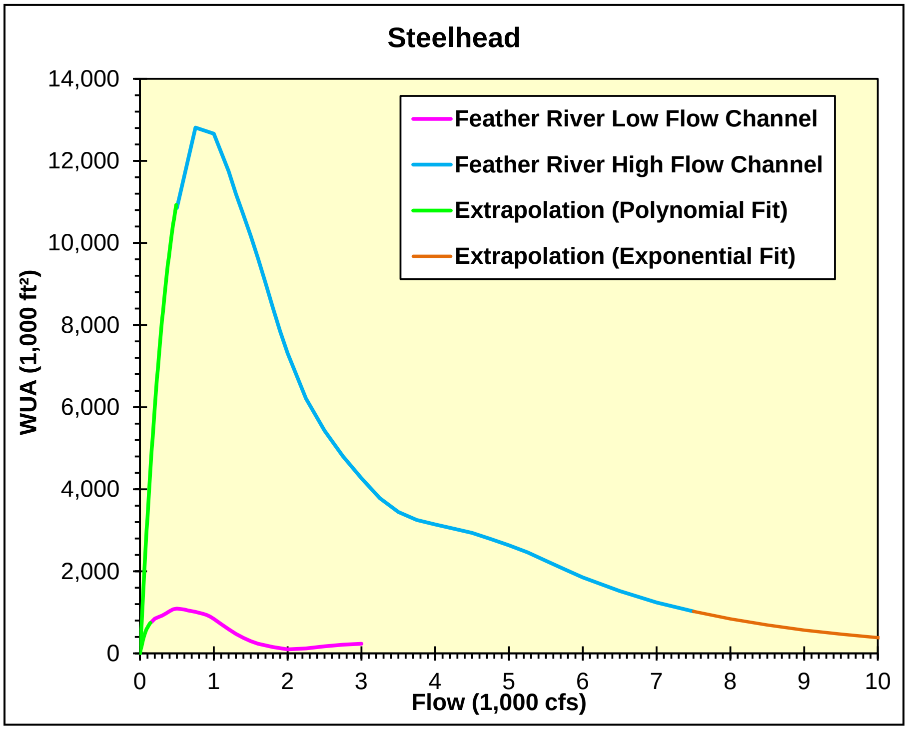

Figure 12. Final Relationship between the Composite WUA and Flow for Steelhead Spawning in the LFC and HFC of the Lower Feather River.

The 15 WUA values extrapolated from the fitted polynomial were combined with the 30 values of the original LFC WUA-flow relationship into a look-up table used for the linear interpolation of steelhead WUA values for simulated monthly flows immediately downstream of the Fish Barrier Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 11**). Similarly, the 50 WUA values extrapolated from the fitted polynomial and the 70 WUA values extrapolated from the fitted exponential function were combined with the 30 values of the original HFC WUA-flow relationship into a look-up table used for the linear interpolation of steelhead WUA values for simulated monthly flows immediately downstream of the Thermalito Afterbay with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 12**).

Table 11. Extrapolated Spawning WUA-Flow Relationship for Steelhead in the Lower Feather River between the Fish Barrier Dam and the Thermalito Afterbay Outlet.

Flow (cfs)	WUA (1,000 ft^2)	Flow (cfs)	WUA (1,000 ft^2)	Flow (cfs)	WUA (1,000 ft^2)
0	0	150	757.810	900	939.150
10	94.756	200	846.400	950	897.040
20	181.102	250	884.980	1,000	841.560
30	259.587	300	919.660	1,100	718.450
40	330.742	350	971.890	1,200	591.180
50	395.082	400	1,031.790	1,300	474.000
60	453.103	450	1,075.030	1,400	378.050
70	505.282	500	1,092.780	1,500	300.270
80	552.080	550	1,084.020	1,600	238.510
90	593.939	600	1,067.460	1,800	154.680
100	631.285	650	1,044.300	2,000	100.720
110	664.522	700	1,031.830	2,250	124.360
120	694.041	750	1,013.030	2,500	171.570
130	720.213	800	989.930	2,750	215.650
140	743.389	850	966.920	3,000	237.410

(Yellow shading:) WUA values obtained through extrapolation using a polynomial function (see text for details).

Table 12. Extrapolated Spawning WUA-Flow Relationships for Steelhead in the Lower Feather River between the Thermalito Afterbay Outlet and the Confluence with Honcut Creek.

Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)	Flow (cfs)	WUA (1,000 ft²)
0	0	380	9,502.383	5,750	2,051.450	24,500	1.292
10	359.785	390	9,652.399	6,000	1,851.590	25,000	1.062
20	712.844	400	9,798.083	6,500	1,523.520	25,500	0.873
30	1,059.246	410	9,939.492	7,000	1,243.430	26,000	0.717
40	1,399.059	420	10,076.682	7,500	1,026.058	26,500	0.589
50	1,732.353	430	10,209.709	8,000	843.107	27,000	0.484
60	2,059.195	440	10,338.628	8,500	692.778	27,500	0.398
70	2,379.653	450	10,463.494	9,000	569.253	28,000	0.327
80	2,693.795	460	10,584.362	9,500	467.752	28,500	0.269
90	3,001.689	470	10,701.287	10,000	384.350	29,000	0.221
100	3,303.400	480	10,814.323	10,500	315.819	29,500	0.181
110	3,598.996	490	10,923.523	11,000	259.507	30,000	0.149
120	3,888.543	500	10,852.180	11,500	213.236	30,500	0.122
130	4,172.107	750	12,808.710	12,000	175.215	31,000	0.101
140	4,449.752	1,000	12,663.550	12,500	143.973	31,500	0.083
150	4,721.545	1,200	11,745.270	13,000	118.302	32,000	0.068
160	4,987.550	1,300	11,191.230	13,500	97.209	32,500	0.056
170	5,247.832	1,400	10,678.780	14,000	79.876	33,000	0.046
180	5,502.454	1,500	10,170.320	14,500	65.634	33,500	0.038
190	5,751.482	1,600	9,623.500	15,000	53.931	34,000	0.031
200	5,994.977	1,700	9,023.130	15,500	44.315	34,500	0.025
210	6,233.004	1,800	8,424.520	16,000	36.413	35,000	0.021
220	6,465.626	1,900	7,847.810	16,500	29.921	35,500	0.017
230	6,692.904	2,000	7,313.430	17,000	24.586	36,000	0.014
240	6,914.901	2,250	6,209.280	17,500	20.202	36,500	0.012
250	7,131.680	2,500	5,428.120	18,000	16.600	37,000	0.010
260	7,343.300	2,750	4,806.330	18,500	13.640	37,500	0.008
270	7,549.824	3,000	4,264.650	19,000	11.208	38,000	0.006
280	7,751.313	3,250	3,780.190	19,500	9.210	38,500	0.005
290	7,947.826	3,500	3,445.820	20,000	7.567	39,000	0.004
300	8,139.424	3,750	3,251.770	20,500	6.218	39,500	0.004
310	8,326.168	4,000	3,142.870	21,000	5.109	40,000	0.003
320	8,508.115	4,250	3,037.770	21,500	4.198	40,500	0.002
330	8,685.327	4,500	2,936.170	22,000	3.450	41,000	0.002
340	8,857.860	4,750	2,788.390	22,500	2.835	41,500	0.002
350	9,025.775	5,000	2,636.030	23,000	2.329	42,000	0.001
360	9,189.128	5,250	2,464.440	23,500	1.914		
370	9,347.978	5,500	2,256.520	24,000	1.573		

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using an exponential function (see text for details).

1.1.4 Temporal Weighting Coefficients

Because CWUAY in formulae 1, 2, 3, and 4 is a scaled composite WUAs for species/runs spawning over various months of their spawning season, and because the species/run-specific spawning intensity does not remain constant throughout the spawning season, the temporal weighting coefficients wm were incorporated into the formulae to account for the expected relative spawning intensity in each month of the assumed species/run-specific spawning period. Each wm is a proportion with a value between 0 and 1, so that, for a given species/run, the sum over the assumed spawning period of the species/run is equal to 1.

1.1.4.1 Upper Sacramento River

The spawning periods and associated temporal weighting coefficients applied to steelhead and the three Chinook salmon runs in the upper Sacramento River were derived from the information on spawning timing and intensity presented in Table 2.7 of the *Design and Guidelines to the Sacramento River Ecological Flows Tool (SacEFT)* (ESSA Technologies, Ltd. 2010), which was used in the assessment of Sacramento River salmonid spawning WUA in the 2013 Draft EIR/EIS of the Bay Delta Conservation Plan (BDCP) (ICF International 2013). In Table 2.7 of ESSA Technologies, Ltd. (2010), the year is divided in half-month intervals, with the spawning periods for steelhead and Chinook runs highlighted in two colors. Time intervals marked with a dark color denote the period between the 25th and 75th percentiles, when half the spawning occurs. The information in Table 2.7 of ESSA Technologies, Ltd. (2010) was reportedly based on documentation for SALMOD (Bartholow and Heasley 2006), which was reportedly based on Vogel and Marine (1991).

For the purpose of this analysis, the monthly weighting coefficients (w_m) were calculated by apportioning the number of days in the spawning month to the number of days in the periods with the spawning proportions of 0.25, 0.5, and 0.25 identified in ESSA Technologies, Ltd. (2010).

For winter-run Chinook salmon (**Table 13**), the spawning period extends from March 1 through August 15, and, according to ESSA Technologies, Ltd. (2010), half of the spawning occurs from May 16 through June 15, while 25 percent of the spawning occurs from March 1 through May 15, and 25 percent occurs from June 16 through August 15. Consistent with these proportions, the monthly weighting coefficient for March was calculated as the product of the spawning proportion assigned to the period March 1 through May 15 (0.25) and the ratio between the 31 days of March and the 76 days in the period of March 1 through May 15. Similarly, the monthly weighting coefficient for April was calculated as the product of the spawning proportion assigned to the period of March 1 through May 15 (0.25) and the ratio between the 30 days of April and the 76 days in the period March 1 through May 15.

The calculations for the May and June weighting coefficients are slightly different because May and June are split between periods with spawning proportions of 0.25 and 0.5. For May, the monthly weighting coefficient was calculated as the product of 0.25 and the ratio between the 15 days of May and the 76 days in the period of March 1 through May 15, plus the product of 0.5 and the ratio between the 16 days of May in the May 16 – June 15 period and the 31 days in the period. For June, the monthly weighting coefficient was calculated as the product of 0.5 and the ratio between the 15 days of June and the 31 days in the period May 16 through June 15, plus the product of 0.25 and the ratio between the 15 days of June in the June 16 – August 15 period and the 61 days in the period.

Similar calculations as described for winter-run Chinook salmon, above, were performed for fall-run Chinook salmon, late fall-run Chinook salmon, and steelhead. The resulting weighting coefficients are displayed in **Table 14** (fall-run Chinook salmon), **Table 15** (late fall-run Chinook salmon), and **Table 16** (steelhead).

Table 13. Monthly Weighting Coefficients for Winter-run Chinook Salmon Spawning in the Rpper Sacramento River.

<table>
<tr><th>Month</th><th>Days</th><th>Overall Weighting</th><th>Monthly Weighting</th></tr>
<tr><td rowspan="2">Mar</td><td>15</td><td rowspan="5">0.25</td><td rowspan="2">0.101974</td></tr>
<tr><td>16</td></tr>
<tr><td rowspan="2">Apr</td><td>15</td><td rowspan="2">0.098684</td></tr>
<tr><td>15</td></tr>
<tr><td rowspan="2">May</td><td>15</td><td rowspan="2">0.307407</td></tr>
<tr><td>16</td><td rowspan="2">0.5</td></tr>
<tr><td rowspan="2">Jun</td><td>15</td><td rowspan="2">0.303411</td></tr>
<tr><td>15</td><td rowspan="4">0.25</td></tr>
<tr><td rowspan="2">Jul</td><td>15</td><td rowspan="2">0.127049</td></tr>
<tr><td>16</td></tr>
<tr><td rowspan="2">Aug</td><td>15</td><td rowspan="2">0.061475</td></tr>
<tr><td>16</td><td></td></tr>
<tr><td>Totals</td><td>184</td><td>1</td><td>1</td></tr>
</table>

Table 14. Monthly Weighting Coefficients for Fall-run Chinook Salmon Spawning in the Upper Sacramento River.

Month	Days	Overall Weighting	Monthly Weighting
Oct	15 16	0.25	0.250000
Nov	15 15	0.5	0.500000
Dec	15 16	0.25	0.250000
Totals	**92**	**1**	**1**

Table 15. Monthly Weighting Coefficients for Late Fall-run Chinook Salmon Spawning in the Upper Sacramento River.

Month	Days	Overall Weighting	Monthly Weighting
Jan	15	0.25	0.508065
	16	0.5	
Feb	15		0.297020
	13	0.25	
Mar	15		0.131356
	16		
Apr	15		0.063559
	15		
Totals	**120**	**1**	**1**

Table 16. Monthly Weighting Coefficients for Steelhead Spawning in the Upper Sacramento River.

Month	Days	Overall Weighting	Monthly Weighting
Nov	15		0.081522
	15	0.25	
Dec	15		0.168478
	16		
Jan	15	0.5	0.172222
	16		
Feb	15		0.155556
	13		
Mar	15		0.172222
	16		
Apr	15	0.25	0.166667
	15		
May	15		0.083333
	16		
Totals	**212**	**1**	**1**

1.1.4.2 Feather River

Information on the relative intensity of spawning during the spawning periods of Feather River salmonids was not available at the time of this analysis. Therefore, the monthly weighting coefficients (w_m) used in this analysis of flow-dependent habitat availability were calculated by simply apportioning the number of days in the spawning month to the total number of days in the assumed spawning periods of Feather River salmonid species.

The monthly weighting coefficients for fall-run Chinook salmon (**Table 17**) were calculated by dividing the number of days of each spawning month by the 92 days of the October-through-December spawning period. Similar calculations were used to calculate monthly weighting coefficients for spring-run Chinook salmon, based on a spawning period of September and October (a total of 61 days), and for steelhead, based on a spawning period of January 1 through April 30 (a total of 120 days) (Table 17).

Table 17. Monthly Weighting Coefficients for Spring-run and Fall-run Chinook Salmon and Steelhead Spawning in the Lower Feather River.

Species and run		Chinook Salmon Spawning				Steelhead Spawning	
		Spring-run		Fall-run			
Month	Days	Period	Monthly Weighting	Period	Monthly Weighting	Period	Monthly Weighting
Sep	30		0.491803		0		0
Oct	31		0.508197		0.336957		0
Nov	30		0		0.326087		0
Dec	31		0		0.336957		0
Jan	31		0		0		0.258333
Feb	28		0		0		0.233333
Mar	31		0		0		0.258333
Apr	30		0		0		0.250000
May	31		0		0		0
Jun	30		0		0		0
Jul	31		0		0		0
Aug	31		0		0		0
Totals	**365**		**1**		**1**		**1**

1.1.5 Spatial Weighting Coefficient

Annual Chinook salmon carcass survey data are available for the lower Feather River from 2000 through 2014 and include whether each carcass was observed in the LFC or the HFC (DWR, no date). USACE's examination of the Chinook salmon carcass data suggests that the majority of Chinook salmon spawning in the lower Feather River occurs in the upstream LFC. Chinook salmon carcasses cannot be identified as spring-run or fall-run. However, as an indicator of phenotypic spring-run Chinook salmon, USACE complied all Chinook salmon carcasses observed from the beginning of the annual carcass survey period through the end of the expected phenotypic spring-run Chinook salmon spawning period (October 15) to estimate the proportion of spring-run Chinook salmon spawning in the LFC and HFC over the period of record (2000 through 2014). As shown in **Table 18**, the vast majority of expected phenotypic spring-run Chinook salmon (an annual average of about 95 percent) spawned in the LFC.

As an indicator of phenotypic fall-run Chinook salmon, USACE complied all Chinook salmon carcasses observed from the beginning of the expected fall-run Chinook salmon spawning period (October 1) through the end of the annual carcass surveys to estimate the proportion of fall-run Chinook salmon spawning in the LFC and HFC over the period of record. Most of the phenotypic fall-run Chinook salmon (an annual average of about 85 percent) spawned in the LFC (**Table 19**).

Because of the vast difference in spatial utilization of both spring-run and fall-run Chinook salmon in the lower Feather River, the scaled composite annual spawning WUA index ($CWUA_Y$) for spring-run and fall-run Chinook salmon (formula 4) incorporate the spatial weighting coefficients w_l and w_h for the Feather River LFC and HFC to account for the marked different in utilization between the LFC and HFC. The coefficients w_l (for the LFC) and w_h (for the HFC) integrate both the relative importance of the reach in terms of maximum achievable WUA and the relative use of the reach by the species as the average proportion of carcasses found in the reach during the 2000–2014 carcass surveys.

Table 18. Number and Proportions of Chinook Salmon Carcasses Collected in the Feather River LFC and HFC from the Beginning of the Annual Carcass Survey through October 15, as an Indicator of Phenotypic Spring-run Chinook Salmon Spawning.

Chinook salmon carcasses by reach collected through October 15				
Reach	LFC		HFC	
Year	No. of fish	Proportion	No. of fish	Proportion
2000	2,252	0.9128	215	0.0872
2001	1,776	0.9197	155	0.0803
2002	2,396	0.9370	161	0.0630
2003	2,393	0.9165	218	0.0835
2004	1,589	0.9190	140	0.0810
2005	1,424	0.9551	67	0.0449
2006	1,938	0.9094	193	0.0906
2007	1,177	0.9800	24	0.0200
2008	312	0.9873	4	0.0127
2009	161	0.9938	1	0.0062
2010	644	0.9802	13	0.0198
2011	1,983	0.9759	49	0.0241
2012	1,794	0.9819	33	0.0181
2013	3,926	0.9023	425	0.0977
2014	2,063	0.9318	151	0.0682
Averages	u_l	**0.9469**	u_h	**0.0531**

Table 19. Number and Proportions of Chinook Salmon Carcasses Collected in the Feather River LFC and HFC from October 1 through the End of the Annual Carcass Surveys, as an Indicator of Phenotypic Fall-run Chinook Salmon Spawning.

Chinook salmon carcasses by reach collected from October 1				
Reach	**LFC**		**HFC**	
Year	**No. of fish**	**Proportion**	**No. of fish**	**Proportion**
2000	4,695	0.8512	821	0.1488
2001	3,820	0.8104	894	0.1896
2002	3,529	0.7883	948	0.2117
2003	3,112	0.6811	1,457	0.3189
2004	2,331	0.7113	946	0.2887
2005	2,821	0.8232	606	0.1768
2006	2,665	0.8533	458	0.1467
2007	1,191	0.9233	99	0.0767
2008	534	0.9303	40	0.0697
2009	261	0.9223	22	0.0777
2010	2,276	0.9366	154	0.0634
2011	6,085	0.9152	564	0.0848
2012	6,707	0.9391	435	0.0609
2013	7,083	0.8621	1,133	0.1379
2014	3,804	0.8349	752	0.1651
Averages	u_l	**0.8522**	u_h	**0.1478**

The spatial coefficient for the LFC (w_l) was computed as:

$$w_l = \frac{\dfrac{\max\left(WUA_l(Q)\right)}{\max\left(WUA_l(Q)\right)+\max\left(WUA_h(Q)\right)} \times u_l}{\dfrac{\max\left(WUA_l(Q)\right)}{\max\left(WUA_l(Q)\right)+\max\left(WUA_h(Q)\right)} \times u_l + \dfrac{\max\left(WUA_h(Q)\right)}{\max\left(WUA_l(Q)\right)+\max\left(WUA_h(Q)\right)} \times u_h}.$$

The coefficients u_l and u_h are the average proportions of carcasses found in each reach during the 2000–2014 carcass surveys displayed in Table 18 for spring-run Chinook salmon and in Table 19 for fall-run Chinook salmon. Similarly, the spatial coefficient for the HFC (w_h) was computed as:

$$w_h = \frac{\frac{\max\left(WUA_h\left(Q\right)\right)}{\max\left(WUA_l\left(Q\right)\right)+\max\left(WUA_h\left(Q\right)\right)}\times u_h}{\frac{\max\left(WUA_l\left(Q\right)\right)}{\max\left(WUA_l\left(Q\right)\right)+\max\left(WUA_h\left(Q\right)\right)}\times u_l+\frac{\max\left(WUA_h\left(Q\right)\right)}{\max\left(WUA_l\left(Q\right)\right)+\max\left(WUA_h\left(Q\right)\right)}\times u_h}.$$

Replacing the specific values of maximum WUA, u_l and u_h, the spatial coefficient for spring-run Chinook salmon spawning in the LFC (w_l) becomes:

$$w_l = \frac{\frac{24,741}{24,741+35,198}\times 0.9469}{\frac{24,741}{24,741+35,198}\times 0.9469+\frac{35,198}{24,741+35,198}\times 0.0531} = \frac{0.4128\times 0.9469}{0.4128\times 0.9469+0.5872\times 0.0531} = 0.9261, \text{ while}$$

the spatial coefficient in the HFC becomes: $w_h = \frac{0.5872\times 0.0531}{0.4128\times 0.9469+0.5872\times 0.0531} = 0.0739$.

Similarly, the spatial coefficient for fall-run Chinook salmon spawning in the LFC (w_l) becomes:

$$w_l = \frac{\frac{24,741}{24,741+35,198}\times 0.8522}{\frac{24,741}{24,741+35,198}\times 0.8522+\frac{35,198}{24,741+35,198}\times 0.1478} = \frac{0.4128\times 0.8522}{0.4128\times 0.8522+0.5872\times 0.1478} = 0.8021, \text{ while}$$

the spatial coefficient in the HFC becomes: $w_h = \frac{0.5872\times 0.1478}{0.4128\times 0.8522+0.5872\times 0.1478} = 0.1979$.

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Appendix 7E

1.1 Analysis of Spawning Weighted Usable Area for Lower American River Salmonids

The term *flow-dependent habitat availability* refers to the quantity and quality of habitat available to individual species and lifestages for a particular instream flow. Typically, the relationship between instream flow and the quantity and quality of instream habitat is expressed in terms of weighted usable area (WUA) produced at a particular flow level.

For the Chinook salmon and steelhead adult spawning lifestage, the term *flow-dependent habitat availability* refers to the amount of appropriate spawning habitat, including the suitable water depths, velocities and substrate, for successful spawning that is, in part, contingent on stream flow. Salmonids typically deposit eggs within a range of depths and velocities that ensure adequate exchange of water between surface and substrate interstices to maintain high oxygen levels and remove metabolic wastes from the redd. Stream flow directly affects the availability of appropriate spawning habitat (SWRI 2002). In general, the amount of habitat suitable for spawning increases as flows increase from very low flows up to a certain flow, and then the amount of suitable spawning habitat generally decreases as flows increase because of excessive velocities, depths, etc. In addition, excessive stream flows can cause scouring of the substrate, resulting in mortality to developing eggs and embryos (Spence et al. 1996).

The physical habitat simulation (PHABSIM) system is a commonly used method to express indices of the quantity and quality of habitat associated with specific flows. PHABSIM is the combination of hydraulic and habitat models, the output of which is expressed as WUA and is used to predict the relationship between instream flow and the quantity and quality of habitat for various lifestages of one or more species of fish.

1.1.1 Scaled Composite WUA Annual Index

In the lower American River, available spawning habitat for fall-run Chinook salmon and steelhead is expressed by scaled composite WUA indices that correspond to the spawning habitat available to the species under the daily flows occurring during their spawning seasons. The scaled composite WUA annual index ($CWUA_Y$) is calculated as the sum of the WUAs that correspond to the simulated average daily flows during the species' spawning season at five sampled reaches within the species' spawning area, multiplied by a temporal weighting coefficient that represents the average relative spawning intensity in the particular day of the spawning season, divided by the maximum WUA for the sum of the five spawning reaches, over the flow range for which the WUA-flow relationship was developed.

For both fall-run Chinook salmon and steelhead that spawns at five distinct reaches (h) within the lower American River during a period of K consecutive days of a particular year Y, the scaled composite WUA annual index ($CWUA_Y$) is expressed by the following formula:

$$CWUA_Y = \frac{\sum_{d=1}^{K} w_d \times \left(\sum_{h=1}^{5} WUA_h \left(Q_{d,Y} \right) \right)}{\max \left(\sum_{h=1}^{5} WUA_h \left(Q \right) \right)} \quad \textbf{(1)}$$

where $WUA_h\,(Q_{d,Y})$ is the WUA of reach h at the daily flow $Q_{d,Y}$ obtained from the WUA-flow relationships developed by the most recent Instream Flow Incremental Methodology (IFIM) studies (USFWS 2003) performed at the five sampled spawning reaches. The denominator of the equation that serves to scale the expression is the maximum achievable WUA for all five spawning reaches combined over the flow range for which the WUA-flow relationships were developed. Finally, w_d are the temporal weighting coefficients for fall-run Chinook salmon or steelhead for each of the days in the K-day spawning periods of fall-run Chinook salmon or steelhead.

Table 1 summarizes the calculation of annual spawning habitat availability in the lower American River by species, specifying the days (d) and river reaches (h) over which the summations are performed.

The simulated average daily flows below Nimbus Dam and equation 1 was used by the U.S. Army Corps of Engineers (USACE) to calculate the expected scaled composite WUA annual indices for fall-run Chinook salmon and steelhead spawning in the lower American River for each of the 73 years simulated with the Folsom Water Control Manual (WCM) Project alternatives and the bases of comparison. For comparative purposes, the resulting annual indices were averaged and compared for the Folsom WCM alternatives relative to the bases of comparison over the entire simulation period and by water year type. Additionally, the resulting annual indices of spawning WUA were used to develop exceedance distributions for comparison of the Folsom WCM alternatives relative to the bases of comparison over the entire simulation period.

Table 1. Summary of Calculations of Annual Spawning Habitat Availability Indexes in the Lower American River by Species.

Species	WUA Equation	Days (*d*)	Reaches (*h*)
Fall-run Chinook salmon	1	98 (Oct 13 – Jan 18)	5 (Upstream RM 21.8; from RM 21.2 to RM 20.7; from RM 20.2 to RM 19.6; from RM 19.1 to RM 18.9; and downstream RM 17.3)
Steelhead	1	114 (Dec 14 – Apr 5)	5 (Upstream RM 21.8; from RM 21.2 to RM 20.7; from RM 20.2 to RM 19.6; from RM 19.1 to RM 18.9; and downstream RM 17.3)

RM = River Mile

The following sections describe the data and calculations used by USACE to develop the main components of CWUAY in equation 1:

- WUA-flow relationships per species/run ($WUA_k(Q)$)
- Temporal weighting coefficients (w_m)

1.1.2 WUA-Flow Relationships

To describe the flow-dependent spawning habitat available to fall-run Chinook salmon and steelhead at different lower American River flow levels, this analysis uses the WUA-flow relationships that were developed by the most recent IFIM study that used two-dimensional (2-D) modeling (USFWS 2003). In the 2003 USFWS 2-D study, the lower American River was divided into five reaches (**Table 2**).

Table 2. Names and River Miles of the Limits of Lower American River Reaches with WUA-Flow Relationships Developed by USFWS (2003).

Reach (*k*)	Reach Name	Downstream Limit (RM)	Upstream Limit (RM)	Model Node
1	Sailor Bar	21.8	22.1	Nimbus
2	Above Sunrise	20.7	21.2	Nimbus
3	Sunrise	19.6	20.2	Nimbus
4	El Manto	18.9	19.1	Nimbus
5	Rossmoor	16.6	17.3	Nimbus

For each species, the WUA values for each of the five study reaches *h* at a particular daily flow $Q_{d,Y}$ were obtained from the WUA-flow relationships developed by the 2-D IFIM study, and summed to calculate a composite value ($\sum_{h=1}^{5} WUA_h\left(Q_{d,Y}\right)$ in equation 1). The daily flow $Q_{d,Y}$ was the daily flow modeled with the Folsom WCM alternatives and the bases of comparison for the particular day *d* and year below Nimbus Dam, the uppermost boundary of the five study reaches.

The WUA-flow relationships developed by the most recent IFIM studies present WUA values within particular flow ranges at particular variable steps (e.g., in the lower American River, the WUA-flow relationships were developed for a flow range of 1,000 cubic feet per second [cfs] to 11,000 cfs, with flow steps of 200 cfs, 400 cfs, and 600 cfs). Because simulated daily flows often do not correspond to one of the specified flows in the WUA-flow relationship, the composite WUA value for a given day was determined by linear interpolation between the available WUA values for the flows immediately below and above the target flow $Q_{d,Y}$. In those cases when the target flow $Q_{d,Y}$ was lower than the lowest flow value in the WUA-flow relationship (1,000 cfs) or higher than the highest flow value in the WUA-flow relationship (11,000 cfs), two series of extrapolated WUA values were generated from fitting a polynomial and a power function to the closest WUA and flow values in the available WUA-flow relationships, as further described below.

A polynomial function was fitted to the WUA values for the seven lower flows in the available WUA-flow relationship (Q = 1,000 cfs, 1,200 cfs, 1,400 cfs, 1,600 cfs, 1,800 cfs, 2,000 cfs, and 2,200 cfs) to generate seven extrapolated WUA values for Q = 0 cfs, 50 cfs, 100 cfs, 200 cfs, 400 cfs, 600 cfs, and 800 cfs. A power function was fitted to the WUA values for the 10 higher flows in the available WUA-flow relationships (Q ranging from 7,000 cfs through 11,000 cfs) to generate 27 extrapolated WUA values for Q ranging from 12,000 cfs through 38,000 in increasing steps of 1,000 cfs. Details of the extrapolation procedure and available WUA-flow relationships for fall-run Chinook salmon and steelhead spawning in the lower American River are provided in the following sections.

1.1.2.1 Fall-run Chinook Salmon

The WUA-flow relationships developed for spawning fall-run Chinook salmon (**Figure 1**) through 2-D modeling were based on Habitat Suitability Curves (HSC) obtained from depth, velocity, and substrate data collected during surveys for shallow and deep fall-run Chinook salmon redds conducted on November 6 and 7, 1996, and on December 11 through 17, 1998. A total of 218 measurements were collected in 1996 (USFWS 1996), and a total of 189 measurements were obtained in 1998 (USFWS 2003).

Figure 1 shows the WUA-flow relationships for the five studied reaches (Sailor Bar, Above Sunrise, Sunrise, El Manto, and Rossmoor) as connected colored circles. The composite WUA-flow relationship, resulting from the sum of the reach-specific relationships, is indicated as a gray line. The white circle on this line, with coordinates WUA = 881,905 square feet (ft^2) and Q = 2,200 cfs, indicates the maximum WUA for all five spawning reaches combined that corresponds to the denominator $\max\left(\sum_{h=1}^{5} WUA_h(Q)\right)$ in equation 1 and is used to scale the composite WUA annual index.

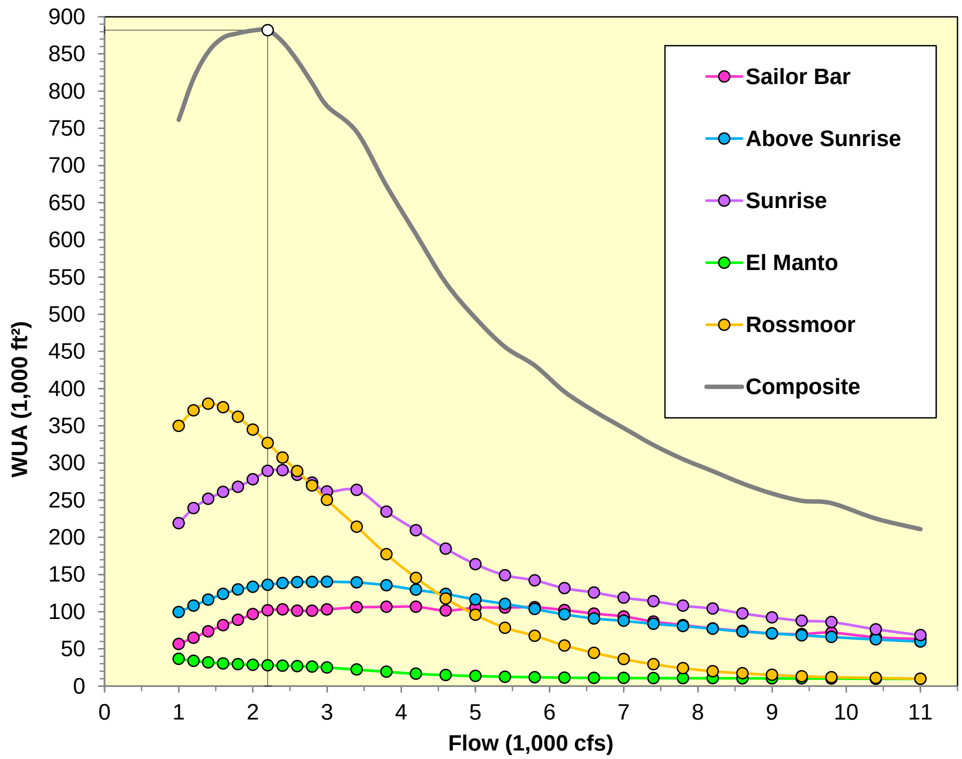

Figure 1. Relationship between Chinook Salmon Spawning Habitat Availability (Expressed as WUA) and Flow for the Five Lower American River Study Reaches and for the Composite of the Five Study Reaches.

The composite WUA curve has 30 data points corresponding to flows ranging from 1,000 cfs through 11,000 cfs that were used for the direct linear interpolation of target daily flows $Q_{d,Y}$ describing daily flow conditions below Nimbus Dam between 1,000 cfs, and 11,000 cfs with the Folsom WCM alternatives and the bases of comparison over the entire simulation period.

To interpolate target daily flows lower than 1,000 cfs, a polynomial function was first fitted to the WUA values for the seven lowest flows in the composite WUA-flow relationship (Q = 1,000 cfs, 1,200 cfs, 1,400 cfs, 1,600 cfs, 1,800 cfs, 2,000 cfs, and 2,200 cfs). The equation of the fitted polynomial was $WUA = 1,257.737 \times Q - 0.590034 \times Q^2 + 7.88 \times 10^{-5} \times Q^3 + 4.67 \times 10^{-9} \times Q^4$, and had a coefficient of determination R² = 0.9999. The polynomial equation was used to generate seven extrapolated WUA values for Q = 0 cfs, 50 cfs, 100 cfs, 200 cfs, 400 cfs, 600 cfs, and 800 cfs.

To interpolate target daily flows higher than 11,000 cfs, a power function was fitted to the WUA values for the 10 higher flows in the composite WUA-flow relationship (Q ranging from 7,000 cfs through 11,000 cfs). The equation of the fitted power function was $\ln(WUA) = 22.230782 - 1.071176 \times \ln(Q)$, and had a coefficient of determination R² = 0.9949. The regression equation was used to generate 27 extrapolated WUA values for Q ranging from 12,000 cfs through 38,000 in increasing steps of 1,000 cfs.

The seven WUA values extrapolated from the fitted polynomial and the 27 WUA values extrapolated from the fitted power function were combined with the 30 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for all simulated average daily flows below Nimbus Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 3**). The composite WUA values in **Table 3** are plotted in **Figure 2**.

Table 3. Composite WUA Values for Fall-run Chinook Salmon Spawning in the Lower American River Used as Look-up Table for Linear Interpolation of Spawning WUA Values for Simulated Average Daily Flows below Nimbus Dam.

Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)	Flow (cfs)	WUA (ft²)
0	0	2,800	810,552	9,000	258,849	23,000	96,057
50	61,922	3,000	779,982	9,400	249,130	24,000	91,776
100	120,953	3,400	745,172	9,800	245,933	25,000	87,850
200	230,584	3,800	672,903	10,400	225,180	26,000	84,235
400	417,855	4,200	607,384	11,000	210,972	27,000	80,898
600	565,864	4,600	542,402	12,000	192,835	28,000	77,807
800	678,846	5,000	494,912	13,000	176,990	29,000	74,937
1,000	761,361	5,400	455,893	14,000	163,484	30,000	72,264
1,200	817,031	5,800	431,125	15,000	151,837	31,000	69,770
1,400	853,047	6,200	395,906	16,000	141,695	32,000	67,437
1,600	871,959	6,600	369,760	17,000	132,786	33,000	65,250
1,800	877,804	7,000	346,898	18,000	124,900	34,000	63,197
2,000	881,528	7,400	324,186	19,000	117,872	35,000	61,265
2,200	881,905	7,800	305,059	20,000	111,570	36,000	59,444
2,400	866,405	8,200	289,010	21,000	105,889	37,000	57,724
2,600	840,949	8,600	272,509	22,000	100,741	38,000	56,099

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

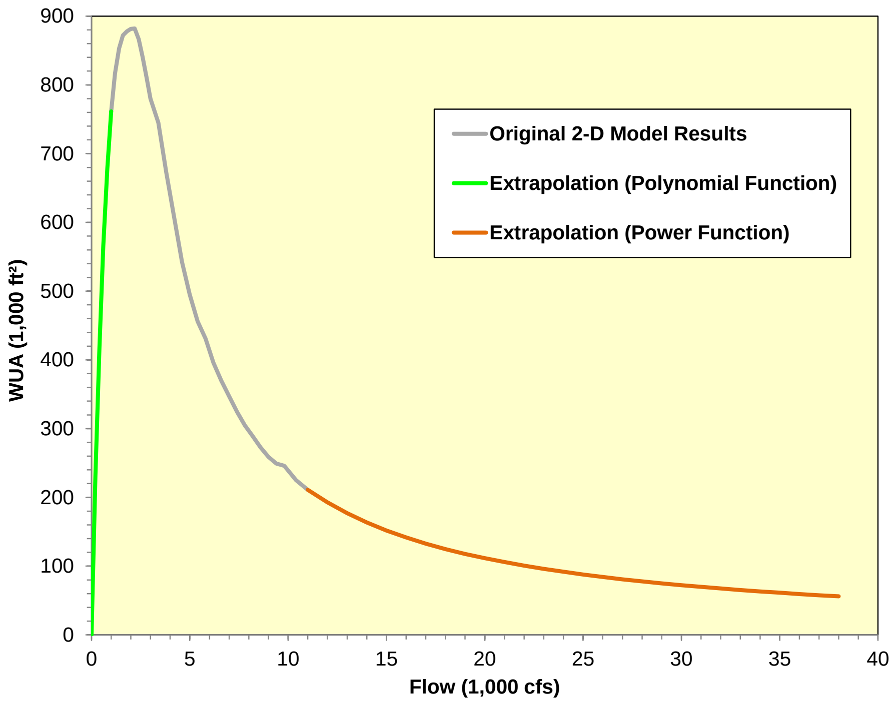

Figure 2. Final Relationship between the Composite Chinook Salmon Spawning WUA and Flow in the Lower American River.

1.1.2.2 Steelhead

Figure 3 displays the WUA-flow relationships developed for lower American River steelhead. As with Figure 1, the WUA-flow relationships for the five studied reaches (Sailor Bar, Above Sunrise, Sunrise, El Manto, and Rossmoor) are shown as connected colored circles. The composite WUA-flow relationship, resulting from the sum of the reach specific relationships, is indicated as a gray line. The white circle on this line, with coordinates WUA = 285,665 ft² and Q = 2,200 cfs, indicates the maximum WUA for all five steelhead spawning reaches combined.

The WUA-flow relationships developed for lower American River steelhead spawning were based on:

- A depth HSC developed from 192 observations of lower American River steelhead redds made by the U.S. Bureau of Reclamation (Reclamation) during 2003 and 2004 (Hannon and Deason 2004) (Figure 4);
- A substrate HSC developed from 190 observations of lower American River steelhead redds made by Reclamation during 2003 and 2004 (Figure 5);
- A velocity HSC developed from 27 observations of lower American River steelhead redds made by the California Department of Fish and Wildlife (CDFW) in 1992 (USFWS 1996); and
- Hydraulic and structural data collected by the U.S. Fish and Wildlife Service (USFWS) and described in USFWS (2003).

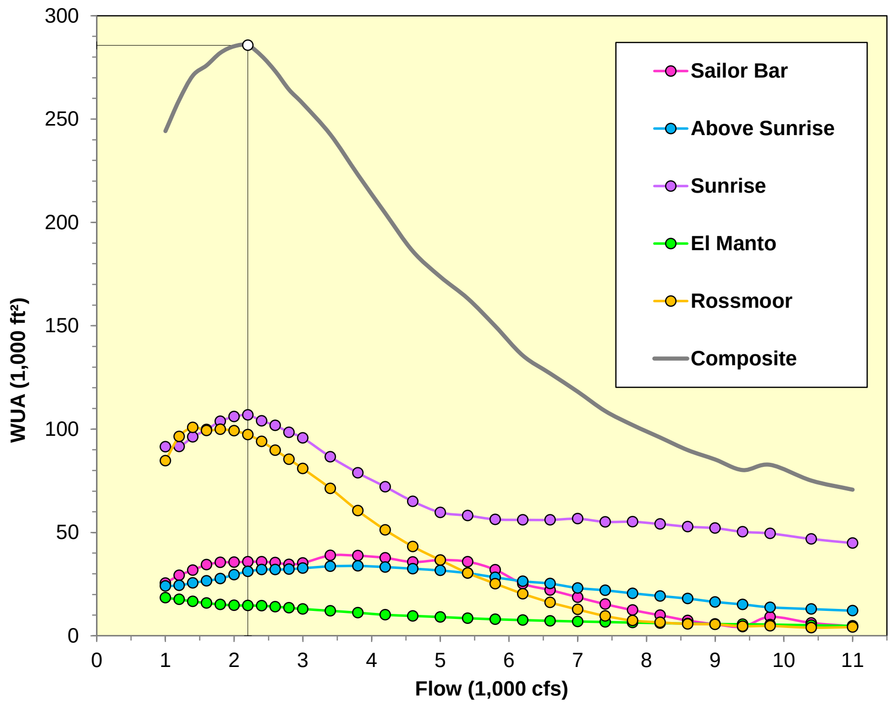

Figure 3. Relationship between Steelhead Spawning WUA and Flow for the Five lower American River Study Reaches and for the Composite WUA of the Five Study Reaches.

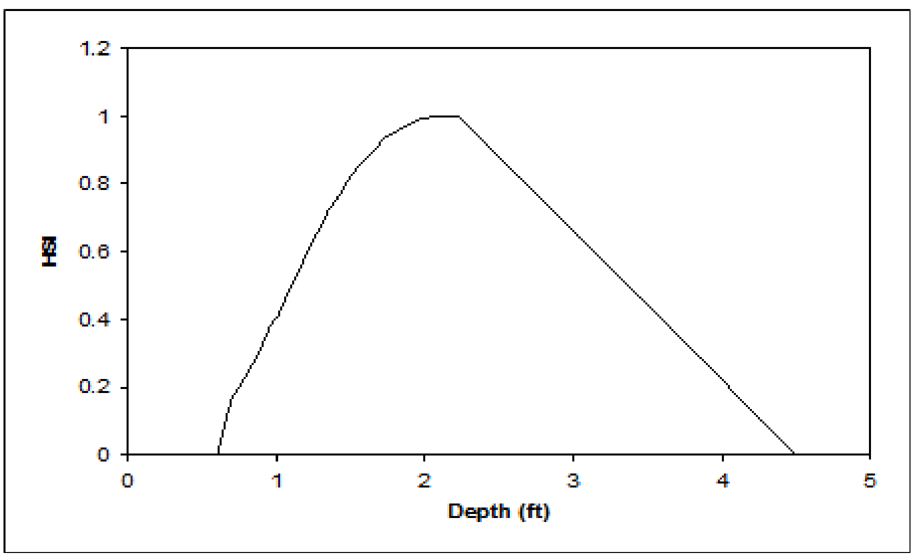

Figure 4. Habitat Suitability Curve based on Lower American River Steelhead Redd Depth Data Collected by Reclamation in 2003 and 2004.

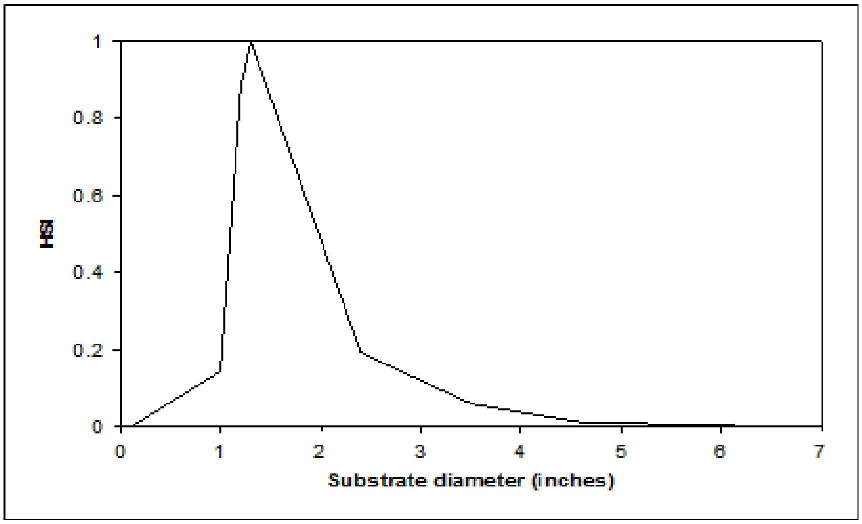

Figure 5. Habitat Suitability Curve Based on Lower American River Steelhead Substrate Diameter Collected by Reclamation in 2003 and 2004.

As with the composite spawning WUA-flow relationship for Chinook salmon, the steelhead composite spawning WUA relationship also has 30 data points corresponding to flows ranging from 1,000 cfs through 11,000 cfs that were used for the direct linear interpolation of target daily flows $Q_{d,Y}$ describing simulated average daily flow below Nimbus Dam between 1,000 cfs and 11,000 cfs with the Folsom WCM alternatives and the bases of comparison. The steelhead composite WUA curve also required extrapolations to account for flows outside the 1,000–11,000 cfs range.

To interpolate WUA values at target daily flows lower than 1,000 cfs, a polynomial function was fitted to the WUA values for the seven lowest flows in the composite WUA-flow relationship (Q = 1,000 cfs, 1,200 cfs, 1,400 cfs, 1,600 cfs, 1,800 cfs, 2,000 cfs, and 2,200 cfs). The equation of the fitted polynomial was $WUA = 476.638 \times Q - 0.327497 \times Q^2 + 0.000110 \times Q^3 - 1.49 \times 10^{-8} \times Q^4$, and had a coefficient of determination $R^2 = 0.9999$. The polynomial equation was used to generate seven extrapolated WUA values for Q = 0 cfs, 50 cfs, 100 cfs, 200 cfs, 400 cfs, 600 cfs, and 800 cfs.

To interpolate WUA values at target daily flows higher than 11,000 cfs, a power function was fitted to the WUA values for the 10 higher flows in the composite WUA-flow relationship (Q ranging from 7,000 cfs through 11,000 cfs). The equation of the fitted power function was $\ln(WUA) = 21.407234 - 1.101644 \times \ln(Q)$, and had a coefficient of determination $R^2 = 0.97999$. The regression equation was used to generate 27 extrapolated WUA values for Q ranging from 12,000 cfs through 38,000 cfs in increasing steps of 1,000 cfs. The seven WUA values extrapolated from the fitted polynomial and the 27 WUA values extrapolated from the fitted power function were combined with the 30 values of the original composite WUA-flow relationship into a look-up table used for the linear interpolation of WUA values for all simulated average daily flows below Nimbus Dam with the Folsom WCM alternatives and the bases of comparison over the entire simulation period (**Table 4**). The composite steelhead spawning WUA values in Table 4 are plotted in **Figure 6**.

Table 4. Composite WUA Values for Steelhead Spawning in the Lower American River Used as Look-up Table for Linear Interpolation of Spawning WUA Values for Simulated Average Daily Flows below Nimbus Dam.

Flow (cfs)	WUA (ft^2)	Flow (cfs)	WUA (ft^2)	Flow (cfs)	WUA (ft^2)	Flow (cfs)	WUA (ft^2)
0	0	2,800	264,182	9,000	85,313	23,000	31,044
50	23,027	3,000	257,478	9,400	80,198	24,000	29,622
100	44,497	3,400	242,542	9,800	82,740	25,000	28,319
200	83,084	3,800	223,125	10,400	75,103	26,000	27,122
400	144,912	4,200	204,398	11,000	70,711	27,000	26,017
600	189,906	4,600	186,065	12,000	63,568	28,000	24,995
800	221,915	5,000	173,712	13,000	58,203	29,000	24,048
1,000	244,184	5,400	163,188	14,000	53,640	30,000	23,166
1,200	259,200	5,800	149,814	15,000	49,714	31,000	22,344
1,400	271,081	6,200	135,625	16,000	46,302	32,000	21,576
1,600	275,989	6,600	126,901	17,000	43,311	33,000	20,857
1,800	282,068	7,000	118,107	18,000	40,668	34,000	20,182
2,000	285,223	7,400	108,736	19,000	38,316	35,000	19,548
2,200	285,665	7,800	101,952	20,000	36,211	36,000	18,951
2,400	280,536	8,200	95,945	21,000	34,316	37,000	18,387
2,600	273,113	8,600	89,863	22,000	32,602	38,000	17,855

WUA values obtained through extrapolation using a polynomial function (see text for details).

WUA values obtained through extrapolation using a power function (see text for details).

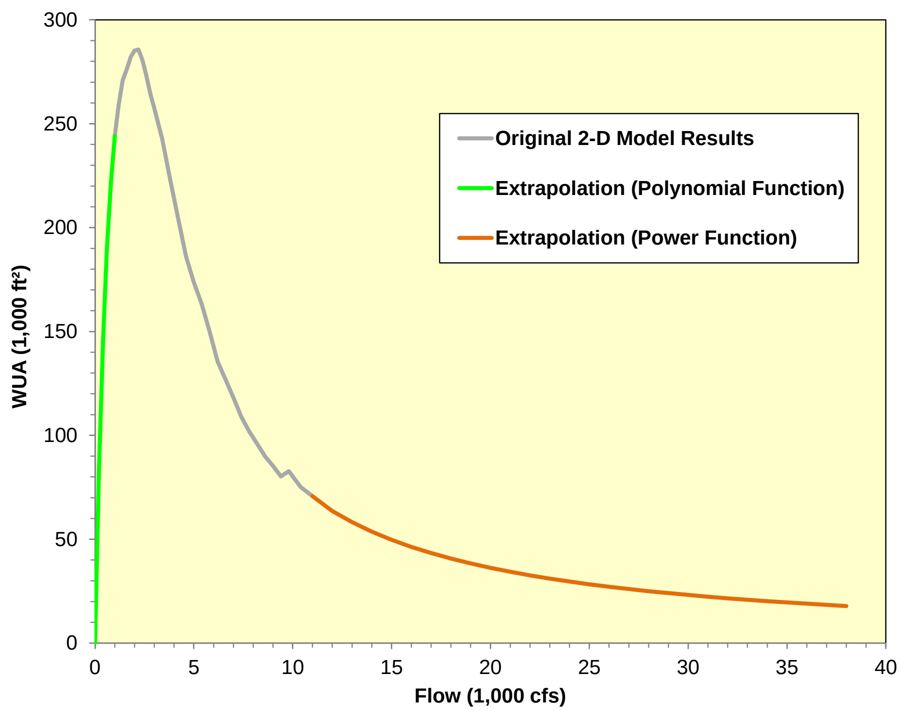

Figure 6. Final Relationship between the Composite Steelhead Spawning WUA and Flow in the Lower American River.

1.1.3 Temporal Weighting Coefficients

Because $CWUA_Y$ in equation 1 is a scaled composite WUA for a species spawning over various months of its spawning season, and because the species' spawning intensity does not remain constant throughout the spawning season, the temporal weighting coefficients w_d were incorporated into equation 1 to account for the expected relative spawning intensity on a particular day. Each w_d is a proportion with a value between 0 and 1, so that, for a given species, the sum of the daily proportions over the assumed spawning period is equal to 1.

In general, to calculate the temporal weighting coefficients, spawning timing is described as an asymmetric logistic function of time. The asymmetric logistic function, also known as Richards sigmoidal curve (Ratkowsky 1983), has the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(\alpha + \beta \times D\right)} \right)^{1/\delta} \qquad \textbf{(2)}$$

where Y_D is the expected cumulative proportion of spawning through day D, and α, β, and δ are parameters that determine the shape of the cumulative curve. The variable D is a continuous variable that indicates the day number at which new spawning occurs during a particular spawning season, counting from a particular starting date. In order to estimate the values of α, β, and δ, the daily cumulative proportions of newly built redds, reported in available annual redd survey reports, were normally used as a proxy for Y_D and were fitted to the asymmetric logistic model through a nonlinear least-squares procedure. In the case of fall-run Chinook salmon spawning in the lower American River, the data describing Y_D arose from combining information in available carcass and redd survey annual reports (see **Section 1.1.3.1** for details).

Once equation 2 was fitted to the data available for a particular species, the fitted curve was rescaled to the commonly accepted spawning period of the species, and the daily temporal weighting coefficients w_d were calculated by subtraction. For example, if $\hat{Y}_D$ is the value of the fitted asymmetric logistic curve at a given day D for a species that spawns in the lower American River from January 1 through April 15, the temporal weighting coefficient for February 15 ($w_{Feb.15}$) is calculated as:

$$w_{Feb.15} = \left(\hat{Y}_{2/16/Year} - \hat{Y}_{2/15/Year} \right) \Big/ \left(\hat{Y}_{4/15/Year} - \hat{Y}_{1/01/Year} \right).$$

1.1.3.1 Fall-run Chinook Salmon

The temporal weighting coefficients and spawning period used for fall-run Chinook salmon spawning in the lower American River were derived from data collected by both redd surveys and carcass surveys. Redd surveys that provide the cumulative distribution of newly built redds over time, which is a better descriptor of spawning timing, were performed only during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider, Urquhart, McEwan, and Munos 1993; Snider and Vyverberg 1995, 1996; Snider et al. 1996). On the other hand, fall-run Chinook salmon carcass surveys have been performed annually since the late 1960s, and data or reports are available for all surveys performed from October 1992 through October 2012 (e.g., Snider and Bandner 1996; Snider and Reavis 1996; Snider, Keenan, and Munos 1993; Snider et al. 1995; Healey 2002, 2003, 2004, 2005, 2006; Healey and Fresz 2007; Healey and Redding 2008; Vincik and Kirsch 2009; Vincik and Mamola 2010; Maher et al. 2012; Phillips and Helstab 2013; Phillips and Maher 2013).

The temporal distributions of fresh carcasses described in these reports can be used to estimate an overall cumulative distribution of fresh carcasses over time that describe when fresh carcasses appear in the surveys, which is subsequent to the actual time of spawning. When appropriately lagged by the time elapsing between spawning and appearance of fresh carcasses in the surveys, the carcass surveys also describe spawning timing. The time elapsing between spawning and redd-construction and post-spawning mortality, or life expectancy after spawning, has been reported to normally be between 2 and 4 weeks (Briggs 1953).

To take advantage of the potential information in the available redd and carcass surveys on fall-run Chinook salmon spawning timing in the lower American River, USACE developed a five-step procedure to estimate the sigmoidal curve describing fall-run Chinook salmon spawning timing in the lower American River that was used to calculate the temporal weighting coefficients for the composite WUA equation 1. The five-step procedure consists of the following steps:

1. Fit an asymmetric logistic function to the daily cumulative proportions of newly built redds obtained from the four annual photogrammetric redd surveys performed during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons.
2. Fit an asymmetric logistic function to the daily cumulative proportions of fresh carcasses obtained from the four carcass surveys performed during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons.
3. Calculate the lag times between the fitted redd and fresh carcass cumulative distributions (i.e., the number of days separating similar cumulative proportions under the asymmetric logistic functions fitted in steps 1 and 2).
4. Fit an asymmetric logistic function to the daily cumulative proportions of fresh carcasses obtained from the available carcass surveys performed during the 1992/93 through the 2012/13 fall-run Chinook salmon spawning seasons.
5. Apply the lag times calculated in step 3 to the curve fitted in step 4 by subtracting the corresponding lag times from the days for particular cumulative proportions of fresh carcasses expected under the curve obtained in step 4. The resulting lagged asymmetric logistic function was used to describe fall-run Chinook salmon spawning timing in the lower American River based on carcass surveys from 1992/93 through the 2012/13 fall-run Chinook salmon spawning seasons and to calculate the temporal weighting coefficients for the species.

During the four photogrammetric redd surveys performed from late September or October through early January during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons, a total of 14,084 newly built redds were counted, ranging from a low of 1,138 redds during the 1992/93 spawning season to a high of 6,205 redds during the 1993/94 spawning season. Given the variation in total number of redds counted each season, as well as the number of weekly aerial surveys performed during each spawning season, a weighted nonlinear least-squares procedure was used to fit the common asymmetric logistic function (equation 2) to the four sets of daily cumulative proportions of newly built redds.

The weights were calculated as the ratio of the annually counted redds to the overall total number of counted redds (14,084 newly-built redds). For example, the 13 daily cumulative proportions of redds built during the 1992/93 spawning season each received a weight of 0.0808 (1,138/14,084 = 0.0808), while the seven daily cumulative proportions of redds built during the 1995/96 spawning season each received a weight of 0.2823 (3,976/14,084 = 0.2823). The common asymmetric logistic function fitted to the redd data had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(8.6114 - 0.1430 \times D\right)} \right)^{1/0.2330} \qquad \textbf{(3)}$$

where D is the day number at which new redds were observed during a particular annual survey, counted from midnight of August 31 of each year. The mean-square error of this fit was 0.0513. **Figure 7** displays the four sets of daily cumulative proportions and the fitted curve of equation 3.

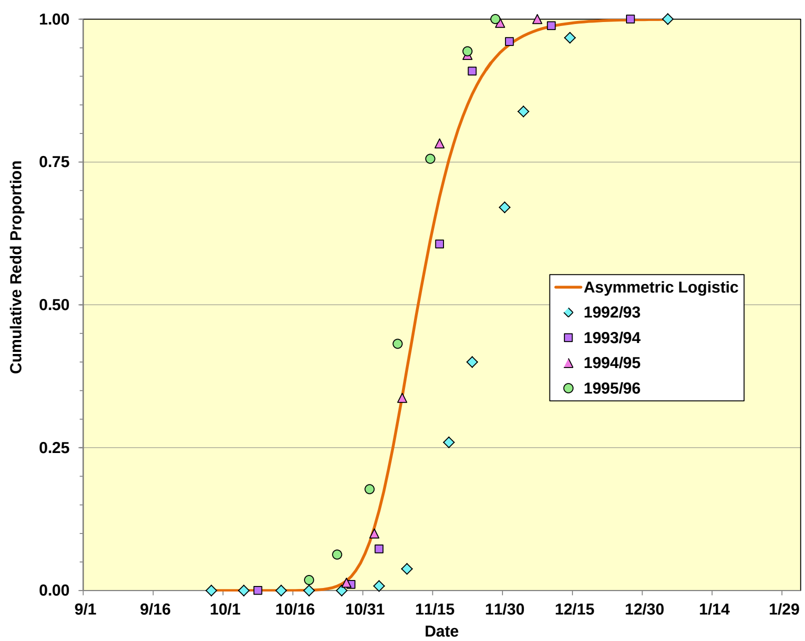

Figure 7. Fall-run Chinook Salmon Cumulative Proportions of Redds in the Lower American River, during the 1992/93 – 1995/96 Spawning Seasons, and Fitted Asymmetric Logistic Curve.

During the four carcass surveys performed from October through mid-January during the 1992/93 spawning season through the 1995/96 fall-run Chinook salmon spawning season, a total of 5,788 fresh carcasses were counted, ranging from a low of 360 fresh carcasses during the 1992/93 spawning season to a high of 1,980 fresh carcasses during the 1995/96 spawning season. A weighted nonlinear least-squares procedure was used to fit the common asymmetric logistic function (equation 2) to the four sets of daily cumulative proportions of fresh carcasses. The weights were calculated as the ratio of the annually counted fresh carcasses to the overall number of counted fresh carcasses (5,788 carcasses). For example, the 18 daily cumulative proportions of fresh carcasses of the 1992/93 spawning season each received a weight of 0.0627 (360/5,788 = 0.0622), while the 11 daily cumulative proportions of fresh carcasses of the 1995/96 spawning season each received a weight of 0.3419 (1,980/5,788 = 0.3421).

Figure 8 displays the four sets of daily cumulative proportions and the fitted asymmetric logistic curve of equation 4.

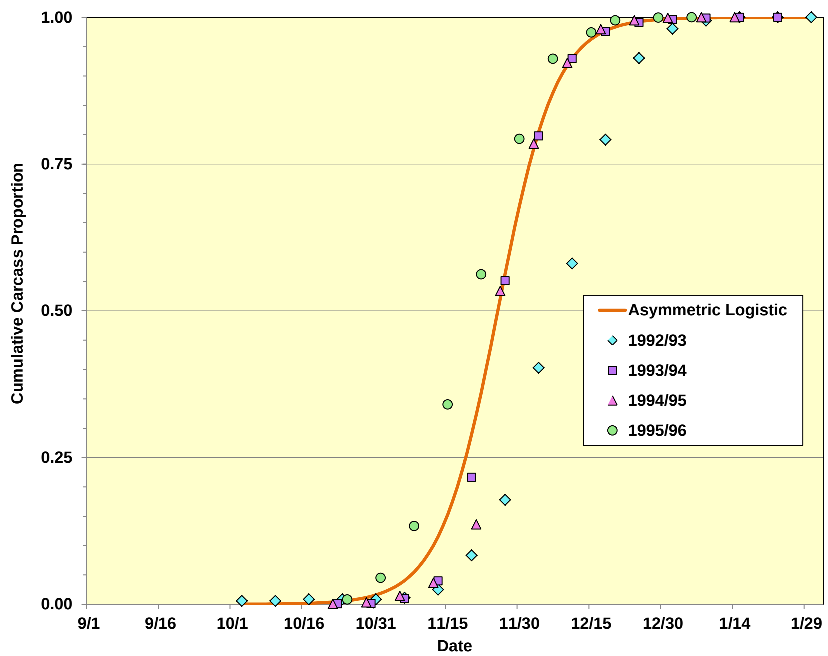

Figure 8. Fall-run Chinook Salmon Cumulative Proportions of Fresh Carcasses in the Lower American River, during the 1992/93 – 1995/96 Spawning Seasons, and Fitted Asymmetric Logistic Curve.

The common asymmetric logistic function fitted to the fresh carcass data had the following expression:

$$Y_D = \left(\frac{1}{1+\exp\left(14.5710 - 0.1677 \times D\right)} \right)^{1/1.0518} . \qquad \textbf{(4)}$$

The mean-square error of this fit was 0.0396.

As part of the third procedural step in which the lag times between the fitted redd and fresh-carcass cumulative distributions were computed, the parameter values of equations 3 and 4 were applied to the following equation:

$$D_{Y'} = \frac{\ln\left[\left(\frac{1}{Y'}\right)^{\hat{\delta}} - 1\right] - \hat{\alpha}}{\hat{\beta}} \, , \qquad \textbf{(5)}$$

where *Y'* are particular expected cumulative proportions under fitted equations 3 and 4 (e.g., 0.05, 0.15, 0.25, 0.5, etc.), $D_{Y'}$ are the days at which those proportions are achieved, and $\hat{\alpha}$, $\hat{\beta}$, and $\hat{\delta}$ are the parameter values in equations 3 and 4. After calculating equation 5 with both sets of parameter estimates, there were two $D_{Y'}$ values for each particular expected cumulative proportion *Y'*, one for the fitted redd cumulative distribution (equation 3) and the other for the fitted fresh carcass cumulative distribution (equation 4). The lag times between the fitted redd and fresh carcass cumulative distributions were then calculated as the differences between the pairs of $D_{Y'}$ values (**Table 5**).

Table 5. Lag Times between Cumulative Proportions (*Y'*%) of the Redd and Fresh Carcass Cumulative Distributions Fitted to Data for the 1992/93 – 1995/96 Chinook Salmon Spawning Seasons.

Cumulative Proportion (*Y'*%)	Day under Fitted Redd Cumulative Curve ($D_{Y'}$)	Day under Fitted Carcass Cumulative Curve ($D_{Y'}$)	Lag Time (days)
1%	55.64	58.05	2.42
5%	60.15	68.36	8.21
15%	64.32	75.86	11.54
25%	66.96	79.77	12.82
50%	72.39	86.47	14.08
75%	78.88	93.09	14.22
85%	82.97	96.91	13.93
95%	91.13	104.14	13.01
99%	102.56	113.99	11.43

$D_{Y'}$ and lag times are expressed in decimal days counted from the midnight of August 31 ($D_{Y'} = 0$)

As part of the fourth procedural step, a new asymmetric logistic function was fitted to the daily cumulative proportions of fresh carcasses obtained from the available carcass surveys performed during the 1992/93 through the 2012/13 fall-run Chinook salmon spawning seasons to incorporate any additional information on spawning timing not present in the shorter data sets used in steps 1 and 2. As with previous fits, a weighted least-square procedure was used. These weights were also calculated as the ratios of the annually counted fresh carcasses of a season to the overall number of counted fresh carcasses (38,366 carcasses). Thus, for example, the weight for the 13 daily cumulative proportions of fresh carcasses of the 1992/93 spawning season became 0.0094 (360/38,366 = 0.0094).

Equation 6 and **Figure 9** display the results of this new fitted asymmetric logistic function.

$$Y_D = \left(\frac{1}{1 + \exp\left(8.3944 - 0.1100 \times D\right)} \right)^{1/0.5373} . \quad \textbf{(6)}$$

The mean-square error of this fit was 0.0220.

Finally, as part of the fifth procedural step, the parameter values of equation 6 were applied to equation 5 to calculate new $D_{Y'}$ values (i.e., days at particular cumulative proportions of the new fitted curve), and the lag times in Table 5 were subtracted from the new $D_{Y'}$ values. The resulting lagged asymmetric logistic curve had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(1.2818 - 0.1010 \times D\right)} \right)^{1/0.0046} . \quad \textbf{(7)}$$

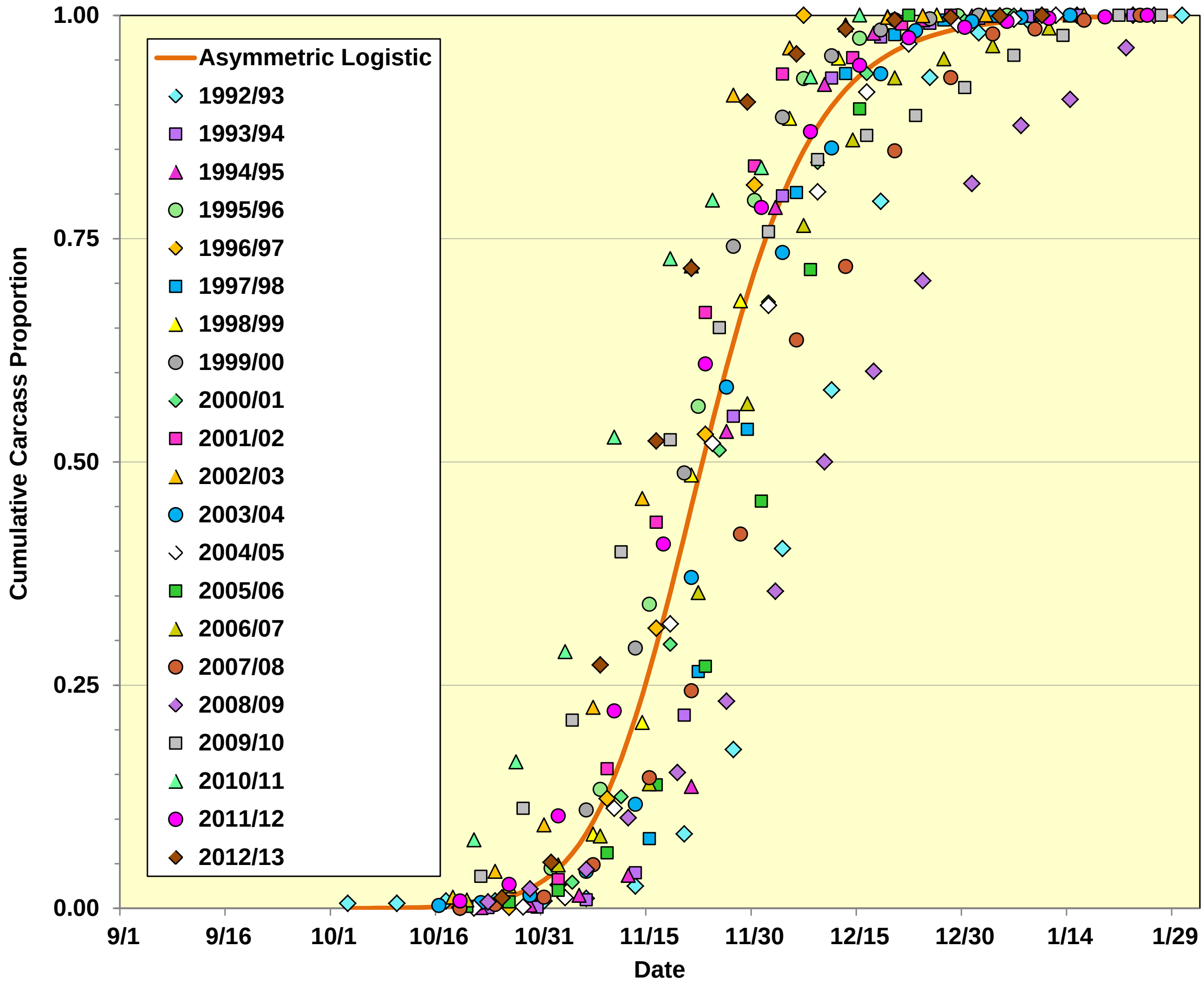

Figure 9. Fall-run Chinook Salmon Cumulative Proportions of Fresh Carcasses in the Lower American River, during the 1992/93 – 2012/13 Spawning Seasons, and Fitted Asymmetric Logistic Curve.

Figure 10 displays the four asymmetric logistic curves obtained from the five-step procedure used to describe fall-run Chinook salmon spawning timing in the lower American River.

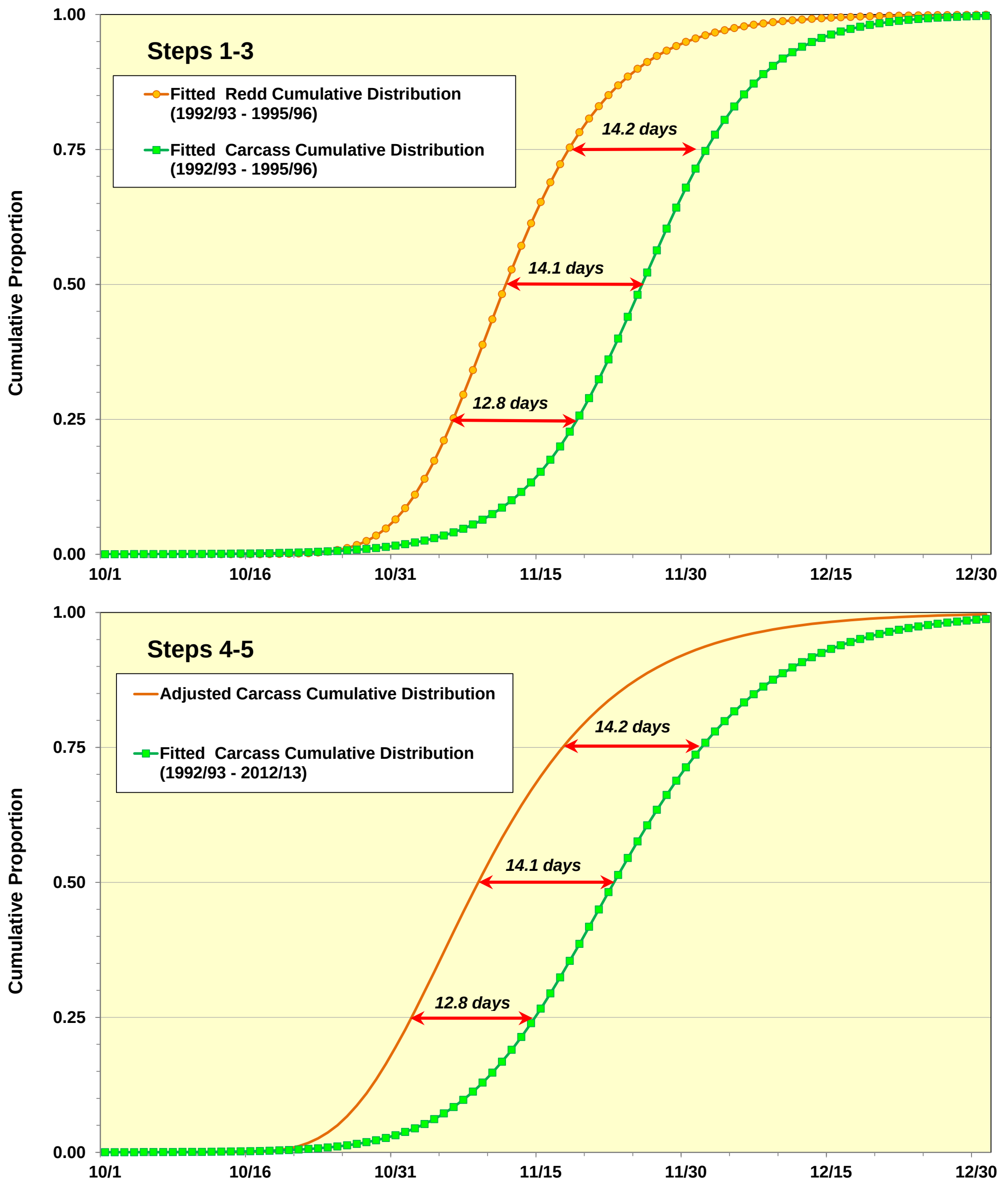

Figure 10. Asymmetric Logistic Curves Obtained from the Five-Step Procedure Used to Describe Fall-run Chinook Salmon Spawning Timing in the Lower American River during the 1992/93 – 2012/13 Spawning Seasons.

The lagged asymmetric logistic curve of equation 7 was used to calculate expected daily spawning proportions by subtraction. Finally, the daily temporal coefficients for fall-run Chinook salmon were obtained by rounding the daily proportions to four decimal places and rescaling to the sum of the rounded proportions. Figure 11 and Table 6 display the final daily weighting coefficients for fall-run Chinook salmon spawning in the lower American River, and the resulting spawning period used in the calculation of the scaled composite WUA annual index ($CWUA_Y$) for the fall-run Chinook salmon. The resulting spawning period extends from October 13 through January 18, a period of K = 98 days.

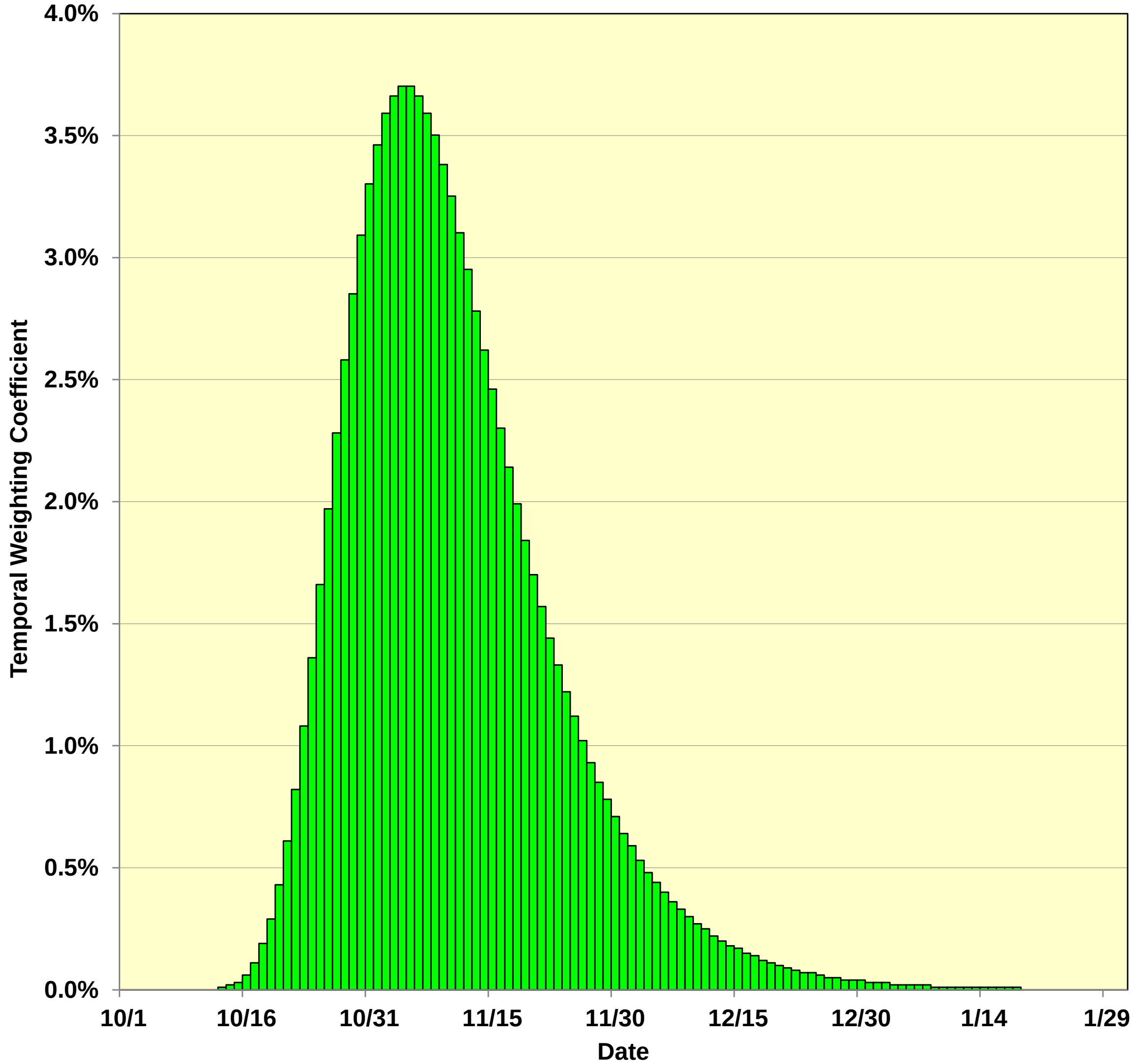

Figure 11. Daily Temporal Weighting Coefficients Used for Fall-run Chinook Salmon Spawning in the Lower American River from October 13 through January 18.

Table 6. Temporal Weighting Coefficients Used for Fall-run Chinook Salmon Spawning in the Lower American River.

Day	Lagged Carcass Fit (%)	Temporal Weighting Coefficient	Day	Lagged Carcass Fit (%)	Temporal Weighting Coefficient
10/12	0.00%	0.000000	**12/1**	0.64%	0.006403
10/13	0.01%	0.000100	**12/2**	0.59%	0.005903
10/14	0.02%	0.000200	**12/3**	0.53%	0.005303
10/15	0.03%	0.000300	**12/4**	0.48%	0.004802
10/16	0.06%	0.000600	**12/5**	0.44%	0.004402
10/17	0.11%	0.001101	**12/6**	0.40%	0.004002
10/18	0.19%	0.001901	**12/7**	0.36%	0.003602
10/19	0.29%	0.002901	**12/8**	0.33%	0.003302
10/20	0.43%	0.004302	**12/9**	0.30%	0.003002
10/21	0.61%	0.006103	**12/10**	0.27%	0.002701
10/22	0.82%	0.008204	**12/11**	0.25%	0.002501
10/23	1.08%	0.010805	**12/12**	0.22%	0.002201
10/24	1.36%	0.013607	**12/13**	0.20%	0.002001
10/25	1.66%	0.016608	**12/14**	0.18%	0.001801
10/26	1.97%	0.019710	**12/15**	0.17%	0.001701
10/27	2.28%	0.022811	**12/16**	0.15%	0.001501
10/28	2.58%	0.025813	**12/17**	0.14%	0.001401
10/29	2.85%	0.028514	**12/18**	0.12%	0.001201
10/30	3.09%	0.030915	**12/19**	0.11%	0.001101
10/31	3.30%	0.033017	**12/20**	0.10%	0.001001
11/1	3.46%	0.034617	**12/21**	0.09%	0.000900
11/2	3.59%	0.035918	**12/22**	0.08%	0.000800
11/3	3.66%	0.036618	**12/23**	0.07%	0.000700
11/4	3.70%	0.037019	**12/24**	0.07%	0.000700
11/5	3.70%	0.037019	**12/25**	0.06%	0.000600
11/6	3.66%	0.036618	**12/26**	0.05%	0.000500
11/7	3.59%	0.035918	**12/27**	0.05%	0.000500
11/8	3.50%	0.035018	**12/28**	0.04%	0.000400
11/9	3.38%	0.033817	**12/29**	0.04%	0.000400
11/10	3.25%	0.032516	**12/30**	0.04%	0.000400
11/11	3.10%	0.031016	**12/31**	0.03%	0.000300
11/12	2.95%	0.029515	**1/1**	0.03%	0.000300
11/13	2.78%	0.027814	**1/2**	0.03%	0.000300
11/14	2.62%	0.026213	**1/3**	0.02%	0.000200
11/15	2.46%	0.024612	**1/4**	0.02%	0.000200
11/16	2.30%	0.023012	**1/5**	0.02%	0.000200
11/17	2.14%	0.021411	**1/6**	0.02%	0.000200
11/18	1.99%	0.019910	**1/7**	0.02%	0.000200
11/19	1.84%	0.018409	**1/8**	0.01%	0.000100
11/20	1.70%	0.017009	**1/9**	0.01%	0.000100
11/21	1.57%	0.015708	**1/10**	0.01%	0.000100
11/22	1.44%	0.014407	**1/11**	0.01%	0.000100
11/23	1.33%	0.013307	**1/12**	0.01%	0.000100
11/24	1.22%	0.012206	**1/13**	0.01%	0.000100
11/25	1.12%	0.011206	**1/14**	0.01%	0.000100
11/26	1.02%	0.010205	**1/15**	0.01%	0.000100
11/27	0.93%	0.009305	**1/16**	0.01%	0.000100
11/28	0.85%	0.008504	**1/17**	0.01%	0.000100
11/29	0.78%	0.007804	**1/18**	0.01%	0.000100
11/30	0.71%	0.007104	**Totals**	99.95%	1

1.1.3.2 Steelhead

The temporal weighting coefficients used for steelhead spawning in the lower American River were derived from the steelhead redd surveys performed by Reclamation and CDFW from February 2002 through April 2013 (Chase 2010; Hannon 2011, 2012, 2013; Hannon and Healey 2002; Hannon et al. 2003; Hannon and Deason 2004, 2005, 2007; See and Chase 2009). Steelhead redd surveys have been conducted in the lower American River from as early as mid-December through as late as mid-June of the following year, and the available data correspond to 10 spawning seasons: 2001/02, 2002/03, 2003/04, 2004/05, 2006/07, 2008/09, 2009/10, 2010/11, 2011/12, and 2012/13. No redd surveys were conducted during the 2005/06 spawning season because of high flows and low water clarity, or during the 2007/08 season.

Redd surveys normally start in middle or late December and sample the month of January to ensure that the monitoring includes the annual initiation of the steelhead spawning season. However, the surveys conducted during the 2001/02 and 2008/09 seasons did not start until February 7, 2002, and February 11, 2009, respectively, when steelhead spawning was already in progress. To avoid any potential bias introduced by the data in these incomplete surveys, USACE did not include the steelhead cumulative proportions of newly constructed redds derived from these surveys in the fitting of the asymmetric logistic function (equation 2) that produced the temporal weighting coefficients for steelhead spawning in the lower American River.

Figure 12 displays the eight sets of daily cumulative proportions used in the fitting of the common asymmetric logistic function. To fit equation 2, the variable D (the days within each spawning season) was counted from midnight of November 30 of each year ($D = 1$) through midnight of July 1 of the following year, or midnight of June 30 if the following year is a leap year ($D = 213$). During the eight spawning seasons, the total number of new redds observed per season was variable (215 in 2002/03, 197 in 2003/04, 155 in 2004/05, 176 in 2006/07, 79 in 2009/10, 89 in 2010/11, 75 in 2011/12, and 317 in 2012/13). The number of weekly surveys performed during each spawning season ranged from seven weekly surveys during the 2002/03 season to 12 weekly surveys during the 2003/04 season.

Given the variation among each spawning season, a weighted nonlinear least-squares procedure was used to fit the common asymmetric logistic function (equation 2) to the eight sets of daily cumulative proportions of newly built redds. The weights were calculated as the ratio of the annually counted redds to the overall total number of counted redds over the eight sampled seasons (1,303 newly-built redds). For example, the 12 daily cumulative proportions of redds built during the 2003/04 spawning season each received a weight of 0.1512 (197/1,303 = 0.1512), while the eight daily cumulative proportions of redds built during the 2011/12 spawning season each received a weight of 0.0576 (75/1,303 = 0.0576), and the nine daily cumulative proportions of redds built during the 2012/13 spawning season each received a weight of 0.2433 (317/1,303 = 0.2433).

The resulting fitted curve had the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(6.5517 - 0.0922 \times D\right)} \right)^{1/1.0078}, \qquad \textbf{(8)}$$

where D is the day number at which new steelhead redds were observed during a particular annual survey, counted from midnight of November 30 of each year. The mean-square error of this fit was 0.0250.

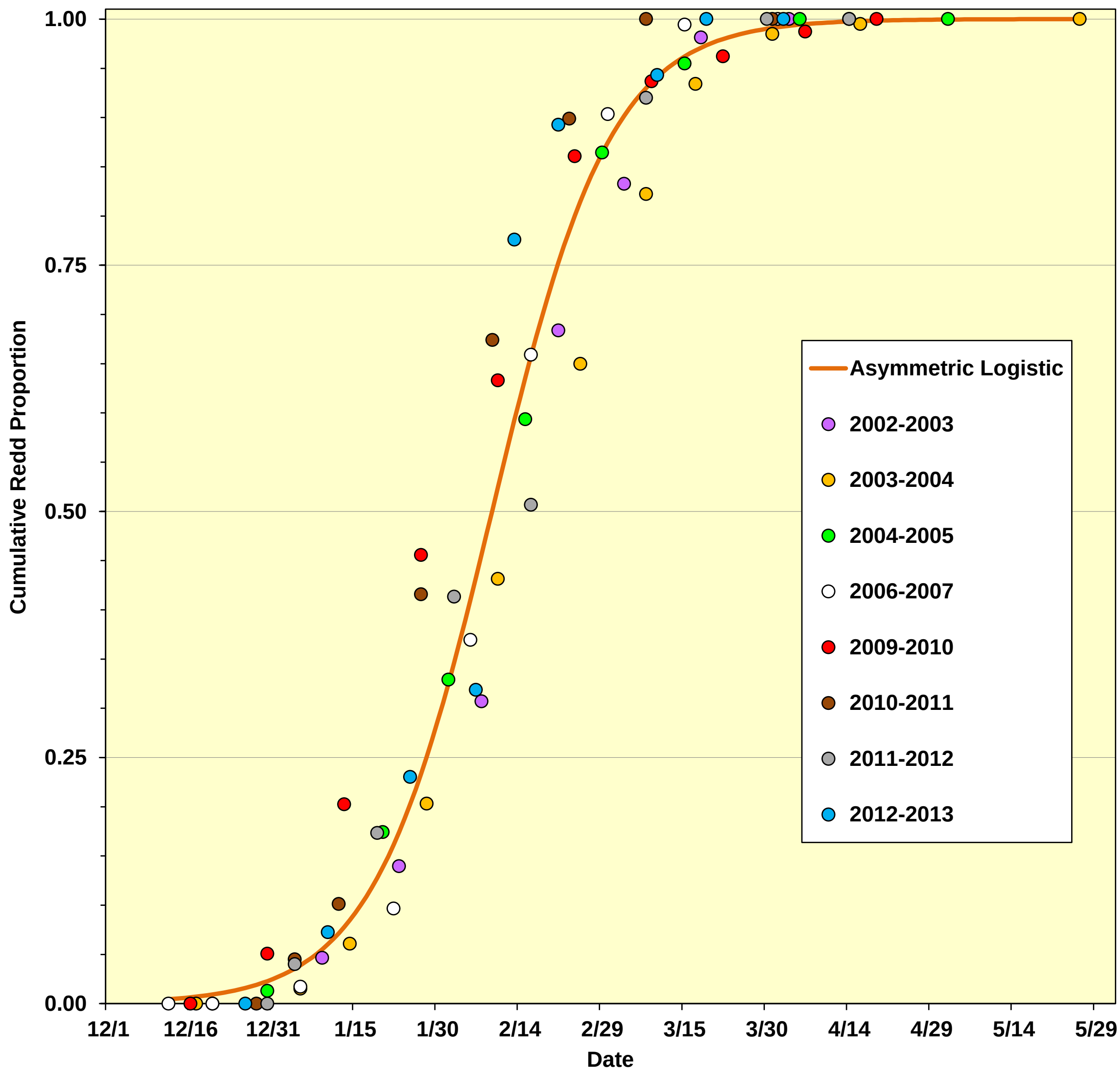

Figure 12. Steelhead Cumulative Proportions of Newly Constructed Redds in the Lower American River during the 2002/03 through 2012/13 Spawning Seasons and the Fitted Asymmetric Logistic Curve.

The cumulative distribution from equation 8 was first trimmed to daily cumulative values between 0.005 and 0.995, and the remaining daily cumulative values were used to calculate the expected daily spawning proportions by subtraction. Finally, the daily temporal coefficients for steelhead were obtained by rounding the daily proportions to four decimal places and rescaling to the sum of the rounded proportions. **Figure 13** and **Table 7** display the final daily weighting coefficients for steelhead spawning in the lower American River, and the resulting spawning period used in the calculation of the scaled composite WUA annual index ($CWUA_Y$) for steelhead. The resulting spawning period extends from December 14 through April 5, a period of K = 114 days.

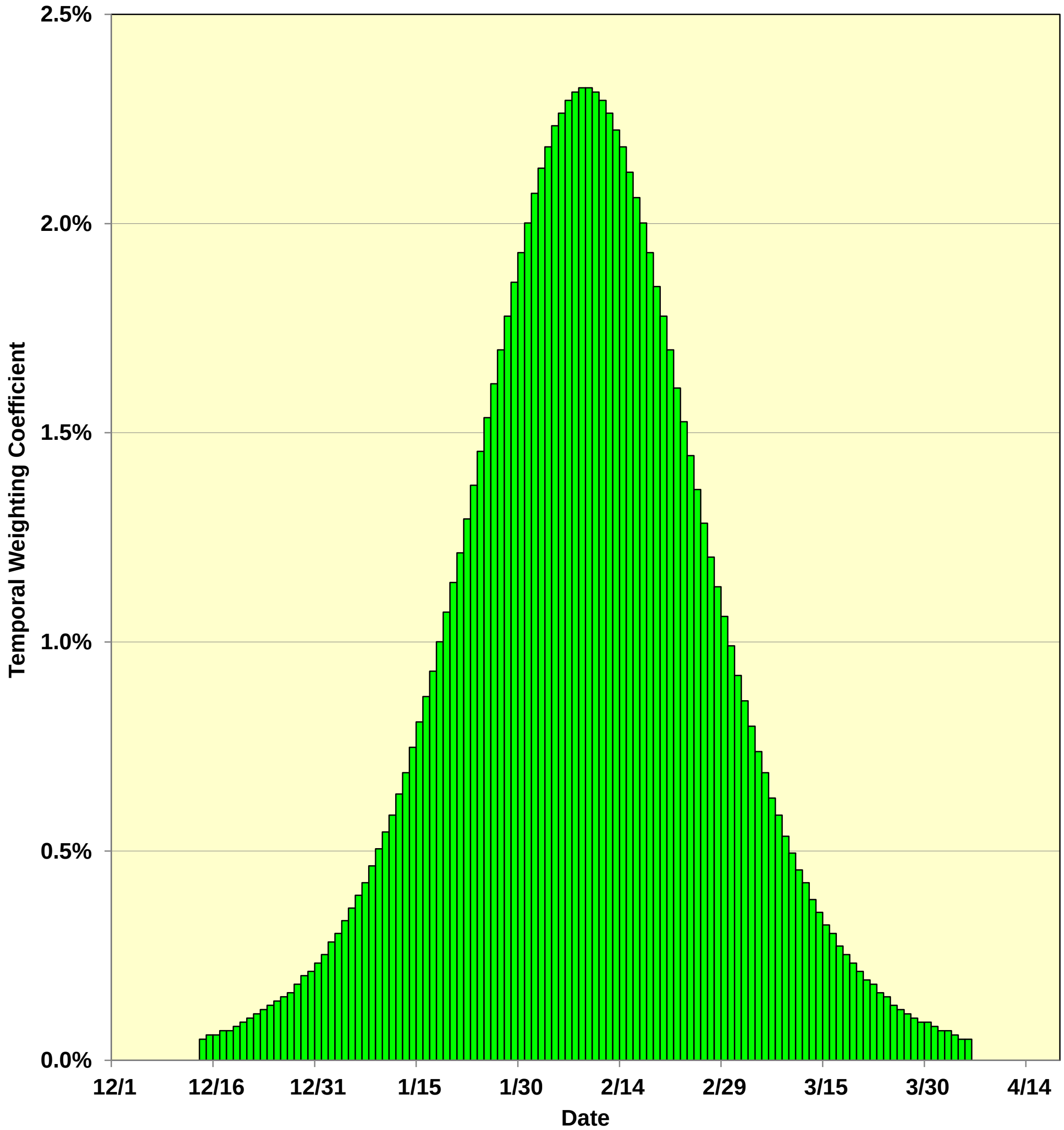

Figure 13. Daily Temporal Weighting Coefficients Used for Steelhead Spawning in the Lower American River from December 14 through April 5.

Table 7. Temporal Weighting Coefficients Used for Steelhead Spawning in the Lower American River.

Day	Estimated Redd Proportion (%)	Temporal Weighting Coefficient	Day	Estimated Redd Proportion (%)	Temporal Weighting Coefficient
12/13	0.00%	0.000000	**2/9**	2.30%	0.023246
12/14	0.05%	0.000505	**2/10**	2.29%	0.023145
12/15	0.06%	0.000606	**2/11**	2.27%	0.022943
12/16	0.06%	0.000606	**2/12**	2.24%	0.022640
12/17	0.07%	0.000707	**2/13**	2.20%	0.022236
12/18	0.07%	0.000707	**2/14**	2.16%	0.021831
12/19	0.08%	0.000809	**2/15**	2.10%	0.021225
12/20	0.09%	0.000910	**2/16**	2.04%	0.020619
12/21	0.10%	0.001011	**2/17**	1.98%	0.020012
12/22	0.11%	0.001112	**2/18**	1.91%	0.019305
12/23	0.12%	0.001213	**2/19**	1.83%	0.018496
12/24	0.13%	0.001314	**2/20**	1.76%	0.017789
12/25	0.14%	0.001415	**2/21**	1.68%	0.016980
12/26	0.15%	0.001516	**2/22**	1.59%	0.016070
12/27	0.16%	0.001617	**2/23**	1.51%	0.015262
12/28	0.18%	0.001819	**2/24**	1.43%	0.014453
12/29	0.20%	0.002021	**2/25**	1.35%	0.013645
12/30	0.21%	0.002122	**2/26**	1.27%	0.012836
12/31	0.23%	0.002325	**2/27**	1.19%	0.012027
1/1	0.25%	0.002527	**2/28**	1.12%	0.011320
1/2	0.28%	0.002830	**2/29**	1.05%	0.010612
1/3	0.30%	0.003032	**3/1**	0.98%	0.009905
1/4	0.33%	0.003335	**3/2**	0.91%	0.009197
1/5	0.36%	0.003639	**3/3**	0.85%	0.008591
1/6	0.39%	0.003942	**3/4**	0.79%	0.007985
1/7	0.42%	0.004245	**3/5**	0.73%	0.007378
1/8	0.46%	0.004649	**3/6**	0.68%	0.006873
1/9	0.50%	0.005054	**3/7**	0.62%	0.006266
1/10	0.54%	0.005458	**3/8**	0.58%	0.005862
1/11	0.58%	0.005862	**3/9**	0.53%	0.005357
1/12	0.63%	0.006367	**3/10**	0.49%	0.004952
1/13	0.68%	0.006873	**3/11**	0.45%	0.004548
1/14	0.74%	0.007479	**3/12**	0.42%	0.004245
1/15	0.80%	0.008086	**3/13**	0.38%	0.003841
1/16	0.86%	0.008692	**3/14**	0.35%	0.003537
1/17	0.92%	0.009299	**3/15**	0.32%	0.003234
1/18	0.99%	0.010006	**3/16**	0.30%	0.003032
1/19	1.06%	0.010714	**3/17**	0.27%	0.002729
1/20	1.13%	0.011421	**3/18**	0.25%	0.002527
1/21	1.20%	0.012129	**3/19**	0.23%	0.002325
1/22	1.28%	0.012937	**3/20**	0.21%	0.002122
1/23	1.36%	0.013746	**3/21**	0.19%	0.001920
1/24	1.44%	0.014554	**3/22**	0.18%	0.001819
1/25	1.52%	0.015363	**3/23**	0.16%	0.001617
1/26	1.60%	0.016171	**3/24**	0.15%	0.001516
1/27	1.68%	0.016980	**3/25**	0.13%	0.001314
1/28	1.76%	0.017789	**3/26**	0.12%	0.001213
1/29	1.84%	0.018597	**3/27**	0.11%	0.001112
1/30	1.91%	0.019305	**3/28**	0.10%	0.001011
1/31	1.98%	0.020012	**3/29**	0.09%	0.000910
2/1	2.05%	0.020720	**3/30**	0.09%	0.000910
2/2	2.11%	0.021326	**3/31**	0.08%	0.000809
2/3	2.16%	0.021831	**4/1**	0.07%	0.000707
2/4	2.21%	0.022337	**4/2**	0.07%	0.000707
2/5	2.24%	0.022640	**4/3**	0.06%	0.000606
2/6	2.27%	0.022943	**4/4**	0.05%	0.000505
2/7	2.29%	0.023145	**4/5**	0.05%	0.000505
2/8	2.30%	0.023246	**Totals**	98.94%	1

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Appendix 7F

1.1 Analysis of Potential Redd Dewatering for Lower American River Salmonids

Flow fluctuations during the fall-run Chinook salmon and steelhead embryo incubation periods are important to fisheries management because reductions in flow can decrease water surface elevations below the depth at which the redds were built. Dewatered redds can result in desiccation and the loss of eggs and developing embryos.

The biological effect of redd dewatering is determined by both the timing and duration of the desiccation and by the magnitude of the decrease in water surface elevation. For example, a decrease in flow can cause the water surface elevation to decrease only to the depth of the undisturbed bed surface without reaching the redd egg pocket that is located deeper within the redd tail spill (A in **Figure 1**). In this situation, the egg pocket can remain wetted, a situation that reduces the potential severity of the effect on eggs and developing embryos. By contrast, if the decrease in flow causes water surface elevation to drop below the depth of the egg pocket (B in Figure 1), the egg pocket can potentially desiccate, a situation that reduces the likelihood of survival of eggs and developing embryos in the redd.

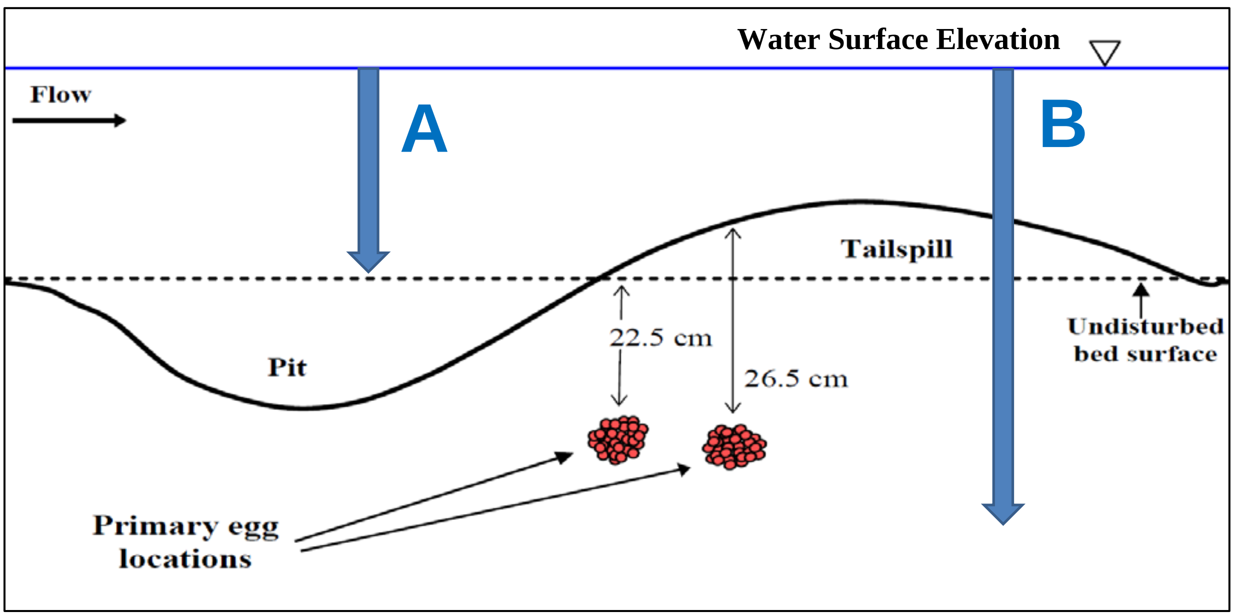

Figure 1. Diagrammatic Side View of a Chinook Salmon Redd Showing the Relative Location and Mean Depth of Egg Pockets, Modified from Evenson (2001).

Given the potentially severe effects of redd dewatering on the survival of eggs and developing embryos, other authors have attempted to directly measure redd dewatering and monitoring of the potential effect of redd dewatering in the lower American River during particular spawning seasons of fall-run Chinook salmon and steelhead, as further described below.

As part of the Chinook salmon redd surveys conducted in the lower American River during the 1991/1992 through the 1995/1996 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider, Urquhart, McEwan, and Munos 1993; Snider and Vyverberg 1995, 1996; Snider et al. 1996), the authors attempted to evaluate the percentage of Chinook salmon redds dewatered by changes in flow that occurred during the survey seasons. During these surveys, the potential dewatering of redds was evaluated by comparing redd locations traced from photographs made at higher flows with photographs of the same locations taken during subsequent, lower-flow conditions. Redd locations no longer inundated were considered to be dewatered. The total number of dewatered redd locations was then expressed as a percentage of the total number of newly constructed redds counted over the entire annual survey.

Because flows either did not decrease or decreased very little during the survey periods, no dewatering of fall-run Chinook salmon redds was observed during the redd surveys corresponding to the 1993/1994, 1994/1995 and 1995/1996 spawning seasons (Snider and Vyverberg 1995, 1996; Snider et al. 1996). During the 1991/1992 fall-run Chinook salmon spawning season, 15 redds located in Sunrise riffles and 25 redds built in Sailor Bar riffles (a total of 40 redds, about 2.5 percent of the 1,626 redds observed during the redd survey period) were considered dewatered when flows dropped from 2,500 cubic feet per second (cfs) to less than 1,000 cfs (Snider and McEwan 1992). No dewatering was reported for the 1992/1993 fall-run Chinook salmon spawning season.

More recently, cbec (2014) estimated the potential for Chinook salmon redd dewatering during the 2013 Chinook salmon spawning season. cbec used Chinook salmon redd survey data provided by Cramer Fish Sciences and a suite of two-dimensional (2-D) hydraulic models developed by cbec for specific reaches of the lower American River. The redd data used in the analysis consisted of ground global positioning system (GPS) observations collected only at gravel augmentation sites and any side channels associated with those sites during surveys conducted on October 28, November 1, November 21, and November 22, 2013. Additionally, redd data included digitized redd locations from a geo-rectified high-resolution aerial photograph of the Lower Sunrise Side Channel (not a gravel augmentation site) taken November 25, 2013.

A suite of five individual 2-D hydraulic models that used the most recent topographic/bathymetric data available at the time of analysis was used to simulate water surface elevations at flow rates of 200, 250, 300, 350, 400, 450, 500, 800, 1,000, 1,250, 1,330, 1,500, and 2,000 cfs. The available 2,150 redd locations were compared with the extent of the inundated areas simulated by the models for the 200-through-2,000-cfs flows. If a particular redd location fell outside the area inundated, it was considered to be dewatered.

cbec's analysis showed that, as flows decreased from 2,000 cfs to 1,000 cfs, very few redds were dewatered (**Figure 2**). When flow decreased to 800 cfs, roughly 2.3 percent of the sampled redds were potentially dewatered (i.e., left outside the inundated area predicted by the 2-D hydraulic models). The expected percentage of the redds dewatered as flows decrease in increments from 800 cfs to 200 cfs increased at a fairly rapid rate, particularly as flow decreases from 400 cfs to 350 cfs. When flow drops to only 200 cfs, 57.2 percent of the sampled redds might be dewatered.

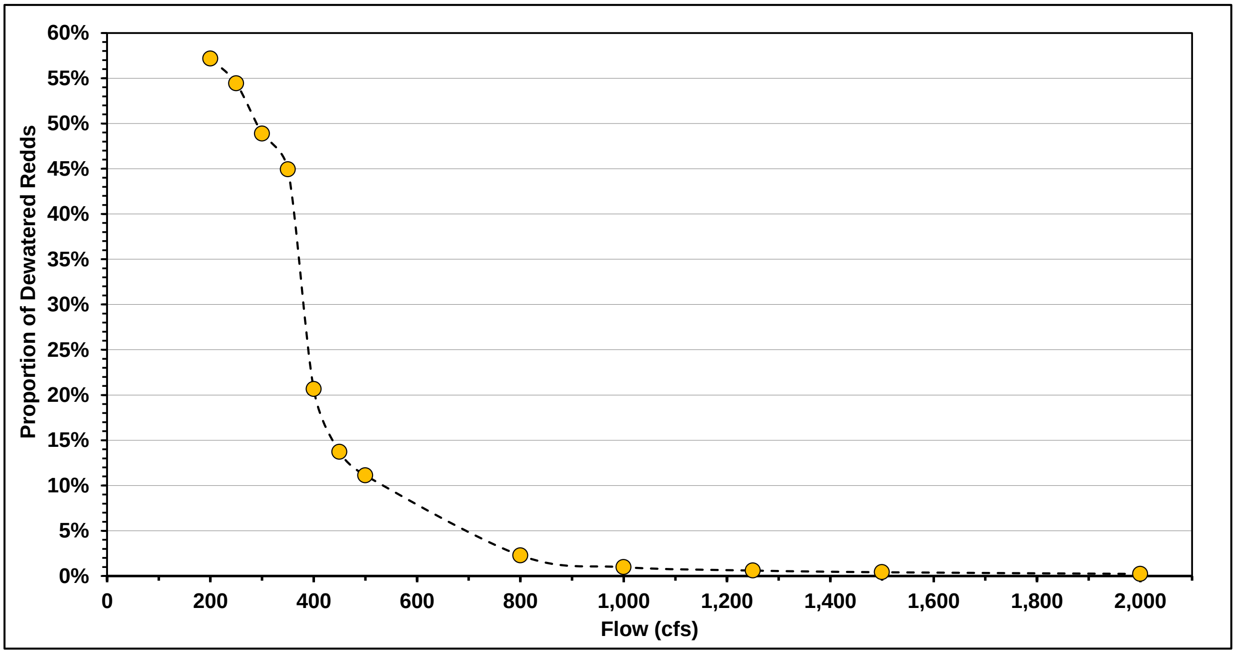

Figure 2. Estimated Percentages of Dewatered Chinook Salmon Redds as a Function of Flow. Data are based on 2,150 redd locations sampled at various gravel augmentation sites in the lower American River and at the Lower Sunrise Side Channel during 2013, and 2-D modeling of inundated areas at various flow rates (cbec 2014).

Hannon and Deason (2005) also attempted to evaluate redd dewatering during lower American River steelhead redd surveys for the 2002/2003, 2003/2004, and 2004/2005 steelhead spawning seasons. During these surveys, redd monitoring was concentrated on redds built in the Lower Sunrise Side Channel located at river mile (RM) 19. A total of 16, 13, and seven steelhead redds were built at this site during the 2002/2003, 2003/2004, and 2004/2005 steelhead spawning seasons, respectively. Fifteen of the 16 redds observed during the 2002/2003 season were built after flood-control releases raised flow up to 5,500 cfs between February 11 and 18, 2003. When flow ramped down to 2,000 cfs through the remainder of the spawning period, five redds were dewatered, representing 31.3-percent dewatering with respect to all redds built in the side channel during the entire 2002/2003 season.

Eleven of the 13 redds observed in the Lower Sunrise Side Channel site during the 2003/2004 spawning season were built between February 19 and 28, 2004, after flows increased up to 7,000 cfs. Five of these redds were later dewatered when flow decreased to 3,000 cfs, representing a 38.5-percent dewatering of all redds built in the side channel during the 2003/2004 spawning season.

Finally, the seven redds observed in the Lower Sunrise Side Channel during the 2004/2005 steelhead spawning season were built during two flood-control releases of 8,000 cfs in mid-February 2005. Four of these redds were later dewatered when flows decreased to about 2,000 cfs through mid-March, representing a 57.1-percent dewatering of all redds built in the side channel during the entire 2004/2005 season.

However, the estimates of Chinook salmon and steelhead redd dewatering discussed above cannot be directly integrated in the U.S. Army Corps of Engineers' (USACE) assessment of the potential for redd dewatering in the lower American River with the Folsom Water Control Manual (WCM) Project alternatives because of the sporadic nature of the estimates, among other reasons. These estimates represent different annual flow and environmental conditions, different spatial and temporal distributions of the annual spawning activity of Chinook salmon and steelhead, and often different estimation and sampling techniques.

Evaluating the potential redd dewatering effects of flow fluctuations on spawning salmonids typically involves calculating flow (or river stage) reductions between consecutive days along the spawning area during the spawning and embryo incubation season and expressing the number of stage reductions of a given magnitude that occurred during the spawning and embryo incubation period. Interpretations of results using this approach are often limited because information concerning the percentage of the spawning population potentially affected by the stage reductions occurring during the spawning and embryo incubation season is not incorporated. In general, most redds are constructed during identifiable peaks of fall-run Chinook salmon and steelhead spawning activity, with variable overall temporal and spatial distributions.

For this analysis, USACE analyzed the potential for fall-run Chinook salmon and steelhead redd dewatering due to daily flow fluctuations in the lower American River with the Folsom WCM alternatives and the bases of comparison through an annual weighted redd dewatering index. In this index, the potential for redd dewatering because of changes in daily flows and corresponding changes in river stage are weighted by the expected temporal and spatial distributions of Chinook salmon and steelhead spawning activity in the lower American River. In addition to the information on the expected temporal and spatial distributions of spawning activity, the index incorporates information on the expected depth distributions of Chinook salmon and steelhead redds, on the duration of embryo incubation based on simulated water temperatures, and on the maximum river stage reduction through fry emergence experienced by redds of a same cohort (i.e., redds built on the same day and within the same spawning area or reach during a spawning season).

The annual weighted redd dewatering index (WRD_Y) provides annual estimates of the maximum proportions of redds, relative to the total number of redds built during the species spawning periods, that were potentially dewatered at least once due to decreases in flow and associated drops in water surface elevation occurring from the date of redd construction through the corresponding date of expected fry emergence. In WRD_Y, the changes in water surface elevation or river stage are evaluated against the overall distributions of Chinook salmon and steelhead redd depths in the lower American River measured at the level of the undisturbed bed surface of the redd (A in Figure 1).

Details on the calculation of the annual dewatering index as well as on the various distributions used in the calculations are provided in the following sections.

1.1.1 Annual Weighted Redd Dewatering Index

The annual weighted redd dewatering index (WRD_Y) provides an annual estimate of the expected maximum proportion of redds, relative to the total number of redds built during the species spawning periods, that were potentially dewatered at least once due to decreases in flow and associated drops in water surface elevation occurring from the date of redd construction through the corresponding date of fry emergence. The equation describing the annual weighted redd dewatering index is:

$$WRD_Y = \sum_{d=1}^{k} w_d \times \left\{ \sum_{h=1}^{18} w_h \times \left[\Pr\left(Redd\ Depth \le \underset{i=d+1 \to ED_{d,h,Y}}{\text{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right) \right) \right] \right\}. \qquad \textbf{(1)}$$

The primary components of equation 1 are described below.

- The factor w_d is a temporal weighting coefficient that indicates the proportion of redds built on a particular day (*d*) relative to all the redds expected to be built during the *k* days of the fall-run Chinook salmon or steelhead spawning periods over the species' entire spawning grounds. The sum of the daily temporal weighting coefficients over the entire spawning season equals 1 ($\sum_{d=1}^{k} w_d = 1$). See **Section F-2** for further details on the temporal weighting coefficients for fall-run Chinook salmon and steelhead spawning in the lower American River.
- The factor w_h is a spatial weighting coefficient that indicates the proportion of redds built on a particular area (*h*) relative to all the redds expected to be built on any given day of the spawning season over the 18 areas in which the lower American River spawning grounds of fall-run Chinook salmon and steelhead are divided. For any given day of the species' spawning season, the sum of the spatial weighting coefficients over the entire spawning ground equals 1 ($\sum_{h=1}^{18} w_h = 1$). See **Section F-3** for further details on the calculation of the spatial weighting coefficients for fall-run Chinook salmon and steelhead spawning in the lower American River.
- The variable $ED_{d,h,Y}$ indicates the duration (in number of days) of the embryo incubation for redds built on day *d* of year *Y* in spawning area *h*. The values of the variables are derived from the time series of simulated daily water temperatures for each of the simulated years with the Folsom WCM alternatives and bases of comparison. See **Section F-4** for details on the calculation of $ED_{d,h,Y}$ for fall-run Chinook salmon and steelhead spawning in the lower American River.
- The variable $Stage_{d,h,Y}$ indicates the mean daily river stage in spawning area *h* on redd construction day *d* of year *Y*. The variable $Stage_{i,h,Y}$ indicates the mean daily river stage in the same spawning area, on any day *i* subsequent to the date of redd construction, until the last day of the calculated embryo incubation period for the redds built on day *d* ($ED_{d,h,Y}$). For each redd cohort (i.e., the group of redds built on the same day *d* and in the same spawning area *h*), the positive river-stage differences between $Stage_{d,h,Y}$ and $Stage_{i,h,Y}$ are evaluated for each day within the period *d*+1 through $ED_{d,h,Y}$ to determine the maximum river-stage difference:

$\underset{i=d+1 \to ED_{d,h,Y}}{\text{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right)$. This value is equivalent to the maximum drop in water surface elevation experienced by redds built on day *d* in spawning area *h* during year *Y*.

- The expression $\Pr\left(Redd\ \ Depth \leq \underset{i=d+1 \to ED_{d,h,Y}}{\text{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right) \right)$ indicates the expected probability of redds being constructed at depths less or equal to the maximum river stage difference experienced by redds built in spawning zone *h* on day *d* throughout their embryo incubation periods. These probabilities were obtained from cumulative distributions of redd depths, measured at the level of the undisturbed bed surface of the redd, that were developed for fall-run Chinook salmon and steelhead spawning in the lower American River (see details in Section F-5).

Once USACE calculated the annual index (WRD_Y) for fall-run Chinook salmon and steelhead spawning in the lower American River using average daily flows (and associated river stages) and average daily water temperatures modeled with the Folsom WCM alternatives and the bases of comparison during each of the years simulated, the resulting annual indices were averaged over the entire simulation period and by water year type for comparison with the Folsom WCM alternatives relative to the bases of comparison.

1.1.2 Temporal Weighting Coefficients

The annual weighted redd dewatering index uses temporal weighting coefficients to indicate the proportion of redds expected to be built on each day of the assumed spawning periods, based on the expected spawning temporal distributions for fall-run Chinook salmon and steelhead.

In general, to calculate the temporal weighting coefficients, spawning timing is described as an asymmetric logistic function of time. The asymmetric logistic function, also known as Richards sigmoidal curve (Ratkowsky 1983), has the following expression:

$$Y_D = \left(\frac{1}{1 + \exp\left(\alpha + \beta \times D \right)} \right)^{1/\delta} \quad \textbf{(2)}$$

where Y_D is the expected cumulative proportion of spawning through day *D*, and α, β, and δ are parameters that determine the shape of the cumulative curve. The variable *D* is a continuous variable that indicates the day number at which new spawning occurs during a particular spawning season, counting from a particular starting date. In order to estimate the values of α, β, and δ, the daily cumulative proportions of newly built redds, reported in available annual redd survey reports, were normally used as a proxy for Y_D and fitted to the asymmetric logistic model through a nonlinear least-squares procedure.

In the case of fall-run Chinook salmon spawning in the lower American River, the data describing Y_D arose from combining information in available carcass and redd survey annual reports. Once equation 2 was fitted to the fall-run Chinook salmon or steelhead data, the fitted curve was rescaled to the assumed spawning period of the species, and the daily temporal weighting coefficients w_d were calculated by subtraction (see **Appendix X [LAR Spawning WUA Appendix]** for details on this procedure).

1.1.2.1 Fall-run Chinook Salmon

USACE derived the temporal weighting coefficients used for fall-run Chinook salmon spawning in the lower American River from data collected by both redd surveys and carcass surveys. Redd surveys that provide the cumulative distribution of newly built redds over time, which is a better descriptor of spawning timing, were performed only during the 1991/1992 through the 1995/1996 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider, Urquhart, McEwan, and Munos 1993; Snider and Vyverberg 1995, 1996; Snider et al. 1996). On the other hand, fall-run Chinook salmon carcass surveys have been performed annually since the late 1960s, and data or reports are available for all surveys performed from October 1992 through October 2012 (Snider and Bandner 1996; Snider and Reavis 1996; Snider, Keenan, and Munos 1993; Snider et al. 1995; Healey 2002, 2003, 2004, 2005, 2006; Healey and Fresz 2007; Healey and Redding 2008; Vincik and Kirsch 2009; Vincik and Mamola 2010; Maher et al. 2012; Phillips and Helstab 2013; Phillips and Maher 2013).

USACE used the temporal distributions of fresh carcasses described in these reports to estimate an overall cumulative distribution of fresh carcasses over time that describes when fresh carcasses appear in the surveys, which is subsequent to the actual time of spawning and redd construction. The time elapsing between (1) spawning and red construction and (2) post-spawning mortality has been reported to typically be between 2 and 4 weeks (Briggs 1953). To take advantage of the information on fall-run Chinook salmon spawning timing in the lower American River in the available redd and carcass surveys, USACE developed a five-step procedure to estimate the sigmoidal curve describing fall-run Chinook salmon spawning timing in the lower American River (see Appendix X [LAR Spawning WUA Appendix] for details on the five-step procedure).

USACE used the lagged asymmetric logistic curve resulting from the five-step procedure to calculate expected daily spawning proportions by subtraction. The daily expected proportions were rounded to four decimal places and scaled to sum to 1 over the spawning period of fall-run Chinook salmon to generate the final temporal weighting coefficients (**Figure 3**). The range of dates for which the proportions are greater than zero defined the fall-run Chinook salmon spawning period in the lower American River that extends from October 13 through January 18, a period of k = 98 days.

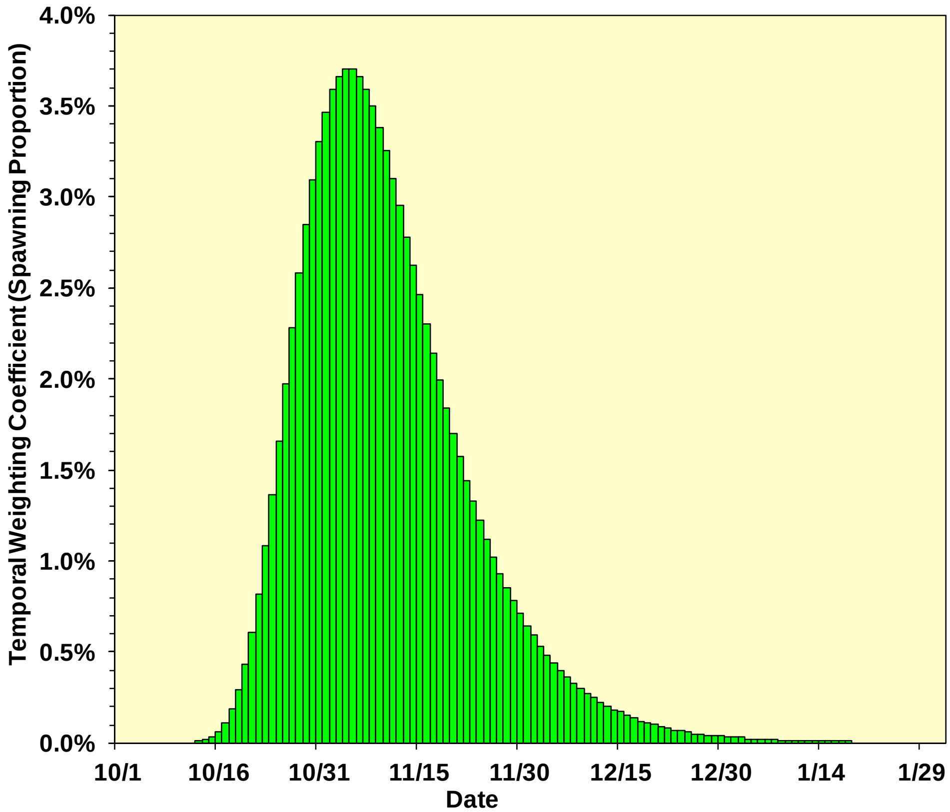

Figure 3. Temporal Weighting Coefficients Used for Fall-run Chinook Salmon Spawning in the Lower American River from October 13 through January 18.

1.1.2.2 Steelhead

USACE derived the temporal weighting coefficients used for steelhead spawning in the lower American River from the steelhead redd surveys performed by Reclamation and CDFW from February 2002 through April 2013 (Chase 2010; Hannon 2011, 2012, 2013; Hannon and Healey 2002; Hannon et al. 2003; Hannon and Deason 2004, 2005, 2007; See and Chase 2009). Data from eight annual steelhead redd surveys were used in the fitting of the asymmetric logistic function (equation 2). The available data correspond to cumulative redd proportions for the sampled weeks of the 2002/2003, 2003/2004, 2004/2005, 2006/2007, 2009/2010, 2010/2011, 2011/2012 and 2012/2013 spawning seasons (see Appendix X [LAR Spawning WUA Appendix] for details on the fitting of equation 2).

The cumulative distribution resulting from the fit of equation 2 was first trimmed to daily cumulative values between 0.005 and 0.995, and the remaining daily cumulative values were used to calculate the expected daily spawning proportions by subtraction. Finally, the daily temporal coefficients for steelhead were obtained by rounding the daily proportions to four decimal places and rescaling to the sum of the rounded proportions.

Figure 4 displays the final temporal weighting coefficients for steelhead spawning in the lower American River and the resulting spawning period used in the calculation of the annual redd dewatering index

($CWUA_Y$) for steelhead. The resulting steelhead spawning period extends from December 14 through April 5, a period of k = 114 days.

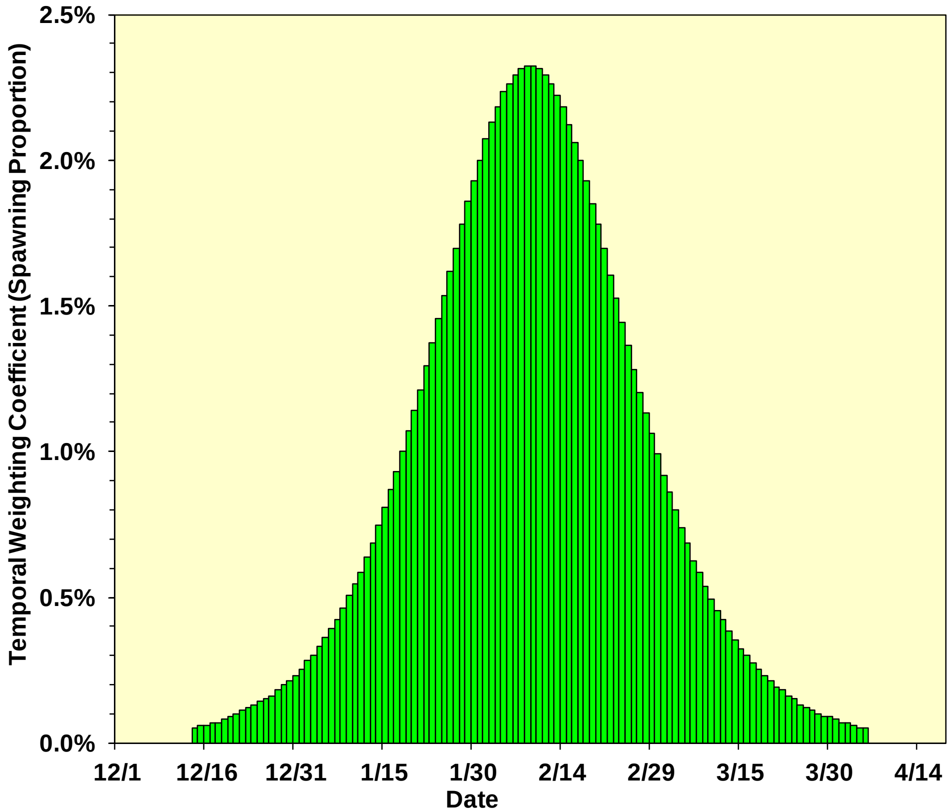

Figure 4. Temporal Weighting Coefficients Used for Steelhead Spawning in the Lower American River from December 14 through April 5.

1.1.3 Spatial Weighting Coefficients

The spatial weighting coefficients (wh) indicate the relative importance of particular spawning areas h with respect to the entire spawning grounds of the species, as represented by the proportions of redds built in a particular area relative to all the redds expected to be built on any given day of the spawning season over the fall-run Chinook salmon and steelhead spawning grounds in the lower American River.

The numbers of observed newly built redds by each river mile of the lower American River obtained from available fall-run Chinook salmon and steelhead redd surveys suggested the demarcation of 18 reaches or spawning areas that summarize the spawning activity of both species along the lower American River. USACE obtained the values of the spatial weighting coefficients for fall-run Chinook and steelhead spawning in the lower American River by summing the redd observations from available redd survey data within each reach and dividing by the total number of redds observed along the entire spawning grounds for fall-run Chinook and for steelhead.

1.1.3.1 Fall-run Chinook Salmon

USACE calculated the spatial weighting coefficients for fall-run Chinook salmon from redd observations by river mile collected during the 1991/1992 through the 1995/1996 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider, Urquhart, McEwan, and Munos 1993; Snider et al. 1996; Snider and Vyverberg 1995, 1996). **Table 1** displays the redd data and the resulting spatial weighting coefficients for fall-run Chinook salmon spawning in the lower American River.

1.1.3.2 Steelhead

USACE calculated the spatial weighting coefficients for steelhead from redd observations by river mile collected during seven steelhead spawning seasons: 2002/2003, 2003/2004, 2004/2005, 2006/2007, 2010/2011, 2011/2012, and 2012/2013 (Hannon 2013, Table 3). **Table 2** displays the redd data and the resulting spatial weighting coefficients for steelhead spawning in the lower American River.

Table 1. Distribution of Observed Redds by River Mile for Fall-run Chinook Salmon in the Lower American River from 1991 through 1995 and Derived Spatial Weighting Coefficients by Spawning Reach.

RM	Number of redds by river mile in survey year:					Total	Spatial Weighting	
	1991	1992	1993	1994	1995	Redds	Coefficients	
22	121	369	1,277	418	560	2,745	0.174729	(17.5%)
21	191	2	1,322	280	561	2,356	0.149968	(15.0%)
20	427	266	1,587	572	1,054	3,906	0.248631	(24.9%)
19	314	220	663	391	595	2,183	0.138956	(13.9%)
18	154	96	164	297	115	826	0.052578	(5.3%)
17	189	9	787	424	601	2,010	0.127944	(12.8%)
16	86	123	13	83	63	368	0.023425	(2.3%)
15	11	0	177	58	66	312	0.019860	(2.0%)
14	33	38	49	56	115	291	0.018523	(1.9%)
13	20	0	20	59	87	186	0.011840	(1.2%)
12	30	1	0	15	45	91	0.005792	(0.6%)
11	0	1	30	0	1	32	0.002037	(0.2%)
10	6	0	4	61	39	110	0.007002	(0.7%)
9	32	6	71	12	12	133	0.008466	(0.8%)
8	0	0	0	1	17	18	0.001146	(0.1%)
7	0	0	21	14	28	63	0.004010	(0.4%)
6	12	7	20	18	15	72	0.004583	(0.5%)
5	0	0	0	6	2	8	0.000509	(0.1%)
Totals	1,626	1,138	6,205	2,765	3,976	15,710	1	(100%)

Table 2. Distribution of Observed Redds by River Mile for Steelhead in the Lower American River from 2003 through 2013 and Derived Spatial Weighting Coefficients by Spawning Reach.

RM	Number of redds by river mile in survey year:							Total Redds	Spatial Weighting Coefficients	
	2003	2004	2005	2007	2011	2012	2013			
22	28	31	40	33	32	38	65	267	0.225507	(22.6%)
21	46	45	27	25	17	17	118	295	0.249155	(24.9%)
20	11	2	6	9	0	6	19	53	0.044764	(4.5%)
19	21	21	10	21	2	10	33	118	0.099662	(10.0%)
18	16	8	3	13	1	1	11	53	0.044764	(4.5%)
17	11	10	0	18	3	1	4	47	0.039696	(4.0%)
16	4	2	3	18	9	1	28	65	0.054899	(5.5%)
15	22	20	11	7	10	0	2	72	0.060811	(6.1%)
14	15	13	5	3	4	0	2	42	0.035473	(3.5%)
13	15	6	3	1	0	0	1	26	0.021959	(2.2%)
12	5	17	2	9	9	0	21	63	0.053209	(5.3%)
11	7	2	3	1	0	0	0	13	0.010980	(1.1%)
10	5	0	1	12	0	0	0	18	0.015203	(1.5%)
9	9	9	3	2	0	0	12	35	0.029561	(3.0%)
8	0	0	0	0	0	0	0	0	0	(0%)
7	0	0	0	0	0	0	0	0	0	(0%)
6	0	0	0	0	0	0	0	0	0	(0%)
5	0	1	14	0	1	1	0	17	0.014358	(1.4%)
Totals	215	187	131	172	88	75	316	1,184	1	(100%)

1.1.4 Water Temperatures and Duration of Embryo Incubation

The annual dewatering index requires the calculation of the estimated duration of embryo incubation, in days, corresponding to each daily redd cohort being evaluated (i.e., $ED_{d,h,Y}$ for the proportion of redds built on day *d* of year *Y* at spawning area *h*). The approach to calculate the embryo incubation period for each fall-run Chinook salmon or steelhead redd cohort is based on lower American River daily water temperatures modeled at location *h* during the day of redd construction *d* and all subsequent days until fry emergence, expressed as accumulated thermal units (ATUs). An ATU is defined as degrees Fahrenheit (°F) above 32°F accumulated during a 24-hour period (CDFW 1998).

USACE used modeled daily average water temperatures for a given simulated year, starting on the day of a given redd's construction, to calculate the number of days required to reach the species-specific threshold ATUs (in °F) for egg incubation through fry emergence (detailed in sections **F-4.1 and F-4-2**, below). These calculations of the duration of embryo incubation are based on ATUs using annual series of daily water temperatures modeled with the Folsom WCM alternatives and the bases of comparison at locations corresponding to the 18 spawning reaches *h*.

The following sections provide details regarding how USACE obtained the ATU thresholds used in the calculations of the duration of embryo incubation for fall-run Chinook salmon and steelhead in the lower American River.

1.1.4.1 Fall-run Chinook Salmon Embryo Incubation

Several ATU thresholds have been identified in the literature for the development of Chinook salmon eggs from fertilization to hatching and from hatching through fry emergence. In its status review of spring-run Chinook salmon in the Sacramento River drainage, CDFW (1998), referring to Armour (1991), stated that the required number of ATUs from the time of egg fertilization to fry emergence was 1,550°F. Moreover, Amour (1991) stated that the development from fertilization to hatching required 850°F ATUs and that the development from hatching to fry emergence required an additional 700°F ATUs.

In a paper evaluating the development and applicability of an early version of the Chinook Salmon Early Lifestage Mortality Model, HCI (1996) stated that key model assumptions were the requirements of 750°F ATUs for the development from fertilized egg to hatching and of another 750°F ATUs for the development from hatching to emergent fry (i.e., a total of 1,500°F from fertilized egg to fry emergence).

In the technical memorandum describing the recent update of the Chinook Salmon Early Lifestage Mortality Model for the lower American River, the Water Forum and USACE (2015; **Appendix X**) reviewed the duration (days) to median hatch (50 percent hatch) and to median emergence (50 percent emergence) for fertilized eggs and pre-emergent fry reported in Seymour (1956), Beacham and Murray (1989), Murray and McPhail (1988), and Jensen and Groot (1991) and used these data to calculate the ATUs to 50 percent hatch and 50 percent fry emergence. They then combined these calculated ATUs with the ATUs to 50 percent hatch and 50 percent emergence for Chinook salmon eggs and pre-emergent fry from variable temperature incubations reported in Geist et al. (2011) to calculate the average ATU to 50 percent hatch (936°F) and the average ATU from 50 percent hatch to 50 percent emergence (713°F).

Therefore, USACE used an ATU threshold of 1,649°F (936°F + 713°F) to calculate the duration of embryo incubation through fry emergence ($ED_{d,h,Y}$) for all fall-run Chinook salmon redd cohorts. For each redd cohort represented by the proportion of fall-run Chinook salmon redds built on day *d* of year *Y* at spawning area *h* ($w_d \times w_h$ with *d* ranging from 1 through 98 and *h* from 1 through 18), the daily thermal units of day *d* (daily water temperature - 32°F) and subsequent days measured at location *h* were summed. A day was added to the embryo incubation period of the redd cohort under consideration while the sum of daily thermal units remained below or equal to 1,649°F.

1.1.4.2 F-4.2. Steelhead Embryo Incubation

Several ATU thresholds corresponding to the duration of embryo incubation through 50 percent hatch and fry emergence for steelhead have been reported in the literature. CDFW's restoration and management plan for California steelhead (McEwan and Jackson 1996) reported that steelhead preferred water temperatures for embryo incubation and fry emergence ranging from 48°F to 52°F. Additionally, they stated:

> *The length of time it takes for eggs to hatch depends mostly on water temperature. Hatching of steelhead eggs in hatcheries takes about 30 days at 51°F (Leitritz and Lewis 1980). Fry emerge from the gravel usually about four to six weeks after hatching, but factors such as redd depth, gravel size, siltation, and temperature can speed or retard this time (Shapovalov and Taft 1954).*

In a manual of hatchery methods for salmon and trout culture, Leitritz (1959) published a table indicating the number of days and ATUs required for development of eggs of various trout species, including *Oncorhynchus mykiss*, to hatch when incubating at constant temperatures ranging from 40°F to 60°F. In a more recent study on steelhead supplementation in rivers in Idaho, Byrne (1996) reported that Thurow (Intermountain Research Station, Boise, Idaho, unpublished data) estimated that 556 degrees Celsius (°C) (1,001°F) ATUs were needed for fry emergence to begin and 722°C (1,300°F) ATUs were needed for 95 percent emergence of hatchery steelhead that spawned naturally in the upper Salmon River, and used Thurow's estimated ATUs to predict the date of first fry emergence and the date that 95 percent of the fry had emerged in Beaver and Frenchman Creeks.

Kraus (1999), in a guide to classroom egg incubation in Alaska, stated that spring-run steelhead eggs require 360°C (648°F) ATUs to hatch and 600°C (1,080°F) ATUs to reach fry emergence. Hannon et al. (2003) used the same requirement of 600°C (1,080°F) ATUs to estimate the time to fry emergence in the report on American River steelhead spawning for 2001–2003.

For many salmonids, including steelhead, various models have been developed in recent decades to calculate the incubation and emergence times, expressed in days or hours, by fitting various functions of constant water temperatures to experimental embryo development data. For example, Crisp (1981) presented four models using a desktop study of the relationship between temperature and hatching time for the eggs of five species of salmonids, including *O. mykiss*. The equations of the four models presented for *O. mykiss* were obtained by fitting the models to 23 pairs of data points, each pair consisting of the water temperatures (T in °C) at which a batch of fertilized eggs is incubated and the corresponding time from egg fertilization to 50 percent hatch, expressed as days (D). The equations of the four *O. mykiss* models were:

- ***Model 1a***: $\log(D) = 2.6638 - 1.1623 \times \log(T)$ with r^2 = 0.978;
- ***Model 1b***: $\log(D) = 4.0313 - 2.0961 \times \log(T+6)$ with r^2 = 0.982;
- ***Model 2***: $\ln(D) = 4.9023 - 0.1384 \times T$ with r^2 = 0.960; and
- ***Model 3b***: $\log(D) = 2.3475 - 0.1123 \times T + 0.00278 \times T^2$ with r^2 = 0.976.

Recognizing the limited data available to develop species-specific equations relating water temperatures (T in °C) at which a batch of fertilized eggs is incubated and the corresponding time from egg fertilization to 50 percent fry emergence, Crisp (1988) collected data on time to 50 percent hatch and corresponding time to 50 percent fry emergence, both expressed in days, obtained from embryo incubation experiments conducted at various constant temperatures ranging from 2.8°C to 12°C (37.0°F to 53.6°F). The data consisted of 60 pairs of duration data encompassing six salmonid species (*Salmo salar*, *S. trutta*, *O. keta*, *O. kisutch*, *O. tshawytscha*, and *O. gorbuscha*). Disregarding the individual species, Crisp (1988) used the data for all species to fit a common linear relationship that would allow the prediction of time to 50 percent fry emergence ($D_{50\%E}$, days) based on the more abundant data on time to 50 percent hatch (

$D_{50\%H}$, days). The fitted equation, $D_{50\%E} = 5.367 + 1.660 \times D_{50\%H}$, was statistically significant ($P <$ 0.001) with an $r^2 = 0.947$.

More recently, in the program IncubWin (Jensen and Jensen 1999) and in its updated version WinSIRP (Jensen et al. 2009), the time to 50 percent hatch of steelhead eggs was derived from a set of two equations resulting from fitting Schnute's Growth Model to water temperatures (T in °C) and developmental time expressed in hours (D). The two equations describing the time to 50 percent hatch are:

$D = 24 \times \left(139.2562^{2.3613821} + \left(139.2562^{2.3613821} - 18.3476^{2.3613821}\right) \times Z\ \right)^{1/2.3613821}$ with Z expressed as $Z = \dfrac{\left(1 - \exp\left(-1 \times 0.408414 \times (T - 1)\right)\right)}{\left(1 - \exp\left(-1 \times 0.408414 \times (19)\right)\right)}$.

In the same programs, the time to steelhead fry emergence expressed in hours was described by a modified Bělehrádek model, with a fitted equation of $D = \dfrac{22{,}129{,}193.76}{\left(T + 14.1975994\right)^{3.00725581}}$.

The above information on steelhead time to 50 percent hatch and time to fry emergence expressed in days is summarized in **Table 3** and was used by USACE to calculate steelhead ATUs in °F-day to 50 percent hatch and fry emergence. USACE used the equations reported in Crisp (1981, 1988), Jensen and Jensen (1999), and Jensen et al. (2009)to estimate the time to 50 percent hatch ($D_{50\%H}$) and time to fry emergence (D_E) for temperatures (T) within the 48°F–52°F range reported by McEwan and Jackson (1996) as preferred temperatures for steelhead embryo incubation and fry emergence. The corresponding ATUs were then calculated as the products of $D_{50\%H}$ or D_E and T – 32°F.

Table 3. Estimated Times (in Days) and Accumulated Thermal Units (ATUs) to 50 Percent Hatch and Fry Emergence for Steelhead Embryos Incubating at Temperatures Ranging from 40°F to 52°F.

Water Temperature (°F)	Time to 50% Hatch (days)	ATU to 50% Hatch (°F-days)	Reference
40.0	80.0	640	Table 4 in Leitritz (1959)
45.0	48.0	624	
50.0	31.0	558	
55.0	24.0	552	
60.0	19.0	532	
51.0	30.0	570	Leitritz and Lewis (1980)
48.0	36.4	582	Crisp (1981) model 1a
49.0	33.9	577	
50.0	31.7	571	
51.0	29.8	566	
52.0	28.1	561	
48.0	37.4	598	Crisp (1981) model 1b
49.0	34.6	589	
50.0	32.2	579	
51.0	29.9	569	
52.0	27.9	559	
48.0	39.3	629	Crisp (1981) model 2
49.0	36.4	619	
50.0	33.7	607	
51.0	31.2	593	
52.0	28.9	578	
48.0	37.1	593	Crisp (1981) model 3b
49.0	34.3	583	
50.0	31.8	572	
51.0	29.6	563	
52.0	27.7	555	
48.0	38.3	613	Jensen and Jensen (1999) Schnute's growth model
49.0	35.4	602	
50.0	32.9	592	
51.0	30.6	582	
52.0	28.6	573	
---	---	648	Kraus (1999)
Average ATU to 50% hatch: 585 (°F-days)			

Water Temperature (°F)	Time to Fry Emergence (days)	ATU to Fry Emergence (°F-days)	Reference
40.0	138.2	1,105	Table 4 in Leitritz (1959) and Crisp (1988) equation
45.0	85.0	1,106	
50.0	56.8	1,023	
55.0	45.2	1,040	
60.0	36.9	1,033	
51.0	55.2	1,048	Leitritz and Lewis (1980) and Crisp (1988) equation
48.0	65.8	1,052	Crisp (1981) model 1a and Crisp (1988) equation
49.0	61.7	1,048	
50.0	58.0	1,045	
51.0	54.8	1,042	
52.0	52.0	1,039	
48.0	67.4	1,079	Crisp (1981) model 1b and Crisp (1988) equation
49.0	62.9	1,069	
50.0	58.8	1,058	
51.0	55.1	1,046	
52.0	51.7	1,035	
48.0	70.7	1,131	Crisp (1981) model 2 and Crisp (1988) equation
49.0	65.8	1,119	
50.0	61.4	1,104	
51.0	57.2	1,087	
52.0	53.4	1,067	
48.0	66.9	1,070	Crisp (1981) model 3b and Crisp (1988) equation
49.0	62.2	1,058	
50.0	58.2	1,047	
51.0	54.6	1,037	
52.0	51.4	1,028	
48.0	73.2	1,172	Jensen and Jensen (1999) modified Beleradek model
49.0	68.2	1,159	
50.0	63.6	1,145	
51.0	59.4	1,129	
52.0	55.6	1,111	
---	---	1,001	Byrne (1993)
---	---	1,300	
---	---	1,080	Kraus (1999)
---	---	1,080	Hannon *et al*. (2003)
Average ATU to fry emergence: 1,080 (°F-days)			

USACE's analysis of redd dewatering for American River steelhead uses an ATU threshold of 1,080°F (the average ATU to fry emergence displayed in Table 3) to evaluate the duration of embryo incubation through fry emergence ($ED_{d,h,Y}$) for all steelhead redd cohorts in the calculations of the annual dewatering index. For each redd cohort represented by the proportion of steelhead redds built on day *d* of year *Y* at spawning area *h* ($w_d \times w_h$ with *d* ranging from 1 through 98 and *h* from 1 through 3), the daily thermal units of day *d* (daily water temperature – 32°F) and subsequent days measured at location *h* are summed. A day is added to the embryo incubation period of the redd cohort while the sum of daily thermal units remains below or equal to 1,080°F.

1.1.5 Depth Frequency Distributions of Redds

The annual dewatering indices require the use of relative cumulative frequency distributions of the redd water depths of fall-run Chinook salmon and steelhead spawning in the lower American River to evaluate the probability that the redds built on spawning day *d* in reach *h* have of being constructed at particular depths, expressed in tenths of a foot.

Specifically, the annual dewatering indices use the relative cumulative frequency distributions of the depths of redds to calculate the expected proportions of redds of each cohort that were constructed at depths less or equal to the maximum river stage difference experienced by redds built in spawning reach *h* on day *d* throughout their corresponding embryo incubation periods. The proportions are described as

$\Pr\left(Redd\ Depth \leq \underset{i=d+1 \to ED_{d,h,Y}}{\text{Max}} \left(Stage_{d,h,Y} - Stage_{i,h,Y} \right) \right)$ in equation 1.

In general, USACE obtained the relative cumulative frequency distributions of the redd depths by fitting available redd depth data to asymmetric logistic functions (equation 2), as described in the following sections.

1.1.5.1 Fall-run Chinook Salmon

The relative cumulative frequency distribution of fall-run Chinook salmon redd depths was the result of USACE's fitting an asymmetric logistic function to two combined annual series of Chinook salmon redd depths (**Figure 5**). The data, provided by Mark Gard, were collected by the U.S. Fish and Wildlife Service (USFWS) during November 6 and 7, 1996 (N = 218 redd depths) and during December 14 to 17, 1998 (N = 189 redd depths). These same data were used by USACE to develop the WUA-flow relationships for fall-run Chinook salmon spawning in the lower American River. The shallowest fall-run Chinook salmon redd depth in this database was 0.4 foot, while the deepest redd was observed at a depth of 6 feet.

The asymmetric logistic function fitted to the data had the following expression:

$$\Pr(D) = \left(\frac{1}{1 + \exp(-4.9417 - 1.4896 \times D)} \right)^{1/0.0007}, \qquad \textbf{(3)}$$

where *D* is the redd depth in feet. The mean-square error of this fit was 0.00011.

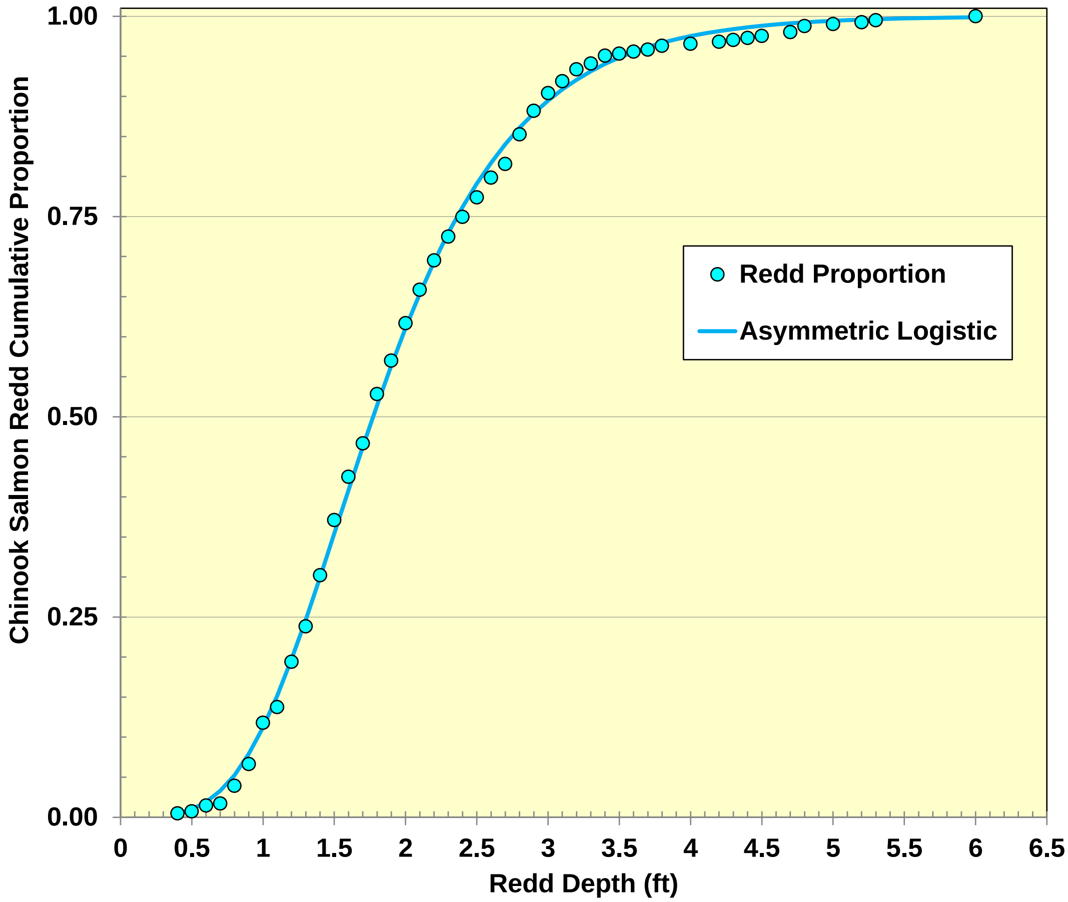

Figure 5. Cumulative Proportions of 407 Fall-run Chinook Salmon Redd Depths Measured in the Lower American River in November 1996 and December 1998 and the Fitted Asymmetric Logistic Curve.

USACE re-scaled the asymmetric logistic function in equation 3 to the observed range of fall-run Chinook salmon redd depths (0.4 foot through 6 feet) and used the function to build a look-up table providing the expected cumulative proportions of redd depths at every hundredth of a foot (**Table 4**).

Table 4. Re-scaled Cumulative Proportions of Fall-run Chinook Salmon Redd Depths Used in the Analysis of Potential Redd Dewatering for the Lower American River.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
0.39	0	**0.83**	0.057951	**1.27**	0.233282	**1.71**	0.471161	**2.15**	0.677271
0.40	0.000396	**0.84**	0.060577	**1.28**	0.238407	**1.72**	0.476456	**2.16**	0.681201
0.41	0.000819	**0.85**	0.063272	**1.29**	0.243565	**1.73**	0.481730	**2.17**	0.685096
0.42	0.001268	**0.86**	0.066036	**1.30**	0.248753	**1.74**	0.486984	**2.18**	0.688954
0.43	0.001746	**0.87**	0.068868	**1.31**	0.253970	**1.75**	0.492214	**2.19**	0.692777
0.44	0.002253	**0.88**	0.071769	**1.32**	0.259216	**1.76**	0.497422	**2.20**	0.696564
0.45	0.002791	**0.89**	0.074740	**1.33**	0.264488	**1.77**	0.502607	**2.21**	0.700314
0.46	0.003360	**0.90**	0.077779	**1.34**	0.269785	**1.78**	0.507767	**2.22**	0.704029
0.47	0.003964	**0.91**	0.080886	**1.35**	0.275106	**1.79**	0.512902	**2.23**	0.707709
0.48	0.004601	**0.92**	0.084062	**1.36**	0.280449	**1.80**	0.518012	**2.24**	0.711352
0.49	0.005274	**0.93**	0.087306	**1.37**	0.285812	**1.81**	0.523095	**2.25**	0.714960
0.50	0.005985	**0.94**	0.090619	**1.38**	0.291195	**1.82**	0.528152	**2.26**	0.718532
0.51	0.006734	**0.95**	0.093998	**1.39**	0.296596	**1.83**	0.533181	**2.27**	0.722069
0.52	0.007522	**0.96**	0.097445	**1.40**	0.302014	**1.84**	0.538182	**2.28**	0.725570
0.53	0.008351	**0.97**	0.100958	**1.41**	0.307447	**1.85**	0.543155	**2.29**	0.729037
0.54	0.009223	**0.98**	0.104538	**1.42**	0.312893	**1.86**	0.548099	**2.30**	0.732468
0.55	0.010137	**0.99**	0.108183	**1.43**	0.318352	**1.87**	0.553014	**2.31**	0.735864
0.56	0.011097	**1.00**	0.111893	**1.44**	0.323822	**1.88**	0.557898	**2.32**	0.739225
0.57	0.012103	**1.01**	0.115668	**1.45**	0.329302	**1.89**	0.562752	**2.33**	0.742551
0.58	0.013155	**1.02**	0.119506	**1.46**	0.334790	**1.90**	0.567576	**2.34**	0.745843
0.59	0.014257	**1.03**	0.123407	**1.47**	0.340285	**1.91**	0.572368	**2.35**	0.749100
0.60	0.015408	**1.04**	0.127369	**1.48**	0.345786	**1.92**	0.577129	**2.36**	0.752323
0.61	0.016609	**1.05**	0.131394	**1.49**	0.351292	**1.93**	0.581857	**2.37**	0.755512
0.62	0.017863	**1.06**	0.135478	**1.50**	0.356801	**1.94**	0.586553	**2.38**	0.758666
0.63	0.019170	**1.07**	0.139622	**1.51**	0.362311	**1.95**	0.591217	**2.39**	0.761787
0.64	0.020531	**1.08**	0.143825	**1.52**	0.367822	**1.96**	0.595848	**2.40**	0.764874
0.65	0.021948	**1.09**	0.148085	**1.53**	0.373333	**1.97**	0.600445	**2.41**	0.767928
0.66	0.023421	**1.10**	0.152401	**1.54**	0.378842	**1.98**	0.605009	**2.42**	0.770948
0.67	0.024952	**1.11**	0.156773	**1.55**	0.384348	**1.99**	0.609539	**2.43**	0.773936
0.68	0.026541	**1.12**	0.161199	**1.56**	0.389850	**2.00**	0.614035	**2.44**	0.776890
0.69	0.028190	**1.13**	0.165679	**1.57**	0.395347	**2.01**	0.618497	**2.45**	0.779812
0.70	0.029899	**1.14**	0.170210	**1.58**	0.400838	**2.02**	0.622924	**2.46**	0.782701
0.71	0.031669	**1.15**	0.174792	**1.59**	0.406321	**2.03**	0.627317	**2.47**	0.785558
0.72	0.033502	**1.16**	0.179424	**1.60**	0.411795	**2.04**	0.631675	**2.48**	0.788383
0.73	0.035397	**1.17**	0.184105	**1.61**	0.417260	**2.05**	0.635997	**2.49**	0.791176
0.74	0.037356	**1.18**	0.188832	**1.62**	0.422714	**2.06**	0.640285	**2.50**	0.793937
0.75	0.039379	**1.19**	0.193605	**1.63**	0.428156	**2.07**	0.644537	**2.51**	0.796667
0.76	0.041467	**1.20**	0.198423	**1.64**	0.433586	**2.08**	0.648754	**2.52**	0.799365
0.77	0.043621	**1.21**	0.203284	**1.65**	0.439002	**2.09**	0.652935	**2.53**	0.802033
0.78	0.045841	**1.22**	0.208187	**1.66**	0.444404	**2.10**	0.657080	**2.54**	0.804670
0.79	0.048128	**1.23**	0.213130	**1.67**	0.449790	**2.11**	0.661190	**2.55**	0.807276
0.80	0.050482	**1.24**	0.218113	**1.68**	0.455159	**2.12**	0.665264	**2.56**	0.809852
0.81	0.052904	**1.25**	0.223133	**1.69**	0.460512	**2.13**	0.669302	**2.57**	0.812397
0.82	0.055393	**1.26**	0.228190	**1.70**	0.465846	**2.14**	0.673305	**2.58**	0.814913

Table 4. Re-scaled Cumulative Proportions of Fall-run Chinook Salmon Redd Depths Used in the Analysis of Potential Redd Dewatering for the Lower American River.(Continued).

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
2.59	0.817400	**3.03**	0.901172	**3.47**	0.947985	**3.91**	0.973238	**4.35**	0.986613
2.60	0.819857	**3.04**	0.902577	**3.48**	0.948752	**3.92**	0.973646	**4.36**	0.986828
2.61	0.822284	**3.05**	0.903963	**3.49**	0.949508	**3.93**	0.974049	**4.37**	0.987040
2.62	0.824683	**3.06**	0.905331	**3.50**	0.950253	**3.94**	0.974446	**4.38**	0.987249
2.63	0.827053	**3.07**	0.906680	**3.51**	0.950988	**3.95**	0.974837	**4.39**	0.987454
2.64	0.829395	**3.08**	0.908012	**3.52**	0.951713	**3.96**	0.975223	**4.40**	0.987657
2.65	0.831709	**3.09**	0.909326	**3.53**	0.952428	**3.97**	0.975603	**4.41**	0.987857
2.66	0.833995	**3.10**	0.910622	**3.54**	0.953132	**3.98**	0.975978	**4.42**	0.988054
2.67	0.836253	**3.11**	0.911901	**3.55**	0.953827	**3.99**	0.976347	**4.43**	0.988248
2.68	0.838483	**3.12**	0.913162	**3.56**	0.954511	**4.00**	0.976711	**4.44**	0.988439
2.69	0.840687	**3.13**	0.914407	**3.57**	0.955187	**4.01**	0.977069	**4.45**	0.988627
2.70	0.842863	**3.14**	0.915635	**3.58**	0.955852	**4.02**	0.977423	**4.46**	0.988813
2.71	0.845013	**3.15**	0.916846	**3.59**	0.956508	**4.03**	0.977771	**4.47**	0.988996
2.72	0.847136	**3.16**	0.918041	**3.60**	0.957155	**4.04**	0.978114	**4.48**	0.989176
2.73	0.849233	**3.17**	0.919220	**3.61**	0.957793	**4.05**	0.978453	**4.49**	0.989354
2.74	0.851304	**3.18**	0.920383	**3.62**	0.958422	**4.06**	0.978786	**4.50**	0.989529
2.75	0.853350	**3.19**	0.921530	**3.63**	0.959042	**4.07**	0.979115	**4.51**	0.989702
2.76	0.855370	**3.20**	0.922661	**3.64**	0.959653	**4.08**	0.979439	**4.52**	0.989872
2.77	0.857364	**3.21**	0.923778	**3.65**	0.960256	**4.09**	0.979758	**4.53**	0.990039
2.78	0.859334	**3.22**	0.924879	**3.66**	0.960850	**4.10**	0.980073	**4.54**	0.990204
2.79	0.861279	**3.23**	0.925965	**3.67**	0.961435	**4.11**	0.980383	**4.55**	0.990367
2.80	0.863200	**3.24**	0.927036	**3.68**	0.962012	**4.12**	0.980688	**4.56**	0.990527
2.81	0.865096	**3.25**	0.928092	**3.69**	0.962581	**4.13**	0.980989	**4.57**	0.990685
2.82	0.866969	**3.26**	0.929134	**3.70**	0.963142	**4.14**	0.981286	**4.58**	0.990840
2.83	0.868817	**3.27**	0.930162	**3.71**	0.963695	**4.15**	0.981578	**4.59**	0.990994
2.84	0.870642	**3.28**	0.931176	**3.72**	0.964240	**4.16**	0.981867	**4.60**	0.991145
2.85	0.872444	**3.29**	0.932176	**3.73**	0.964778	**4.17**	0.982151	**4.61**	0.991294
2.86	0.874223	**3.30**	0.933162	**3.74**	0.965308	**4.18**	0.982431	**4.62**	0.991440
2.87	0.875979	**3.31**	0.934134	**3.75**	0.965830	**4.19**	0.982707	**4.63**	0.991585
2.88	0.877713	**3.32**	0.935094	**3.76**	0.966344	**4.20**	0.982978	**4.64**	0.991727
2.89	0.879424	**3.33**	0.936039	**3.77**	0.966852	**4.21**	0.983246	**4.65**	0.991868
2.90	0.881113	**3.34**	0.936972	**3.78**	0.967352	**4.22**	0.983510	**4.66**	0.992006
2.91	0.882781	**3.35**	0.937892	**3.79**	0.967845	**4.23**	0.983770	**4.67**	0.992142
2.92	0.884427	**3.36**	0.938800	**3.80**	0.968331	**4.24**	0.984027	**4.68**	0.992276
2.93	0.886051	**3.37**	0.939694	**3.81**	0.968810	**4.25**	0.984280	**4.69**	0.992409
2.94	0.887654	**3.38**	0.940576	**3.82**	0.969282	**4.26**	0.984529	**4.70**	0.992539
2.95	0.889237	**3.39**	0.941447	**3.83**	0.969747	**4.27**	0.984774	**4.71**	0.992667
2.96	0.890799	**3.40**	0.942304	**3.84**	0.970206	**4.28**	0.985016	**4.72**	0.992794
2.97	0.892340	**3.41**	0.943151	**3.85**	0.970658	**4.29**	0.985254	**4.73**	0.992919
2.98	0.893861	**3.42**	0.943985	**3.86**	0.971104	**4.30**	0.985489	**4.74**	0.993042
2.99	0.895363	**3.43**	0.944807	**3.87**	0.971543	**4.31**	0.985720	**4.75**	0.993163
3.00	0.896844	**3.44**	0.945619	**3.88**	0.971976	**4.32**	0.985948	**4.76**	0.993282
3.01	0.898306	**3.45**	0.946419	**3.89**	0.972403	**4.33**	0.986173	**4.77**	0.993399
3.02	0.899749	**3.46**	0.947207	**3.90**	0.972823	**4.34**	0.986395	**4.78**	0.993515

Table 4. Re-scaled Cumulative Proportions of Fall-run Chinook Salmon Redd Depths Used in the Analysis of Potential Redd Dewatering for the Lower American River.(Continued).

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
4.79	0.993629	**5.04**	0.995997	**5.29**	0.997631	**5.54**	0.998759	**5.79**	0.999537
4.80	0.993742	**5.05**	0.996074	**5.30**	0.997685	**5.55**	0.998796	**5.80**	0.999562
4.81	0.993853	**5.06**	0.996151	**5.31**	0.997737	**5.56**	0.998832	**5.81**	0.999587
4.82	0.993962	**5.07**	0.996226	**5.32**	0.997789	**5.57**	0.998868	**5.82**	0.999612
4.83	0.994069	**5.08**	0.996300	**5.33**	0.997841	**5.58**	0.998903	**5.83**	0.999636
4.84	0.994175	**5.09**	0.996374	**5.34**	0.997891	**5.59**	0.998938	**5.84**	0.999660
4.85	0.994280	**5.10**	0.996446	**5.35**	0.997941	**5.60**	0.998973	**5.85**	0.999684
4.86	0.994383	**5.11**	0.996517	**5.36**	0.997990	**5.61**	0.999006	**5.86**	0.999707
4.87	0.994484	**5.12**	0.996587	**5.37**	0.998038	**5.62**	0.999040	**5.87**	0.999730
4.88	0.994584	**5.13**	0.996656	**5.38**	0.998086	**5.63**	0.999073	**5.88**	0.999753
4.89	0.994682	**5.14**	0.996724	**5.39**	0.998133	**5.64**	0.999105	**5.89**	0.999775
4.90	0.994779	**5.15**	0.996791	**5.40**	0.998179	**5.65**	0.999137	**5.90**	0.999797
4.91	0.994875	**5.16**	0.996857	**5.41**	0.998225	**5.66**	0.999168	**5.91**	0.999819
4.92	0.994969	**5.17**	0.996922	**5.42**	0.998269	**5.67**	0.999199	**5.92**	0.999840
4.93	0.995062	**5.18**	0.996986	**5.43**	0.998314	**5.68**	0.999230	**5.93**	0.999861
4.94	0.995153	**5.19**	0.997049	**5.44**	0.998357	**5.69**	0.999260	**5.94**	0.999882
4.95	0.995243	**5.20**	0.997111	**5.45**	0.998400	**5.70**	0.999289	**5.95**	0.999902
4.96	0.995332	**5.21**	0.997172	**5.46**	0.998442	**5.71**	0.999318	**5.96**	0.999923
4.97	0.995419	**5.22**	0.997233	**5.47**	0.998484	**5.72**	0.999347	**5.97**	0.999942
4.98	0.995506	**5.23**	0.997292	**5.48**	0.998525	**5.73**	0.999375	**5.98**	0.999962
4.99	0.995590	**5.24**	0.997351	**5.49**	0.998565	**5.74**	0.999403	**5.99**	0.999981
5.00	0.995674	**5.25**	0.997408	**5.50**	0.998605	**5.75**	0.999431	**6.00**	1
5.01	0.995756	**5.26**	0.997465	**5.51**	0.998644	**5.76**	0.999458		
5.02	0.995838	**5.27**	0.997521	**5.52**	0.998683	**5.77**	0.999484		
5.03	0.995918	**5.28**	0.997577	**5.53**	0.998721	**5.78**	0.999511		

1.1.5.2 Steelhead

The relative cumulative frequency distribution of steelhead redd depths was the result of USACE's fitting an asymmetric logistic function to three annual series of steelhead redd depths combined (**Figure 6**). The redd depth data, provided by John Hannon, were collected during the 2002, 2003, and 2004 steelhead redd surveys performed by USBR in the lower American River on February 25 through March 15, 2002 (N = 80 redd depths); on January 7 through March 19, 2003 (N = 113 redd depths); and on January 13 through April 16, 2004 (N = 133 redd depths). The shallowest redd depth in this database was 0.6 foot, while the deepest steelhead redd was observed at 4.6 feet.

The asymmetric logistic function fitted to the resulting data had the following expression:

$$\Pr(D) = \left(\frac{1}{1 + \exp(4.7384 - 2.2891 \times D)} \right)^{1/0.9992}, \quad (4)$$

where D is the redd depth in feet. The mean-square error of this fit was 0.00045.

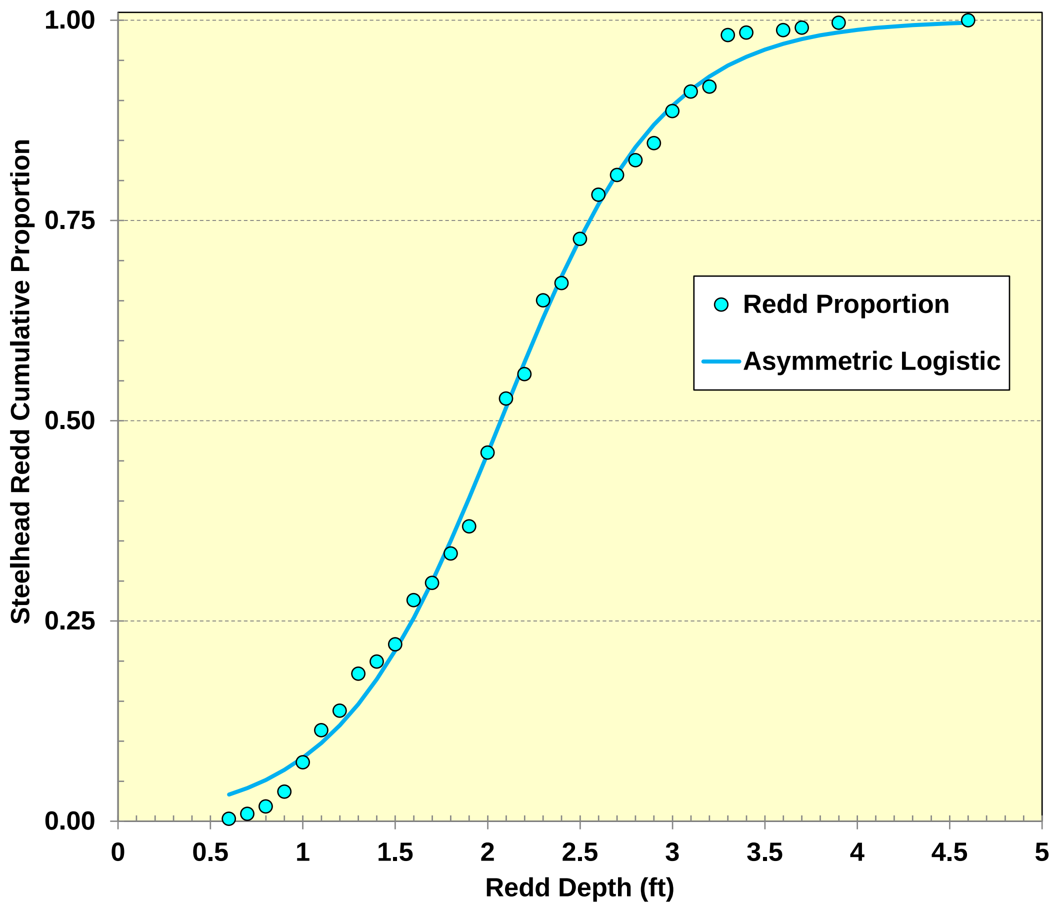

Figure 6. Cumulative Proportions of 326 Steelhead Redd Depths Measured in the Lower American River during the 2001/2002, 2002/2003 and 2003/2004 Redd Surveys, and Fitted Asymmetric Logistic Curve.

The asymmetric logistic function in equation 4 was re-scaled to the observed range of steelhead redd depths (0.6 ft. through 4.6 ft.) and used to build a look-up table providing the expected cumulative proportions of redd depths for every hundredth of a foot (**Table 5**).

1.1.6 Stage-Flow Relationships

The calculation of the annual weighted redd dewatering index (WRD_Y) requires estimates of the mean daily stages or water surface elevations at each spawning reach *h* during each redd construction day *d* of the evaluated year *Y*, as well as during any subsequent day until the last day of the corresponding embryo incubation period ($ED_{d,h,Y}$).

Table 5. Re-scaled Cumulative Proportions of Steelhead Redd Depths Used in the Analysis of Potential Redd Dewatering for the Lower American River.

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
0.59	0	**1.03**	0.054957	**1.47**	0.178678	**1.91**	0.395729	**2.35**	0.650163
0.60	0.000774	**1.04**	0.056848	**1.48**	0.182584	**1.92**	0.401507	**2.36**	0.655475
0.61	0.001564	**1.05**	0.058776	**1.49**	0.186543	**1.93**	0.407307	**2.37**	0.660747
0.62	0.002372	**1.06**	0.060740	**1.50**	0.190554	**1.94**	0.413125	**2.38**	0.665978
0.63	0.003197	**1.07**	0.062741	**1.51**	0.194617	**1.95**	0.418962	**2.39**	0.671168
0.64	0.004039	**1.08**	0.064780	**1.52**	0.198732	**1.96**	0.424816	**2.40**	0.676315
0.65	0.004900	**1.09**	0.066856	**1.53**	0.202900	**1.97**	0.430686	**2.41**	0.681418
0.66	0.005779	**1.10**	0.068972	**1.54**	0.207120	**1.98**	0.436569	**2.42**	0.686477
0.67	0.006677	**1.11**	0.071126	**1.55**	0.211391	**1.99**	0.442464	**2.43**	0.691491
0.68	0.007594	**1.12**	0.073321	**1.56**	0.215715	**2.00**	0.448371	**2.44**	0.696460
0.69	0.008530	**1.13**	0.075555	**1.57**	0.220090	**2.01**	0.454286	**2.45**	0.701382
0.70	0.009486	**1.14**	0.077830	**1.58**	0.224516	**2.02**	0.460210	**2.46**	0.706257
0.71	0.010463	**1.15**	0.080146	**1.59**	0.228993	**2.03**	0.466140	**2.47**	0.711085
0.72	0.011460	**1.16**	0.082504	**1.60**	0.233521	**2.04**	0.472074	**2.48**	0.715865
0.73	0.012478	**1.17**	0.084904	**1.61**	0.238099	**2.05**	0.478012	**2.49**	0.720596
0.74	0.013518	**1.18**	0.087347	**1.62**	0.242727	**2.06**	0.483951	**2.50**	0.725278
0.75	0.014580	**1.19**	0.089833	**1.63**	0.247405	**2.07**	0.489891	**2.51**	0.729910
0.76	0.015663	**1.20**	0.092363	**1.64**	0.252132	**2.08**	0.495829	**2.52**	0.734493
0.77	0.016770	**1.21**	0.094937	**1.65**	0.256908	**2.09**	0.501763	**2.53**	0.739025
0.78	0.017899	**1.22**	0.097555	**1.66**	0.261732	**2.10**	0.507694	**2.54**	0.743506
0.79	0.019052	**1.23**	0.100218	**1.67**	0.266603	**2.11**	0.513618	**2.55**	0.747937
0.80	0.020229	**1.24**	0.102927	**1.68**	0.271522	**2.12**	0.519534	**2.56**	0.752316
0.81	0.021430	**1.25**	0.105682	**1.69**	0.276487	**2.13**	0.525441	**2.57**	0.756644
0.82	0.022656	**1.26**	0.108484	**1.70**	0.281497	**2.14**	0.531338	**2.58**	0.760920
0.83	0.023907	**1.27**	0.111332	**1.71**	0.286553	**2.15**	0.537222	**2.59**	0.765144
0.84	0.025184	**1.28**	0.114227	**1.72**	0.291652	**2.16**	0.543092	**2.60**	0.769316
0.85	0.026488	**1.29**	0.117170	**1.73**	0.296796	**2.17**	0.548947	**2.61**	0.773436
0.86	0.027817	**1.30**	0.120162	**1.74**	0.301982	**2.18**	0.554786	**2.62**	0.777504
0.87	0.029174	**1.31**	0.123201	**1.75**	0.307210	**2.19**	0.560606	**2.63**	0.781519
0.88	0.030558	**1.32**	0.126290	**1.76**	0.312479	**2.20**	0.566407	**2.64**	0.785482
0.89	0.031971	**1.33**	0.129427	**1.77**	0.317788	**2.21**	0.572187	**2.65**	0.789393
0.90	0.033411	**1.34**	0.132615	**1.78**	0.323136	**2.22**	0.577944	**2.66**	0.793251
0.91	0.034881	**1.35**	0.135852	**1.79**	0.328522	**2.23**	0.583677	**2.67**	0.797058
0.92	0.036380	**1.36**	0.139139	**1.80**	0.333945	**2.24**	0.589386	**2.68**	0.800812
0.93	0.037909	**1.37**	0.142476	**1.81**	0.339405	**2.25**	0.595068	**2.69**	0.804514
0.94	0.039469	**1.38**	0.145865	**1.82**	0.344899	**2.26**	0.600722	**2.70**	0.808164
0.95	0.041059	**1.39**	0.149304	**1.83**	0.350427	**2.27**	0.606347	**2.71**	0.811762
0.96	0.042681	**1.40**	0.152795	**1.84**	0.355988	**2.28**	0.611942	**2.72**	0.815308
0.97	0.044335	**1.41**	0.156337	**1.85**	0.361581	**2.29**	0.617506	**2.73**	0.818804
0.98	0.046021	**1.42**	0.159930	**1.86**	0.367204	**2.30**	0.623037	**2.74**	0.822248
0.99	0.047740	**1.43**	0.163576	**1.87**	0.372856	**2.31**	0.628534	**2.75**	0.825640
1.00	0.049493	**1.44**	0.167273	**1.88**	0.378536	**2.32**	0.633996	**2.76**	0.828983
1.01	0.051279	**1.45**	0.171022	**1.89**	0.384242	**2.33**	0.639422	**2.77**	0.832274
1.02	0.053101	**1.46**	0.174824	**1.90**	0.389974	**2.34**	0.644812	**2.78**	0.835516

Table 5. Re-scaled Cumulative Proportions of Steelhead Redd Depths Used in the Analysis of Potential Redd Dewatering for the Lower American River (Continued).

Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion	Redd Depth (ft)	Scaled Cumulative Proportion
2.79	0.838708	**3.23**	0.936341	**3.67**	0.977673	**4.11**	0.993661	**4.55**	0.999626
2.80	0.841850	**3.24**	0.937756	**3.68**	0.978235	**4.12**	0.993872	**4.56**	0.999705
2.81	0.844943	**3.25**	0.939144	**3.69**	0.978784	**4.13**	0.994079	**4.57**	0.999781
2.82	0.847987	**3.26**	0.940504	**3.70**	0.979321	**4.14**	0.994281	**4.58**	0.999856
2.83	0.850983	**3.27**	0.941837	**3.71**	0.979847	**4.15**	0.994479	**4.59**	0.999929
2.84	0.853931	**3.28**	0.943143	**3.72**	0.980362	**4.16**	0.994672	**4.60**	1
2.85	0.856831	**3.29**	0.944423	**3.73**	0.980865	**4.17**	0.994861		
2.86	0.859683	**3.30**	0.945677	**3.74**	0.981358	**4.18**	0.995046		
2.87	0.862489	**3.31**	0.946906	**3.75**	0.981839	**4.19**	0.995227		
2.88	0.865248	**3.32**	0.948110	**3.76**	0.982311	**4.20**	0.995403		
2.89	0.867962	**3.33**	0.949290	**3.77**	0.982772	**4.21**	0.995576		
2.90	0.870630	**3.34**	0.950446	**3.78**	0.983223	**4.22**	0.995745		
2.91	0.873252	**3.35**	0.951578	**3.79**	0.983664	**4.23**	0.995910		
2.92	0.875830	**3.36**	0.952687	**3.80**	0.984096	**4.24**	0.996071		
2.93	0.878364	**3.37**	0.953774	**3.81**	0.984518	**4.25**	0.996229		
2.94	0.880855	**3.38**	0.954838	**3.82**	0.984931	**4.26**	0.996383		
2.95	0.883302	**3.39**	0.955880	**3.83**	0.985335	**4.27**	0.996534		
2.96	0.885706	**3.40**	0.956901	**3.84**	0.985730	**4.28**	0.996682		
2.97	0.888068	**3.41**	0.957901	**3.85**	0.986116	**4.29**	0.996826		
2.98	0.890389	**3.42**	0.958880	**3.86**	0.986494	**4.30**	0.996967		
2.99	0.892668	**3.43**	0.959839	**3.87**	0.986864	**4.31**	0.997105		
3.00	0.894906	**3.44**	0.960778	**3.88**	0.987226	**4.32**	0.997239		
3.01	0.897105	**3.45**	0.961697	**3.89**	0.987579	**4.33**	0.997371		
3.02	0.899263	**3.46**	0.962597	**3.90**	0.987925	**4.34**	0.997500		
3.03	0.901383	**3.47**	0.963479	**3.91**	0.988263	**4.35**	0.997626		
3.04	0.903463	**3.48**	0.964342	**3.92**	0.988594	**4.36**	0.997749		
3.05	0.905506	**3.49**	0.965187	**3.93**	0.988918	**4.37**	0.997869		
3.06	0.907511	**3.50**	0.966014	**3.94**	0.989234	**4.38**	0.997987		
3.07	0.909479	**3.51**	0.966823	**3.95**	0.989544	**4.39**	0.998102		
3.08	0.911410	**3.52**	0.967616	**3.96**	0.989847	**4.40**	0.998214		
3.09	0.913306	**3.53**	0.968392	**3.97**	0.990143	**4.41**	0.998324		
3.10	0.915166	**3.54**	0.969152	**3.98**	0.990432	**4.42**	0.998431		
3.11	0.916990	**3.55**	0.969895	**3.99**	0.990715	**4.43**	0.998536		
3.12	0.918781	**3.56**	0.970623	**4.00**	0.990992	**4.44**	0.998639		
3.13	0.920537	**3.57**	0.971335	**4.01**	0.991263	**4.45**	0.998739		
3.14	0.922260	**3.58**	0.972032	**4.02**	0.991527	**4.46**	0.998837		
3.15	0.923949	**3.59**	0.972715	**4.03**	0.991786	**4.47**	0.998933		
3.16	0.925607	**3.60**	0.973382	**4.04**	0.992039	**4.48**	0.999027		
3.17	0.927232	**3.61**	0.974036	**4.05**	0.992287	**4.49**	0.999118		
3.18	0.928826	**3.62**	0.974675	**4.06**	0.992529	**4.50**	0.999208		
3.19	0.930389	**3.63**	0.975301	**4.07**	0.992765	**4.51**	0.999295		
3.20	0.931921	**3.64**	0.975914	**4.08**	0.992997	**4.52**	0.999381		
3.21	0.933424	**3.65**	0.976513	**4.09**	0.993223	**4.53**	0.999465		
3.22	0.934897	**3.66**	0.977099	**4.10**	0.993444	**4.54**	0.999547		

In equation 1, the variable $Stage_{d,h,Y}$ indicates the mean daily river stage in spawning reach *h* on redd construction day *d* of year *Y*, and the variable $Stage_{i,h,Y}$ indicates the mean daily river stage in the same spawning area, on any day *i* subsequent to the date of redd construction, until the last day of the embryo incubation period for the redds built on day *d*. Eighteen reach-specific stage-flow relationships were used to interpolate daily stage or water surface elevation that corresponds to the simulated average daily flow output.

The 18 reach-specific stage-flow relationships used (**Figure 7**) were developed by cbec on March 2015 and used by USACE for this analysis of potential redd dewatering in the lower American River with the Folsom WCM alternatives and the bases of comparison. The reach-specific stage-flow relationships were constructed by first developing individual stage-flow relationships for each of the available measured cross-sections spaced 0.25 mile apart and then averaging the resulting stage-flow relationships into 1-mile sections. Each of the resulting 18 reach-specific stage-flow relationships provides water surface elevations expressed in feet for 139 flows ranging from 200 cfs to 180,000 cfs, in increasing steps of 100 cfs (19 values), 500 cfs (12 values), 1,000 cfs (92 values), and 5,000 cfs (16 values).

Because the calculation of the annual weighted redd dewatering index (WRD_Y) requires the derivation of mean daily stages from simulated mean daily flows with the Folsom WCM alternatives and the bases of comparison for each spawning reach *h* during each redd construction day *d* of the evaluated year *Y*, as well as during any subsequent day until the last day of the corresponding embryo incubation period ($ED_{d,h,Y}$), and because the 18 reach-specific stage-flow relationships provide stage values for only 139 flows, daily stages were determined by linear interpolation between the available stage values for the flows immediately below and above the target flow $Q_{d,Y}$.

1.1.7 Annual Weighted Redd Dewatering Index Calculation

The calculations of the annual weighted redd dewatering indices (WRD_Y) for fall-run Chinook salmon and steelhead spawning in the lower American River for the simulated daily flows and water temperatures with the Folsom WCM alternatives and the bases of comparison during each of the simulation years were performed using Microsoft Excel templates and a macro. The step-by-step calculations included in these templates and the macro are summarized in the following paragraphs.

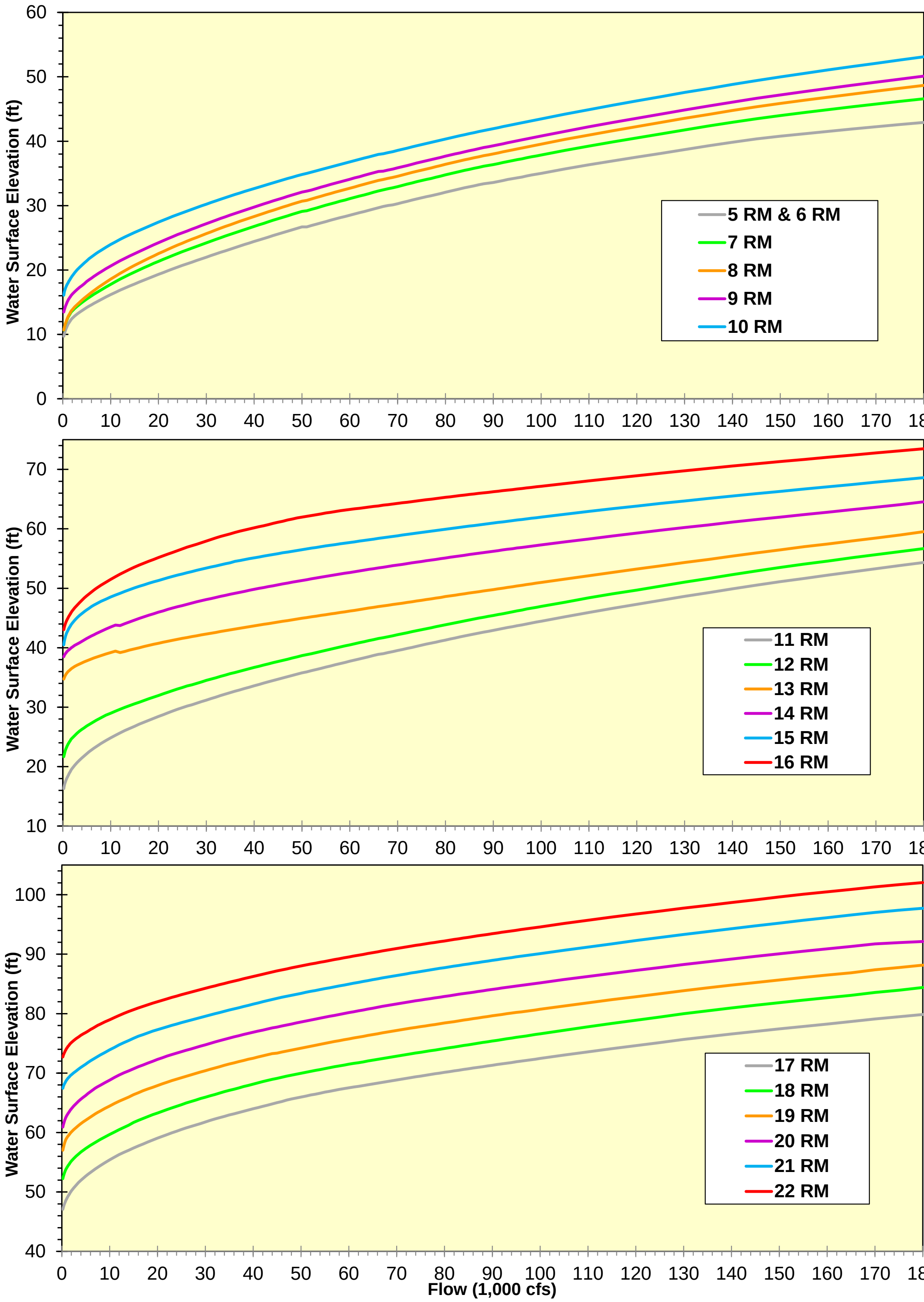

Figure 7. Relationships between Water Surface Elevation (Feet) and Flow (Thousand cfs) Developed by cbec for Each of the 18 Spawning Reaches Used in the Redd Dewatering Analysis for Chinook Salmon and Steelhead in the Lower American River.

Step 1. For the first spawning reach (h = RM 22) and the first day of the spawning period (d = October 13 for fall-run Chinook salmon and d = December 14 for steelhead) during the first year Y of the entire simulation period, count the number of days while the daily ATUs, derived from the reach-specific simulated daily water temperatures, remain below a target of 1,649°F for Chinook salmon and 1,080°F for steelhead. The resulting counts ($ED_{d,h,Y}$) are the durations of fall-run Chinook salmon and steelhead embryo incubation for redds built on day d of year Y, in spawning area h.

Step 2. For the same year Y, spawning reach h and spawning day d, calculate the daily flow at which the fall-run Chinook salmon or steelhead redds are built using the simulated average daily flows. For fall-run Chinook salmon, the spawning flow ($Q_{h,d,Y}$) is calculated as the minimum of the modeled daily flows for day d and the previous 7 days. For steelhead, the spawning flow ($Q_{h,d,Y}$) are calculated as the minimum of the modeled daily flows for day d and the previous 3 days.

Step 3. Using the stage-flow relationship for spawning reach h, calculate the stage or water surface elevation ($Stage_{d,h,Y}$) that corresponds to the spawning flow ($Q_{h,d,Y}$) calculated in the previous step, using linear interpolation if needed.

Step 4. Using the stage-flow relationship for spawning reach h, calculate the stages or water surface elevations ($Stage_{i,h,Y}$) that correspond to the simulated daily average flows for all days within the range $i = d + 1$ through $i = d + ED_{d,h,Y}$.

Step 5. Calculate the maximum positive difference between the spawning-day stage ($Stage_{d,h,Y}$) and the stages on subsequent days (from step 4). This value represents the maximum drop in water elevation experienced by redds built in spawning area h on day d of year Y throughout their embryo incubation period.

Step 6. Compute the proportion of the redds built in spawning area h on day d of year Y potentially dewatered by the maximum drop in water elevation calculated in step 5 by using the Excel function VLOOKUP with the value from step 5 rounded to two decimal places, and Table 4 for fall-run Chinook salmon or Table 5 for steelhead.

Step 7. Multiply the proportions derived from step 6 by the temporal weighting coefficient corresponding to spawning day *d* (w_d) and by the spatial weighting coefficient corresponding to spawning reach *h* (w_h). The result of this step ($WRD_{d,h,Y}$) represents the maximum proportion of the redds built on spawning day *d* of year *Y* in reach *h* that are potentially exposed to at least 1 day of dewatering during their embryo incubation period, weighted over all redds built in year *Y*.

Step 8. For spawning day *d* and year *Y*, repeat steps 1 through 7 with each of the 17 remaining spawning reaches (*h* = RM 21 through *h* = RM 5) and save the resulting partial dewatering proportions $WRD_{d,h,Y}$.

Step 9. Repeat steps 1 through 8 for each of the remaining 97 Chinook salmon spawning days (*d* = October 12 through January 18) and 113 steelhead spawning days (*d* = December 15 through April 5) and save the resulting partial dewatering proportions $WRD_{d,h,Y}$.

Step 10. Sum the partial dewatering proportions $WRD_{d,h,Y}$ from steps 7, 8, and 9 to obtain WRD_Y, the annual weighted redd dewatering index for year *Y*.

Step 11. Repeat steps 1 through 10 for the remaining years of the simulation period.

Once all of the annual weighted redd dewatering indices for fall-run Chinook salmon and steelhead in the lower American River were calculated using simulated daily flows and associated river stages, and simulated daily water temperatures with the Folsom WCM alternatives and the bases of comparison, the resulting annual indices were averaged over the entire simulation period and by water year type, and were ranked and sorted to produce probability of exceedance distributions, for comparison of the redd dewatering indices, with the Folsom WCM alternatives relative to the bases of comparison.

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LOWER AMERICAN RIVER CHINOOK SALMON EARLY LIFESTAGE MORTALITY MODEL: *UPDATES AND REFINEMENTS*

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1.0 Introduction

1.1 Background

In 1983, the first version of a Chinook Salmon Early Lifestage Mortality Model ("Mortality Model") was developed by the U.S. Bureau of Reclamation (USBR) for application on the lower Sacramento River to estimate annual, thermally-induced losses of initial Chinook salmon year-class production. In 1990, this Mortality Model was further revised and refined through a collaborative effort by the U.S. Fish and Wildlife Service (USFWS), the California Department of Fish and Wildlife (CDFW, formerly CDFG), and the USBR for use in the Shasta Reservoir temperature control device studies (USBR 1991). The USFWS and CDFW worked cooperatively to produce a list of biological criteria and assumptions that served as the underlying biological basis for the model's refinement. From these fishery assumptions and biological criteria, the USBR revised the Mortality Model to assess spawning and hatching success of the various Chinook salmon runs that use the lower Sacramento River, under different in-river thermal regimes that would result from various alternatives for controlling release temperatures from Shasta Reservoir.

Since 1990, the Mortality Model has been further modified by the USBR to facilitate its application to the lower American River. The Sacramento Water Forum (Water Forum) has used this "lower American River version" of the Mortality Model (LAR Mortality Model) as one tool for assessing the relative benefits of alternative flow patterns to fall-run Chinook salmon production in the lower American River. Because of the importance of the modeling output in identifying preferred lower American River flow regimes and Folsom Reservoir coldwater pool management, and because additional information has become available since the LAR Mortality Model was originally developed in the mid-1990s that could be incorporated into the model to improve its accuracy, a Water Forum directed effort, in collaboration with the U.S. Army Corps of Engineers (Corps), to update the LAR Mortality Model was undertaken in 2013. This technical memorandum documents the model refinements made as part of that effort.

1.2 USBR Chinook Salmon Lower American River Mortality Model

1.2.1 Model Description

In April of 1995, the USBR developed the LAR Mortality Model, based on the Mortality Model initially developed for the lower Sacramento River. The LAR Mortality Model calculates daily temperature-induced mortality for three early lifestages of Chinook salmon: (1) pre-spawn eggs; (2) fertilized eggs; and (3) pre-emergent fry. Accumulated thermal units (ATU), defined as the difference between in-river water temperatures and 32°F, are accounted for on a daily basis by the model, and are used to track lifestage development. For example, incubating eggs exposed to 42°F water for one day would experience 10 ATUs. Eggs are assumed to hatch upon exposure to 750 ATUs following fertilization. Similarly, the model assumes that fry emerge from the gravel upon being exposed to 750 ATUs following hatching.

Mortality incurred by the three early lifestages defined above, during a specified period of time, is based on in-river temperatures (i.e., thermal exposures). The LAR Mortality Model was designed to be coupled with the USBR's water temperature model. This monthly temperature model consists of a USBR-modified version of a Corps' monthly reservoir model and a stream model developed by the USBR. The reservoir model simulates one-dimensional, vertical distribution of reservoir water temperature using monthly input data on initial storage and temperature conditions, inflow, outflow, evaporation, precipitation, radiation, and average air temperature to compute release water temperatures from Folsom and Nimbus dams. Using these data, the USBR's stream model calculates resultant monthly mean water temperatures in the lower American River at specified locations downstream of Nimbus Dam.

While the USBR's water temperature model can be used to determine monthly mean water temperatures, it does not define day-to-day temperature variations within a month and, therefore, its output cannot be used to quantify fishery impacts on a daily basis. A daily temperature model would be required for such evaluations. Because a daily temperature model that could work effectively with the 82 years of hydrologic record was unavailable at the time that the LAR Mortality Model was developed, the LAR Mortality Model was programmed to interpolate daily mean water temperatures from the monthly mean water temperature data output from the USBR water temperature model.

1.2.2 Model Approach to Estimating Early Lifestage Mortality

To understand how the model calculates early lifestage losses, the LAR Mortality Model input parameters must be identified and understood. The principal model parameters are as follows.

JD - Julian day (1-365)

ESD - Daily percent of run spawning. The ESD is reduced by prior pre-spawning losses (AKIL).

FRY - Daily percent of run hatching from the egg to pre-emergent fry stage. The FRY occurs 750 ATUs after the ESD and is reduced by prior egg losses (EKIL).

EFRY - Daily percent of run developing from a pre-emergent fry into an emergent fry. The fry emerge 750 ATUs after they hatch into a pre-emergent fry and are reduced by prior pre-emergent fry losses (FKIL).

AD - Percent of pre-spawning adults present on each day. AD is computed from the adults from the previous day plus daily arrivals (PSD), minus daily spawn (SD), minus pre-spawning losses occurring that day (AKIL). The PSD and SD are distributed over river reaches by multiplying each of these factors by RD.

RD - Reach distribution.

ED - Percent of eggs present on each day. ED is computed from the eggs of the previous day plus the daily ESD, minus the daily FRY, minus the egg losses occurring that day (EKIL).

FD - Percent of pre-emergent fry present on each day. FD is computed from the pre-emergent fry of the previous day plus the daily FRY, minus the daily EFRY, minus the pre-emergent fry losses occurring that day (FKIL).

TR - The average daily river temperature within the reach (e.g., Reach 2) computed from the river temperature model output (T) in °F.

PSM - The daily pre-spawn egg mortality (in percent) computed via a step-function from TR and the pre-spawn egg criteria (PSC). The average exposure time for these data was assumed to be 30 days.

EM - The daily egg mortality (in percent) computed via a step-function from TR and the fertilized egg criteria (EC).

FM - The daily pre-emergent fry mortality (in percent) computed via a step-function from TR and the pre-emergent fry criteria (FC).

PSC - Set of instantaneous daily mortality rates for pre-spawn eggs at various temperatures.

EC - Set of instantaneous daily mortality rates for fertilized-eggs at various temperatures.

FC - Set of instantaneous daily mortality rates for pre-emergent fry at various temperatures.

AKIL - The daily pre-spawning loss in percent. This is computed from the AD prior to the pre-spawning loss (previous day AD + daily arrivals - daily spawn) multiplied by the PSM for that day.

EKIL - The daily egg loss in percent. This is computed from the ED prior to the egg loss multiplied by the EM for that day.

FKIL - The daily pre-emergent fry loss in percent. This is computed from the FD prior to the fry loss multiplied by the FM for that day.

Based on these parameters, the LAR Mortality Model calculates the annual percent loss of total production potential (i.e., eggs brought to the river by female salmon). The model accounts for the daily loss of eggs and/or fry in the calculation of total mortality over the exposure period. To do so, the model independently calculates a daily percent pre-spawning loss (AKIL), a daily percent egg loss (EKIL), and a daily percent pre-emergent fry loss (FKIL) for distinct river reaches between Nimbus Dam and the lower end of the spawning grounds.

The daily AKIL value is computed using the percent of pre-spawning adults present on each day (AD), daily arrivals, daily spawning, and the daily pre-spawning mortality of adults (PSM), which is based on water temperature exposure (i.e., thermal exposure to date). A given day's AKIL value is equal to: (AD from previous day + current day PSD – current day SD), multiplied by the current day PSM. Similarly, daily EKIL values are computed using the percent of spawning on each day (ED), prior to egg loss, multiplied by a daily egg mortality factor in percent (EM) for that day, based on thermal exposure. Finally, daily FKIL values are computed using the percent of pre-emergent fry present on each day (FD), prior to fry loss, multiplied by the daily pre-emergent fry mortality factor (FM - %) for that day, based on thermal exposure.

Daily pre-spawning, egg, and fry mortalities are calculated by summing AKIL, EKIL, and FKIL, respectively, for all river reaches identified in the model. Monthly and annual salmon mortalities for the river are computed by summing the daily losses for all reaches and lifestages.

Because the mortality estimates calculated by the model are based on modeled mean monthly water temperatures, mortality estimates should not be interpreted to be true quantitative predictions, but rather viewed as a "relative index" of Chinook salmon early lifestage losses resulting from different thermal exposure scenarios.

A Water Forum Issue Paper (HCI 1996) documented additional assumptions and criteria coded into the LAR Mortality Model. These assumptions and criteria are summarized below.

- The temporal spawning distribution for fall-run Chinook salmon in the lower American River was defined using CDFW angler creel survey data for the years 1990-1994 and historic (1944-1946) fall-run Chinook salmon passage at the fishway at Old Folsom Dam.

- The spatial spawning distribution for fall-run Chinook salmon in the lower American River was defined based on aerial redd survey data collected by the CDFW in the fall of 1991, 1992, and 1993.

- Annual lower American River spawning was to be initiated (by the model) when the daily mean river water temperature declined to 60°F each year, rather than on a characteristic temporal distribution. The threshold temperature of 60°F for initiation of spawning (spawning initiation trigger) was set for the model after consultation and agreement with CDFW. This decision was based on data generated from aerial redd surveys conducted on the lower American River by CDFW from 1991-1993.

- The model did not account for Chinook salmon arriving annually prior to September 1 each year. Adult Chinook salmon entering the lower American River to spawn prior to the time when daily mean water temperatures decrease to 60°F are "held" by the model and are not "spawned" until after in-river water temperatures declined to ≤60°F (i.e., until after the "60°F date" was reached) during the fall.

- Immigrating adult Chinook salmon arriving at the lower American River spawning grounds when daily mean river temperatures are ≤60°F (i.e., after the "60°F date") are "spawned" by the model one week (7 days) later.

The lower American River-specific assumptions and criteria defined above were programmed into the LAR Mortality Model code by the USBR in April of 1995, which finalized the development of the original 1995 LAR Mortality Model.

1.3 Purpose and Intended Use of this Memorandum

The purpose of this memorandum is to document the methodology used to update and refine the LAR Mortality Model assumptions and coding. The following LAR Mortality Model assumptions were refined based on new data and information that has become available since the model was originally developed.

- The temporal distribution for the arrival of spawning fall-run Chinook salmon in the lower American River.

- The temporal distribution for fall-run Chinook salmon spawning in the lower American River.

- The spatial distribution of pre-spawn arriving and spawning fall-run Chinook salmon in the lower American River.

- The thermally-induced Chinook salmon daily mortality rates for pre-spawn eggs, fertilized eggs, and pre-emergent fry.

- The ATU thresholds associated with the end of the fertilized-egg and pre-emergent fry lifestages.

Following their refinement based on new data/information, these updated assumptions were coded into the LAR model to produce the updated 2015 version of the LAR Mortality Model. This memorandum also documents the code corrections and programming language conversion that was performed on the original model, in addition to the updates and refinements. Finally, this memorandum conducts a progressive model sensitivity analysis to identify the effects of each of the major updates and refinements made to the model on its annual average mortality estimates for the lower American River.

2.0 Chinook Salmon Adult Temporal and Spatial Distributions

The LAR Mortality Model requires input regarding: (1) the temporal distribution of pre-spawning adult fall-run Chinook salmon arrival and staging in the lower American River; (2) the temporal distribution of adult fall-run Chinook salmon spawning in the lower American River; and (3) the spatial distribution of fall-run Chinook salmon spawning in the lower American River. For this technical memorandum, the timing of adult fall-run Chinook salmon arriving in the lower American River is referred to as "pre-spawn arrival temporal distribution", the time at which fall-run Chinook salmon spawn is referred to as the "spawning temporal distribution", and the location (i.e., river mile) at which spawning occurs is referred to as "spawning spatial distribution." The approach used for refining the calculations and the model weighting coefficients for pre-spawn arrival and spawning temporal distributions, and spawning spatial distributions are provided in the following subsections.

2.1 Chinook Salmon Pre-Spawn Arrival Temporal Distribution

It has generally been reported in the literature that fall-run Chinook salmon spend a variable amount of time in their natal rivers prior to the onset of the spawning activity. For example, Moyle (2002) states that, in California, fall-run Chinook salmon typically spawn within a few days or weeks of arriving on the spawning grounds. The lifestage of adult fall-run Chinook salmon in a river prior to spawning is referred to as "staging".

Estimates of the time spent staging by fall-run Chinook salmon prior to spawning are typically based upon enumeration of immigrating adult fall-run Chinook salmon through a weir located in the lower reaches of a river, or through monitoring surveys of live fish concurrently with redd surveys. Such data have not been collected in the lower American River. However, as part of a study to evaluate angler effort and harvest of anadromous fishes in the Central Valley recreational river fishery, CDFW has performed periodic creel censuses in the lower American River that provide estimates of the fall-run Chinook salmon monthly catch, both retained and released, that can be used to assess the temporal distribution of pre-spawning adult fall-run Chinook salmon in the lower American River.

During each annual angler survey, the number of anglers and the number of fish caught and retained, and caught and released, were sampled over 3 sections of the lower American River extending from Discovery Park to Nimbus Dam, on 8 randomly selected days (4 weekend, 4 weekday) per month and river section. Three primary statistical descriptors were calculated for each month and river section: (1) angling effort in terms of angler-hours; (2) catch-per-unit-effort (CPUE) in terms of fish per angler-hour for each target species; and (3) catch for each target species. For each species, results were presented in tables displaying the total number of angler-hours targeting the species, the estimated catch kept and the estimated catch released by month and river section.

The estimated monthly catches of adult fall-run Chinook salmon in the lower American River obtained from available CDFW angler survey reports[5] (e.g., Wixom et al. 1995; Murphy et al. 1999; Murphy et al. 2001a and 2001b; Schroyer et al. 2002; Massa and Schroyer 2003; and Titus et al. 2008, 2009 and 2010) were used to obtain the temporal distribution of in-river adult fall-run Chinook salmon prior to spawning by applying the following steps:

1.) The monthly catches of Chinook salmon kept and released from available annual angler survey reports were summed over the three river sections and organized annually over the period extending from June 1 through May 31 of the following calendar year (**Table 1**).

2.) The monthly catches (of both kept and released fish) each year were divided by the annual total catch to obtain relative monthly catch proportions. These proportions were summed and plotted against time (days extending from June 1 through May 31) by allocating each monthly proportion to the last day of the sampled month.

3.) An asymmetric logistic function was fitted to all of the monthly cumulative proportions of fish caught during all of the ten years of available data. The resulting curve (**Figure 1**) was used to represent the temporal distribution of adult Chinook salmon arriving in the lower American River prior to and during the fall-run Chinook salmon spawning season.

The lower American River Chinook salmon pre-spawn arrival temporal distributions have the potential to be influenced by the straying of late fall-run Chinook salmon into the lower American River, as was particularly evidenced during the 2008/09 spawning season. Chinook salmon have been encountered in the CDFG carcass surveys (Vincik and Kirsch 2009; Healey and Redding 2008; Healey and Fresz 2007; Healey 2005, 2004) through the month of January, although a low percentage of fresh carcasses have been encountered after the first week of January (generally 0.2 to 3%). The highest number of fresh Chinook salmon carcasses encountered after the first week of January was observed during the 2008/2009 survey season, when 12% of all fresh carcasses were observed after the first week of January 2009 (Vincik and Kirsch 2009). Spawning during the latter part of January is somewhat atypical of fall-run, but is phenotypically consistent with late fall-run Chinook salmon. During the 2008/2009 surveys, recovery and analysis of 53 coded-wire tagged (CWT) carcasses obtained throughout the month of January 2009 documented that all of them were late fall-run Chinook salmon strays

[5] Brown and Titus (2007) also was available, although no survey information was reported for the period extending from June through October and, therefore, was not included in the dataset used to develop the cumulative temporal distribution.

originating from the Coleman National Fish Hatchery on Battle Creek. In addition to adipose fin-clipped (i.e., hatchery) carcasses, non-adipose fin-clipped carcasses also were encountered during January. Vincik and Kirsch (2009) speculated that the late spawning Chinook salmon in the lower American River may be attributable to the straying of hatchery and presumed wild Chinook salmon from other systems and is not likely a self-sustaining run within the lower American River. However, they recognize the need to further explore this issue in future monitoring efforts. More recently, Kormos et al. (2012) found that relative to the total of 23,945 Chinook salmon carcasses sampled during 2010/2011, 162 (less than 1% of all Chinook salmon) were classified as late fall-run Chinook salmon, of which approximately 23% (37 fish) were of hatchery origin.

Table 1. Estimated angler's monthly catch of Chinook salmon (both retained and released) in the lower American River, organized by biological years that extend from June 1 through May 31 of the following calendar year.

Year	Estimated Chinook Salmon Angler's Retained and Released Catch (No. of Fish)													Source
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	
1991/92	0	1,056	5,999	1,567	2,450	3,906	49	0	0	0	0	0	15,027	Wixon *et al.* (1995)
1992/93	438	503	1,164	219	816	2,461	1,359	0	0	0	0	0	6,960	Wixon *et al.* (1995)
1993/94	73	455	796	2,061	4,685	12,219	211	131	0	0	0	0	20,631	Wixon *et al.* (1995)
1998/99	120	---	933	4,744	16,824	14,697	943	228	0	0	0	0	38,489	Murphy and Hanson (1998); Murphy *et al.* (2001a)
1999/00	707	1,452	1,976	4,840	17,962	20,697	2,728	60	0	0	0	0	50,422	Murphy *et al.* (2001a, 2001b)
2000/01	1,109	693	582	2,020	25,806	10,294	2,559	57	---	0	0	0	43,120	Murphy *et al.* (2001b); Schroyer *et al.* (2002)
2002/03	491	1,330	7,375	4,604	22,136	12,547	258	---	---	---	---	---	48,741	Massa and Schroyer (2003)
2007/08	0	0	464	238	618	1,310	483	524	127	36	0	0	3,800	Titus *et al.* (2008)
2008/09	28	165	295	432	311	1,678	592	451	67	0	0	0	4,019	Titus *et al.* (2009)
2009/10	0	41	0	78	746	547	306	81	90	0	0	0	1,889	Titus *et al.* (2010)

The fitting of the asymmetric logistic function in step 3 was performed in Excel using the Solver function with a weighted non-linear least squares procedure. The weighting procedure was used to avoid the disproportionate influence of individual monthly proportions (e.g., the years 1991/92 and 1992/93) relative to all monthly proportions in the estimation of the parameters of the asymmetric logistic function.

The weights were calculated as the ratio of the annual estimated total of Chinook salmon caught to the total number of Chinook salmon caught over the 10 years (i.e., 233,098 fish). For example, the 7 monthly proportions for the 1992/93 biological year that had a total annual catch of 6,960 fish each received a weight of 0.029859 (i.e., 6,960 / 233,098 = 0.029859).

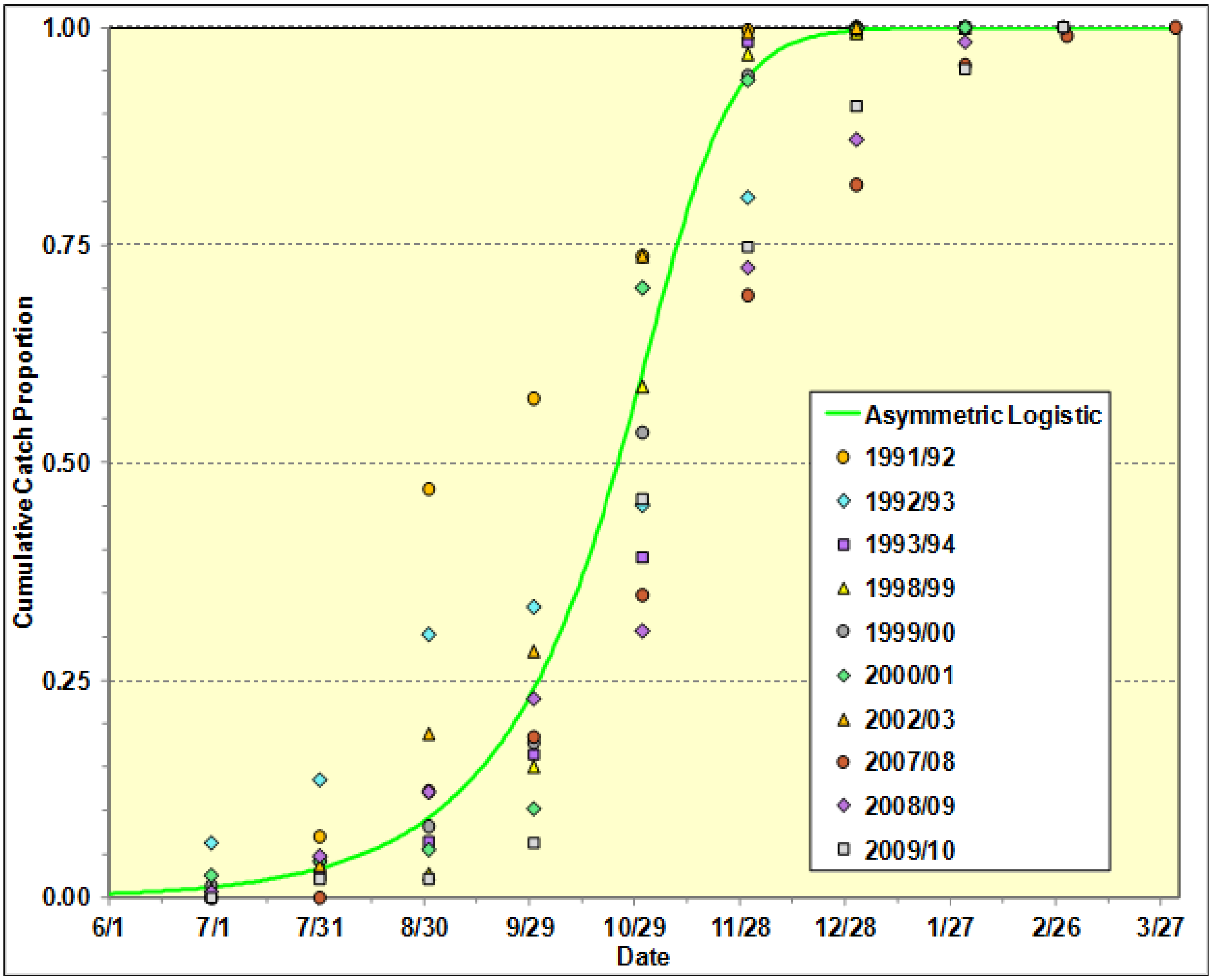

Figure 1. Chinook salmon monthly proportions of estimated angler's catch in the lower American River, during the 1991/92 – 1993/94, 1998/99 – 2000/01, 2002/03, and 2007/08 – 2009/10 biological years, and the common fitted asymmetric logistic curve representing the cumulative temporal distribution for all years.

In the Central Valley, adult fall-run Chinook salmon are reported to generally begin migrating upstream annually in July, with immigration continuing through December in most years (Vogel and Marine 1991). It has been reported that adult fall-run Chinook salmon typically begin entering the lower American River in September and October, and continue through January (SWRI 2001). Both historic (fish passage at Old Folsom Dam, 1944-1946) and recent survey data indicate that adult Chinook salmon arrivals in the lower American River peak in November.

CDFW does not make any distinction by run assignation to the Chinook salmon in the creel survey reports, and it is not possible to know which fish caught during January (or later) are fall-run or late fall-run Chinook salmon, or a mixed stock. Because there is no dependable quantitative basis to rely upon to exclude data in the analysis, all CDFW Chinook salmon catch data were included in the temporal weighting procedure without arbitrary rejection of certain data. In addition, because fish typically exhibit life history periodicities and behaviors that vary somewhat from the anthropogenic characterization of the species/run as a whole, it is likely that some fish spawning later in the season (i.e., January) are indeed fall-run Chinook salmon that exhibit a very truncated staging period. Although it might be reasonable to conclude that most of the fish spawning during February and March are late fall-run Chinook salmon, the fish caught after January represent only about 0.1% of the total number of fish caught included in the CDFW dataset. In subsequent steps of the analysis, the right hand tail of the resultant fall-run Chinook salmon pre-spawn arrival temporal distribution is adjusted to not extend beyond the completion of the assumed fall-run Chinook salmon spawning period (January 18), as further described below. Because the adult Chinook salmon arrival data are presented on a monthly basis, it is not possible to parse out those fish that may have arrived during January after the spawning end date (January 18) from those that arrived prior to the spawning end date.

It was necessary for the asymmetric logistic function resulting from the catch cumulative proportions to correspond with the asymmetric logistic function describing the temporal distribution for Chinook salmon spawning (see Section 2.2). Consequently, the curve estimated in step 3 was constrained to predict a cumulative proportion of adult fall-run Chinook salmon arrivals equal to 0.999490 by day 140 (i.e., January 18), because the asymmetric logistic function describing the temporal distribution of Chinook salmon spawning (Section 2.2) ends on January 18 (Day 140) and predicts a proportion of 0.999490 (or 99.95%) on day 140.

The asymmetric logistic function resulting from the constrained weighted least squares fit to the cumulative catch proportions in Figure 1 had the following expression (Equation 1):

$$Y_D = \left(\frac{1}{1 + \exp\left(7.2295 - 0.0972 \times D\right)} \right)^{1/3.0211} \qquad \textbf{(1)}$$

where D is the day number starting September 1 of each year (*e.g.*, during the 1992/93 year, D = 1 corresponds to September 1, 1992, while D = -91 corresponds to June 1, 1992 and D = 123 corresponds to January 1, 1993). The mean square error of the fitted common asymmetric logistic function was 0.0250 (indicating a relatively minor amount of variability in the data set not accounted for by the fitted model).

The asymmetric logistic curve of Equation 1 was used to calculate the expected daily proportions of Chinook salmon arriving in the lower American River between June 1 and January 18 by subtraction. The resulting daily proportions were first rounded to four decimal places and finally rescaled by dividing each daily value by the sum of all daily rounded values (that equaled to 0.9944 or 99.44%). The final daily temporal weighting coefficients describing the temporal distribution of adult fall-run Chinook salmon arriving in the lower American River are presented in **Figure 2**.

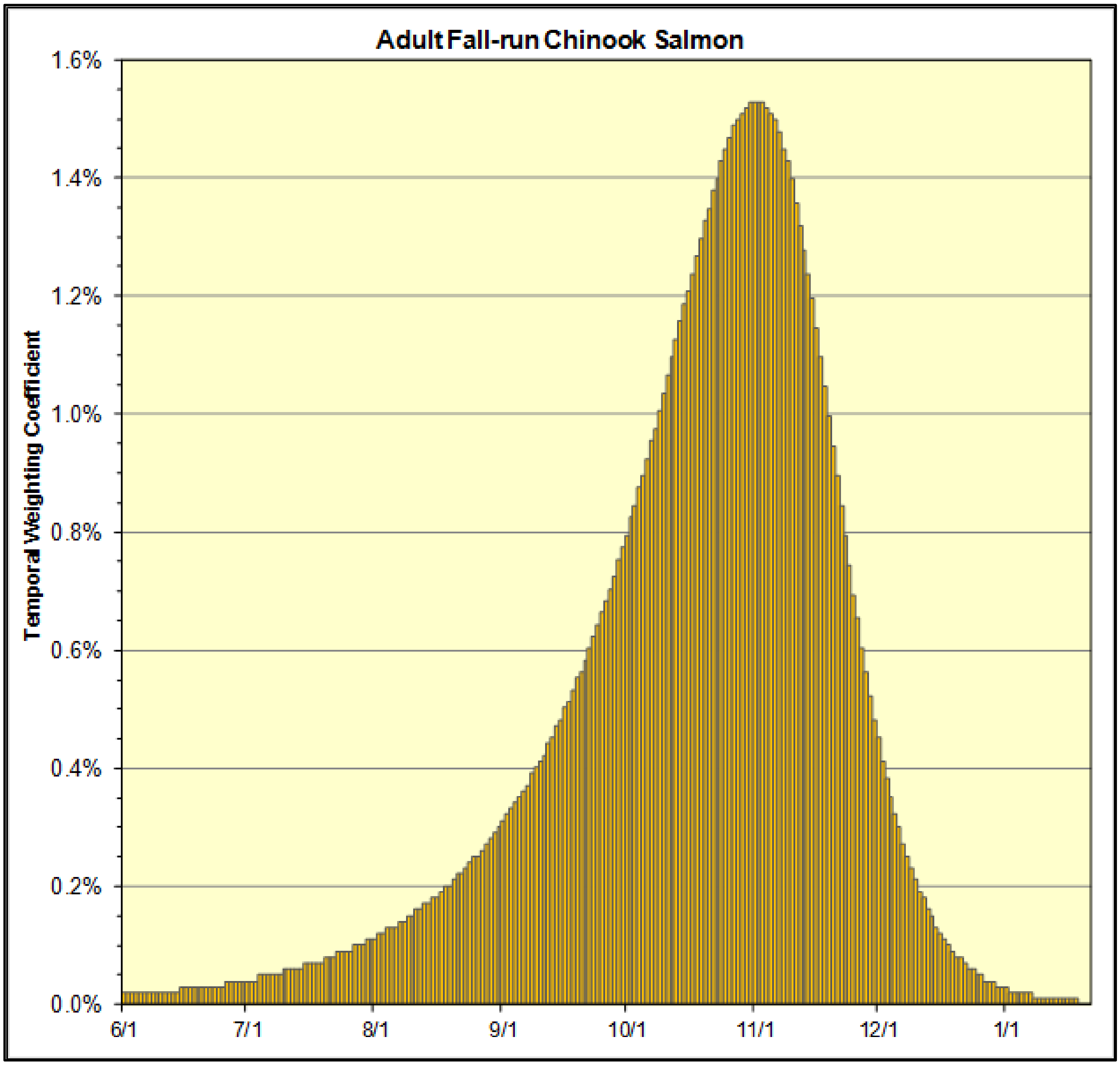

Figure 2. Daily temporal weighting coefficients used for adult fall-run Chinook salmon arrival in the lower American River.

2.2 Chinook Salmon Spawning Temporal Distribution

The timing of adult Chinook salmon spawning activity is influenced by inherent behavioral characteristics and the occurrence of appropriate spawning temperatures. It has been previously reported that fall-run Chinook salmon spawning in the lower American River is initiated when water temperatures decline to about 60°F (SWRI 2001) and the original LAR Mortality Model stated that annual lower American River spawning was to be initiated (by the model) when the daily mean river water temperature became ≤60°F each year, rather than on a characteristic temporal distribution (HCI 1996). However, as discussed below, more recent lower American River water temperature and temporal Chinook salmon spawning distribution data indicate that the 60°F threshold is not a reliable assumption for determining the initiation of Chinook salmon spawning in the lower American River.

Water temperature monitoring data from the U. S. Geological Survey (USGS) Fair Oaks Gage from 1998 through 2012 were compared with temporal Chinook salmon spawning distributions (**Figure 3**) that were estimated using Chinook salmon carcass and redd survey data, as discussed in further detail later in this section. Based on carcass survey data (and estimation of the lag period between spawning and appearance of fresh carcasses in the carcass surveys) in the lower American River from 1998 through 2012, the initiation of fall-run Chinook salmon spawning (represented by 10% of the annual cumulative distribution) occurs when daily average water temperatures decreased to values generally ranging from 59.7 to 64.0°F, and to 67.4°F during one year (2001), with an average of 62.3°F (Figure 3).

As discussed in detail in Section 3.0, relatively high water temperatures (≥ ~60°F) at the beginning of the fall-run Chinook salmon spawning season can induce pre-spawning adult losses and decrease early lifestage viability. In recent years, mean daily water temperatures at or below 60°F in the upper reaches of the lower American River have not occurred until dates ranging from October 28 to November 16. From 1998 through 2012, the average date on which mean daily water temperatures declined to 60°F in the upper reaches of the lower American River was November 6. For these same years, an average of 43% of the annual runs of fall-run Chinook salmon was estimated to have spawned by November 6. Thus, lower American River water temperature regimes during the fall in recent years may have the potential to reduce the initial year class strength and eventual productivity of fall-run Chinook salmon.

The LAR Mortality Model requires input regarding the temporal distribution of spawning adult fall-run Chinook salmon in the lower American River. For LAR Mortality Model application purposes, it appears that the assumption that fall-run Chinook salmon do not spawn until water temperatures decline to 60°F in the lower American River is not valid. By contrast, it is more appropriate to base the model's temporal spawning distribution on fall-run Chinook salmon redd and carcass data.

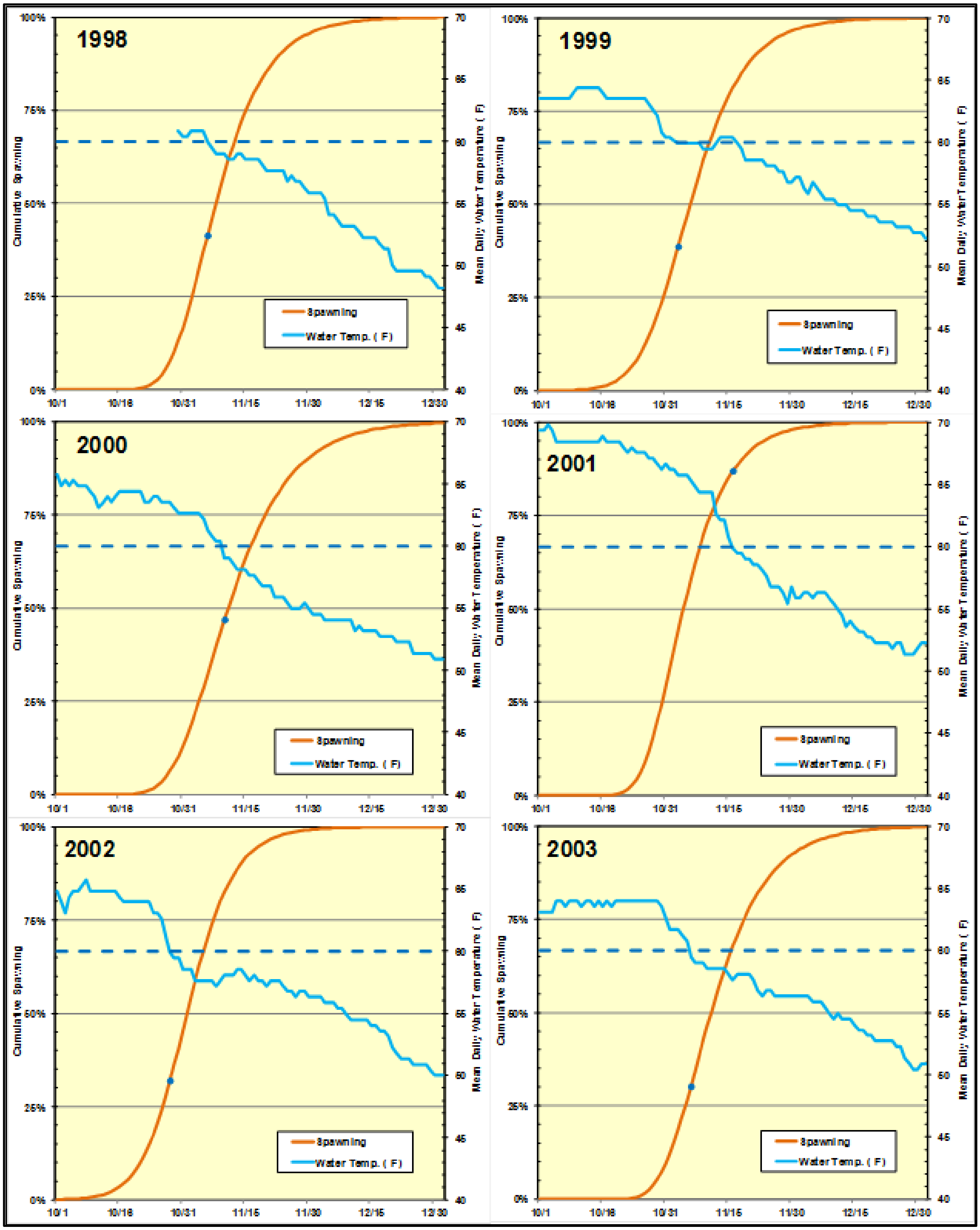

Figure 3. Mean daily water temperature at the USGS Fair Oaks Gage and the cumulative temporal distribution of adult fall-run Chinook salmon spawning in the lower American River from 1998 through 2012.

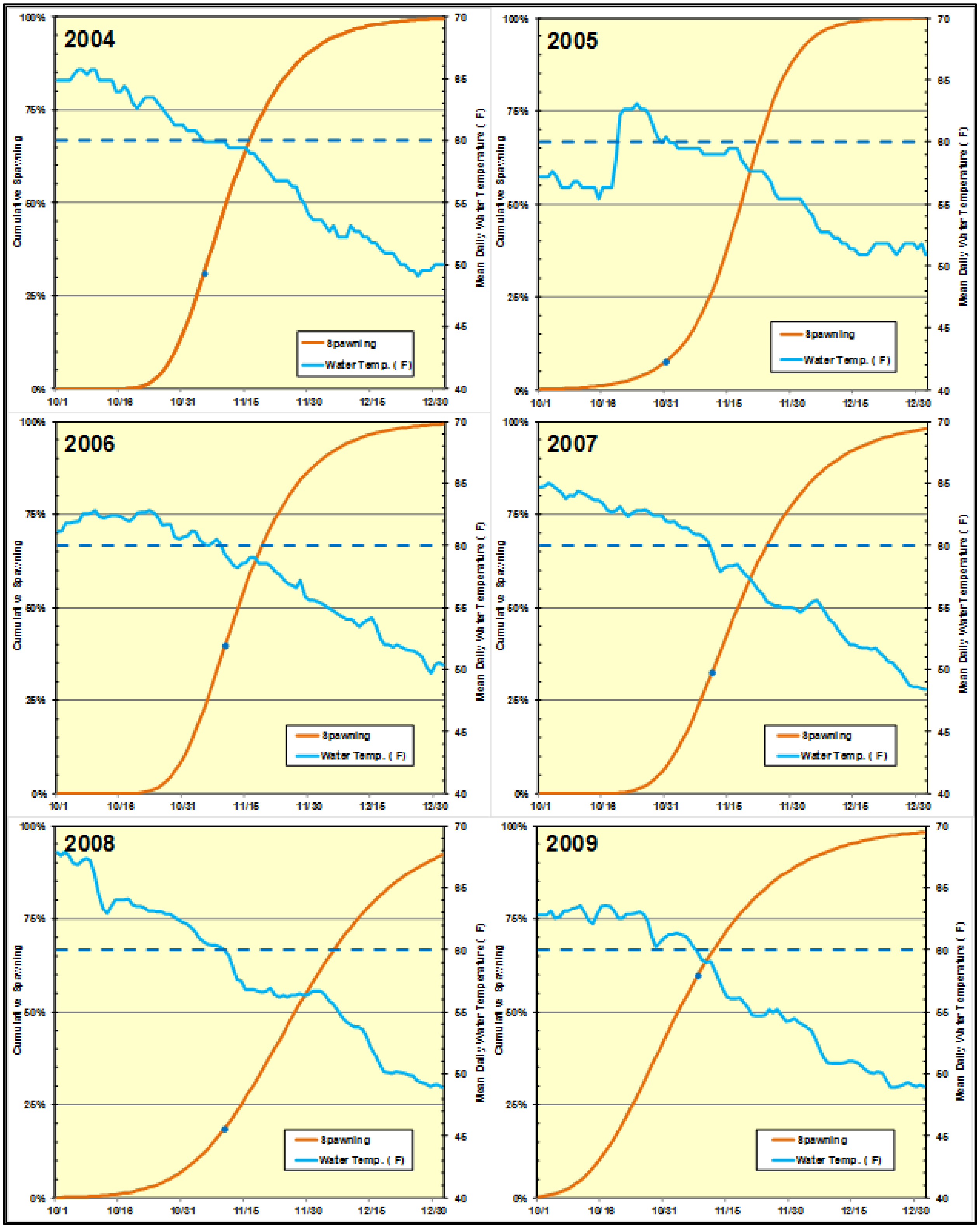

Figure 3 (continued). Mean daily water temperature at the USGS Fair Oaks Gage and the cumulative temporal distribution of adult fall-run Chinook salmon spawning in the lower American River from 1998 through 2012.

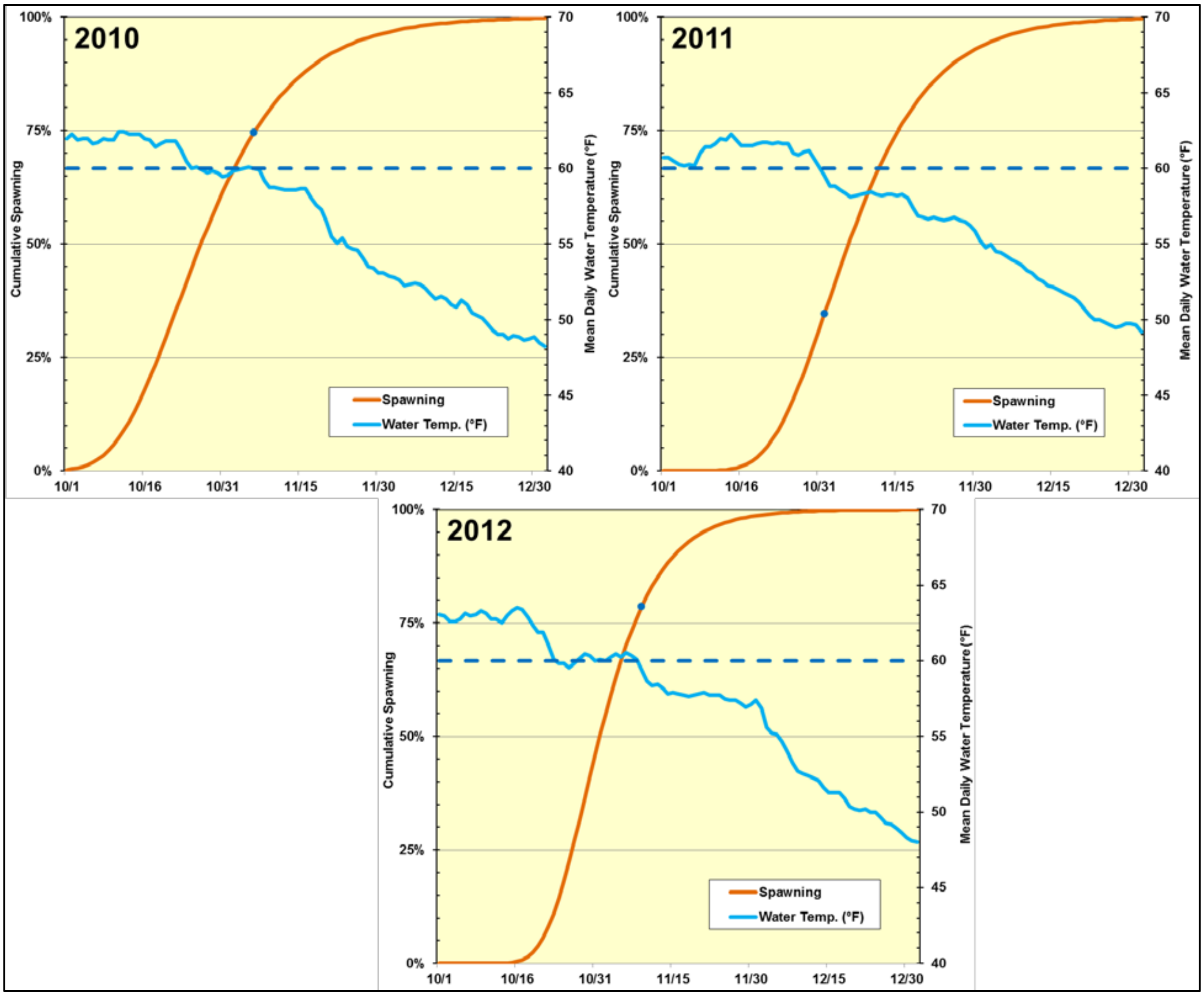

Figure 3 (continued). Mean daily water temperature at the USGS Fair Oaks Gage and the cumulative temporal distribution of adult fall-run Chinook salmon spawning in the lower American River from 1998 through 2012.

Both photogrammetric redd surveys and spawning stock escapement surveys ("carcass surveys") were used in the first step toward the derivation of a temporal distribution of spawning adult fall-run Chinook salmon. The aerial redd surveys conducted on the lower American River provide data that can be used to develop the cumulative distribution of newly built redds over time, and are better descriptors of spawning timing than carcass surveys. However, approximately weekly aerial redd surveys were conducted only during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons in the lower American River (Snider and McEwan 1992; Snider et al. 1993, 1996; Snider and Vyverberg 1995, 1996). By contrast, fall-run Chinook salmon carcass surveys have been performed annually since the late 1960s, and data or reports are available for all surveys performed from October 1992 through October 2012 (e.g., Snider and Bandner 1996; Snider and Reavis 1996; Snider et al. 1993 and 1995; Healey 2002, 2003, 2004, 2005 and 2006; Healey and Fresz 2007; Healey and Redding 2008; Vincik and Kirsch

2009; Vincik and Mamola 2010; Maher et al. 2012; Phillips and Maher 2013; and Phillips and Helstab 2013). The temporal distributions of fresh carcasses described in these reports can be used to estimate an overall cumulative distribution of fresh carcasses over time that describe when fresh carcasses appear in the surveys, which is subsequent to the actual time of spawning. When adjusted by the time elapsing between spawning and appearance of fresh carcasses in the surveys, the carcass surveys also describe spawning timing. The time elapsing between redd construction, spawning and post-spawning mortality, or life expectancy after spawning, has been reported to be between 2 and 4 weeks (Briggs 1953).

To take advantage of the information on lower American River fall-run Chinook salmon spawning timing contained in the available redd and carcass surveys, a 5-step procedure was developed to estimate the cumulative temporal distribution of fall-run Chinook salmon spawning in the lower American River that, in turn, was used in the calculation of the temporal weighting coefficients to be input into the LAR Mortality Model. The 5-step procedure consists of the following steps.

1.) Fit an asymmetric logistic function to the weekly cumulative proportions of newly built redds obtained from the four annual photogrammetric redd surveys performed during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons.

2.) Fit an asymmetric logistic function to the cumulative proportions of fresh carcasses obtained from the four annual carcass surveys performed during the 1992/93 through 1995/96 fall-run Chinook salmon spawning seasons.

3.) Calculate the lag times between the fitted redd and fresh-carcass cumulative distributions (i.e., the number of days separating particular cumulative proportions under the asymmetric logistic functions fitted in Steps 1 and 2, above).

4.) Fit an asymmetric logistic function to the cumulative proportions of fresh carcasses obtained from the available carcass surveys performed during the 1992/93 through the 2012/13 fall-run Chinook salmon spawning seasons.

5.) Apply the lag times calculated in Step 3 to the curve fitted in Step 4 by subtracting the corresponding lag times from the days for particular cumulative proportions of fresh carcasses expected under the curve obtained in Step 4. The resulting adjusted asymmetric logistic function was used to describe fall-run Chinook salmon spawning timing in the lower American River based on carcass surveys from 1992/93 through the 2012/13 fall-run Chinook salmon spawning seasons, and to calculate the temporal weighting coefficients required as input into the Mortality Model.

Each of the steps in the spawning temporal distribution determination are described in detail, below.

Step 1

During the four photogrammetric redd surveys performed from late September or October through early January during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons, a total of 14,084 newly-built redds were counted, ranging from a low of 1,138 redds during the 1992/93 spawning season to a high of 6,205 redds during the 1993/94 spawning season. Given the variation in total number of redds counted each season, as well as the number of weekly aerial surveys performed during each spawning season, a weighted nonlinear least squares procedure was used to fit a common asymmetric logistic function to the four sets of daily cumulative proportions of newly built redds.

The weights were calculated as the ratio of the annually counted redds to the overall total number of counted redds (i.e., a total of 14,084 newly-built redds). For example, the data points associated with each aerial redd survey representing the cumulative proportions of redds built during the 1992/93 spawning season (a total of 1,138 redds counted) each received a weight of 0.0808 (i.e., 1,138/14,084 = 0.0808), while the data points associated with each aerial redd survey representing the cumulative proportions of redds built during the 1995/96 spawning season (a total of 3,976 redds counted) each received a weight of 0.2823 (i.e., 3,976/14,084 = 0.2823). The common asymmetric logistic function fitted to the redd data for all four years had the following expression (Equation 2):

$$Y_D = \left(\frac{1}{1 + \exp\left(8.6114 - 0.1430 \times D\right)} \right)^{1/0.2330} \qquad \textbf{(2)}$$

where D is the day number at which new redds were observed during a particular annual survey, starting September 1 of each year. The mean square error of the fitted common asymmetric logistic function was 0.0513 (indicating a relatively minor amount of variability in the data set not accounted for by the fitted model). **Figure 4** displays the four sets of daily cumulative proportions and the fitted curve of Equation 2.

Step 2

During the four annual carcass surveys performed from October through mid-January during the 1992/93 through the 1995/96 fall-run Chinook salmon spawning seasons, a total of 5,788 fresh carcasses were counted, ranging from a low of 360 fresh carcasses during the 1992/93 spawning season to a high of 1,980 fresh carcasses during the 1995/96 spawning season. A weighted nonlinear least squares procedure was used to fit a common asymmetric logistic function to the four annual sets of cumulative proportions of fresh carcasses. The weights were calculated as the ratio of the annually counted fresh carcasses to the overall number of counted fresh carcasses (i.e., 5,788 carcasses), similar to the procedure described above for redd surveys.

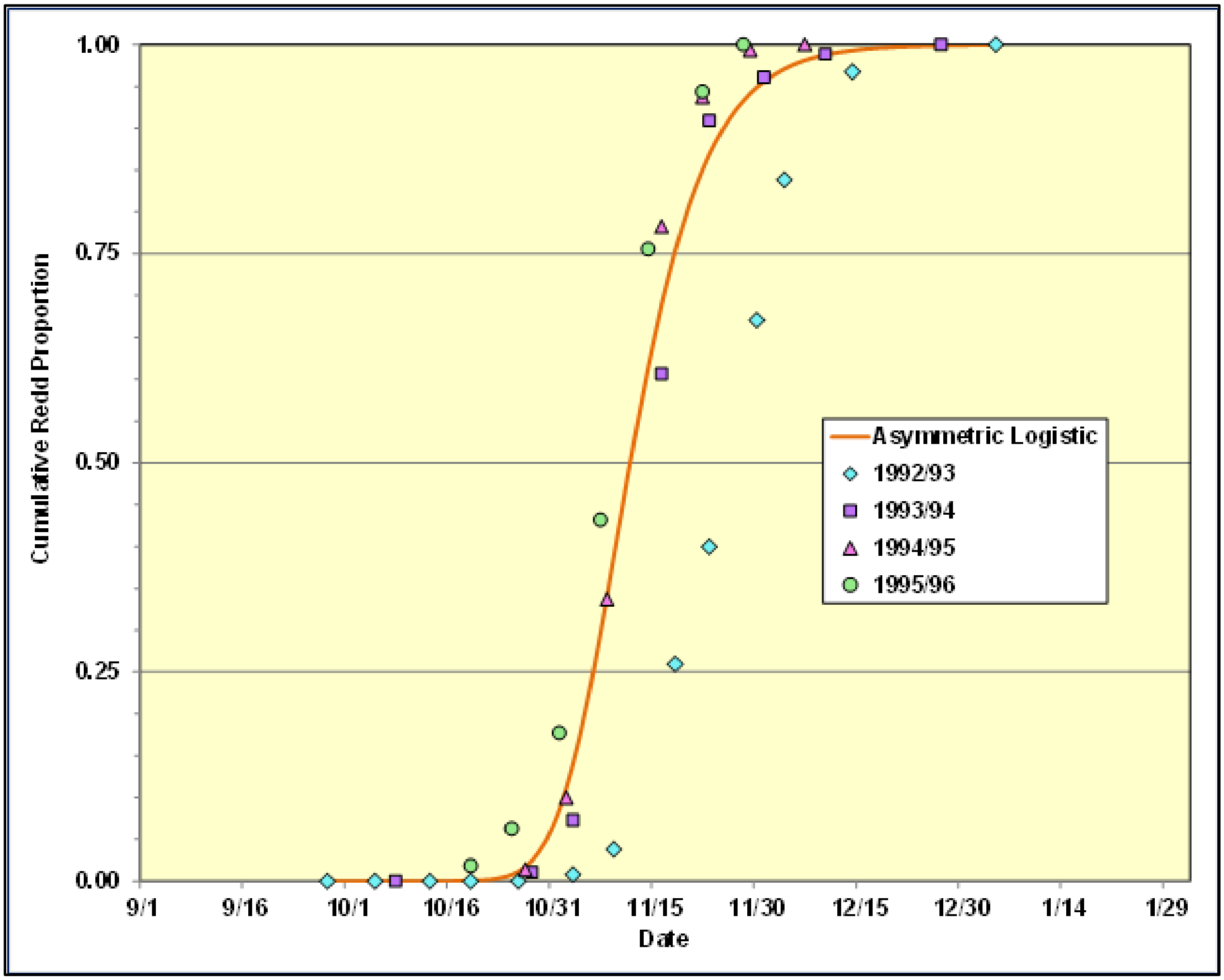

Figure 4. Fall-run Chinook salmon cumulative proportions of newly constructed redds in the lower American River from weekly aerial redd surveys conducted during the 1992/93 – 1995/96 spawning seasons, and the common fitted asymmetric logistic curve for all years.

The common asymmetric logistic function fitted to the fresh carcass data had the following expression (Equation 3):

$$Y_D = \left(\frac{1}{1 + \exp\left(14.5710 - 0.1677 \times D\right)} \right)^{1/1.0518} \qquad \textbf{(3)}$$

The mean square error of this fit was 0.0396 (indicating a relatively minor amount of variability in the data set not accounted for by the fitted model). **Figure 5** displays the four annual sets of cumulative proportions and the fitted curve of Equation 3.

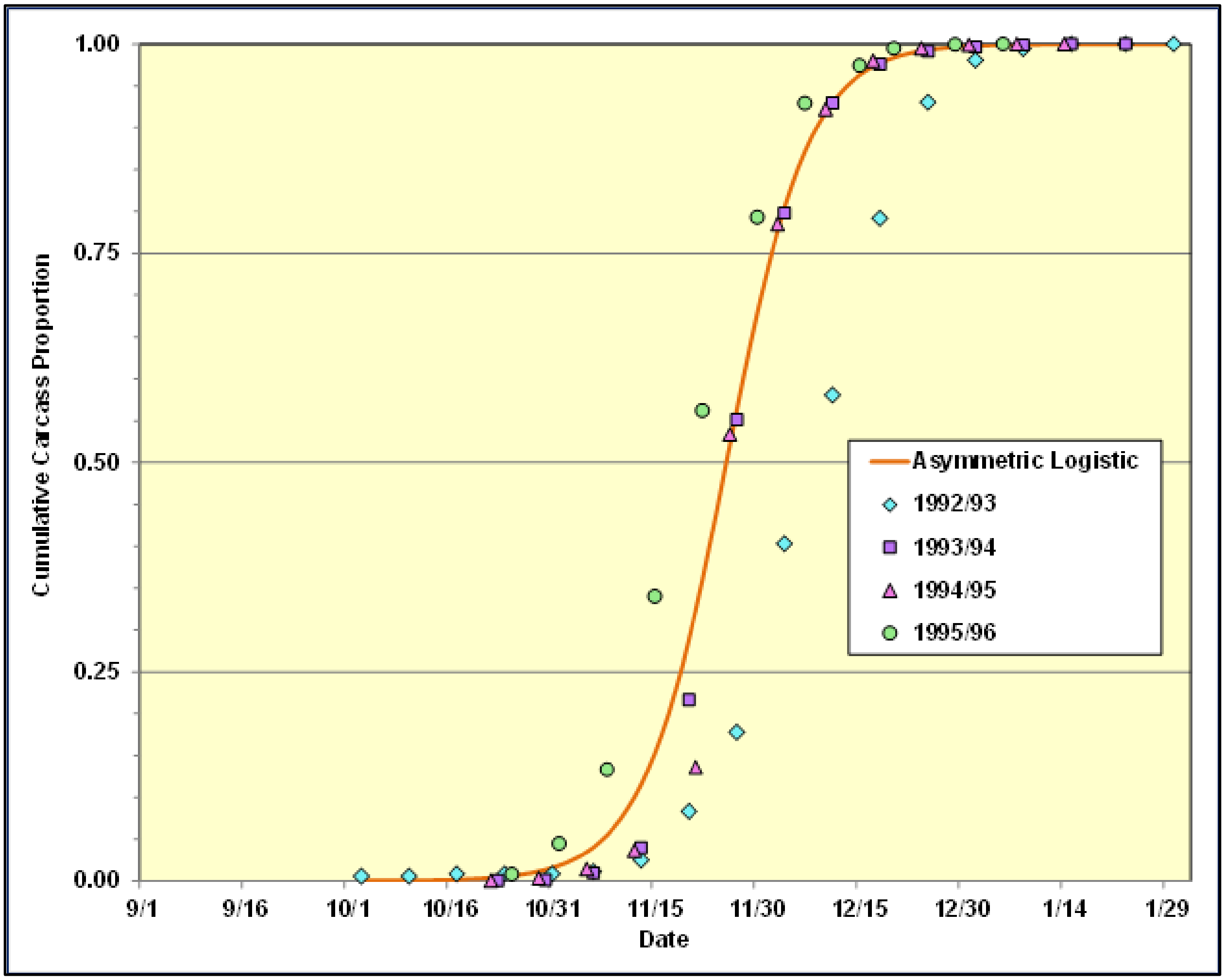

Figure 5. Fall-run Chinook salmon cumulative proportions of fresh carcasses in the lower American River, during the 1992/93 – 1995/96 spawning seasons, and the common fitted asymmetric logistic curve for all years.

Step 3

As part of the third procedural step, where the lag times between the fitted redd and fresh-carcass cumulative temporal distributions are computed, the parameter values of Equations 2 and 3 are applied to the following expression (Equation 4):

$$D_{Y'} = \frac{\ln\left[\left(\frac{1}{Y'}\right)^{\hat{\delta}} - 1\right] - \hat{\alpha}}{\hat{\beta}} \tag{4}$$

where *Y'* are particular expected cumulative proportions under fitted Equations 2 and 3 (e.g., 0.05, 0.1, 0.25, 0.5, etc.), $D_{Y'}$ are the days at which those proportion are achieved, and $\hat{\alpha}$, $\hat{\beta}$ and

$\hat{\delta}$ are the parameter values in Equations 2 and 3. After calculating Equation 4 with both sets of parameter estimates, there are two $D_{Y'}$ values for each particular expected cumulative proportion *Y'* – one for the fitted redd cumulative distribution (Equation 2), and the other for the fitted fresh-carcass cumulative distribution (Equation 3). The lag times between the fitted redd and fresh-carcass cumulative distributions are then calculated as the differences between the pairs of $D_{Y'}$ values. **Table 2** summarizes the results of these lag-time calculations for representative expected cumulative proportions, encompassing the vast majority of the range of the cumulative distributions.

Table 2. Lag times between cumulative proportions (Y'%) of the redd and fresh-carcass cumulative temporal distributions fitted to data for the 1992/93 – 1995/96 Chinook salmon spawning seasons.

Cumulative Proportion (*Y'%*)	Day under Fitted Redd Cumulative Curve ($D_{Y'}$)	Day under Fitted Carcass Cumulative Curve ($D_{Y'}$)	Lag Time (days)
1%	55.6	58.1	2.4
5%	60.2	68.4	8.2
10%	62.6	73.0	10.4
15%	64.3	75.9	11.5
20%	65.7	78.0	12.3
25%	67.0	79.8	12.8
50%	72.4	86.5	14.1
75%	78.9	93.1	14.2
80%	80.7	94.8	14.1
85%	83.0	96.9	13.9
90%	86.1	99.7	13.6
95%	91.1	104.1	13.0
99%	102.6	114.0	11.4
$D_{Y'}$ and lag times are expressed in days starting from September 1 each year.			

Step 4

As part of the fourth procedural step, a new common asymmetric logistic function was fitted to the cumulative proportions of fresh fall-run Chinook salmon carcasses obtained from all of the 21 years of available carcass surveys (1992/93 through 2012/2013) to incorporate additional information on spawning timing not present in the shorter data sets used in steps 1 and 2. Consistent with the previously described weighting methods, a weighted least square procedure was used, in which weights were calculated as the ratios of the annually counted fresh carcasses during a season to the overall number of counted fresh carcasses (i.e., a total of 38,366 carcasses). **Figure 6** displays the results of this new fitted asymmetric logistic function (Equation 5).

$$Y_D = \left(\frac{1}{1 + \exp\left(8.3944 - 0.1100 \times D\right)} \right)^{1/0.5373} \tag{5}$$

The mean square error of this fit was 0.0220 (indicating a relatively minor amount of variability in the data set not accounted for by the fitted model). Examination of Figure 6 indicates relatively high variability in the temporal cumulative distributions of fresh carcasses among years, with no consistent trend (i.e., “shifting”) in the timing of spawning between early and late years included in the analysis.

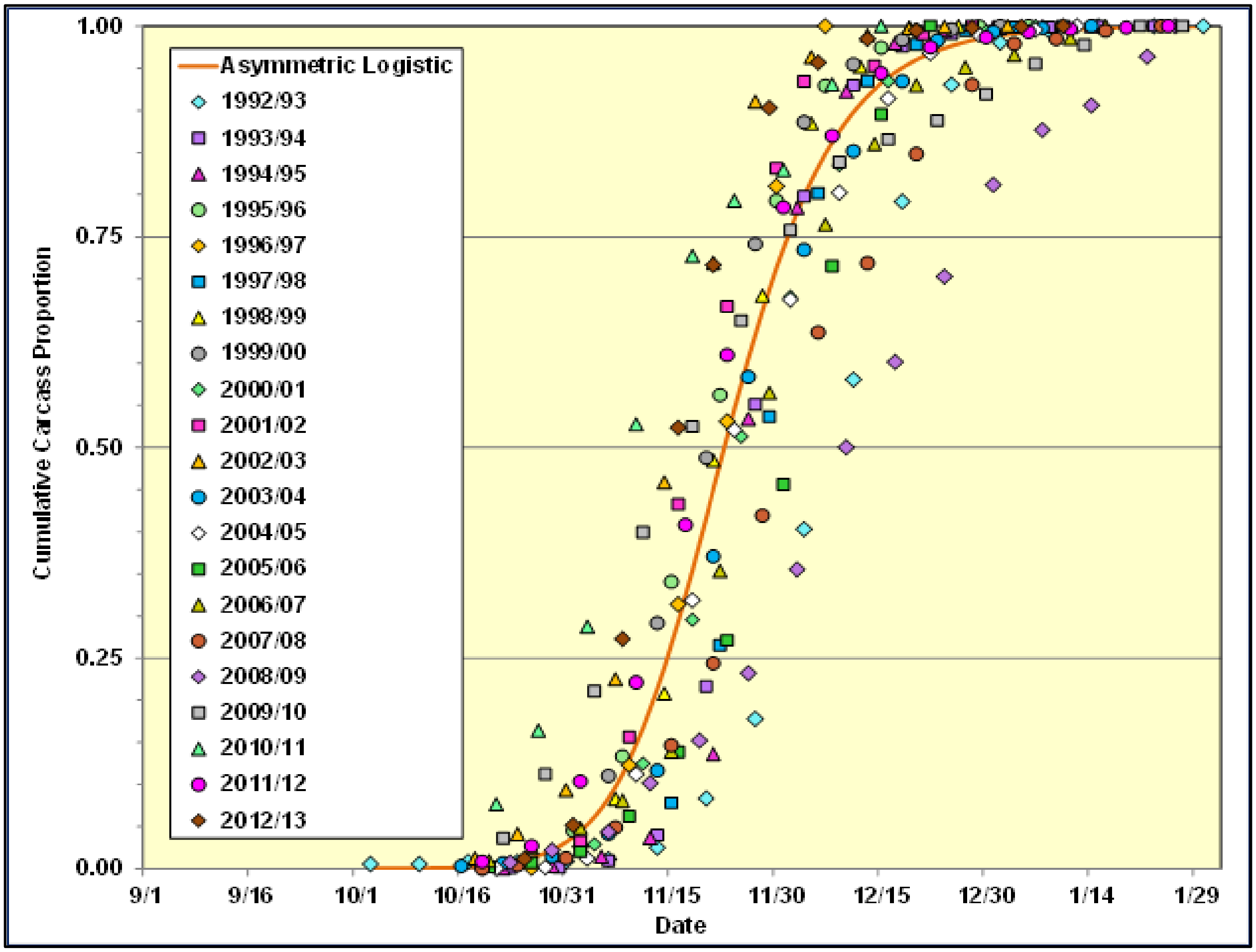

Figure 6. Fall-run Chinook salmon cumulative proportions of fresh carcasses in the lower American River, during the 1992/93 – 2012/13 spawning seasons, and the common fitted asymmetric logistic curve for all years.

Step 5

Finally, as part of the fifth procedural step, the parameter values of Equation 5 are applied to Equation 4 to calculate new $D_{Y'}$ values (i.e., days at particular cumulative proportions of the new fitted curve), and the lag times in Table 2 are subtracted from the new $D_{Y'}$ values. The resulting adjusted asymmetric logistic curve had the following expression (Equation 6):

$$Y_D = \left(\frac{1}{1 + \exp\left(1.2818 - 0.1010 \times D\right)} \right)^{1/0.0046} \quad \textbf{(6)}$$

Figure 7 displays the 4 asymmetric logistic curves obtained from the 5-step procedure used to describe fall-run Chinook salmon spawning timing in the lower American River.

Because a logistic equation essentially can range from values approaching negative infinity to positive infinity, and because all of the daily values associated with the distribution must sum to 1, the practical application of the logistic equation to describe the temporal distribution of spawning required identifying the potential starting and ending dates of fall-run Chinook salmon spawning in the lower American River. Therefore, the asymmetric logistic curve of Equation 6 was used to calculate expected daily spawning proportions by subtraction. Finally, the daily temporal coefficients for fall-run Chinook salmon were obtained by rounding the daily proportions to four decimal places and rescaling to the sum of the rounded proportions (that equaled 0.9995 or 99.95%). **Figure 8** displays the final daily weighting coefficients that are presented in **Table 3**. The resulting spawning period extends from October 13 through January 18, a period consisting of 98 days.

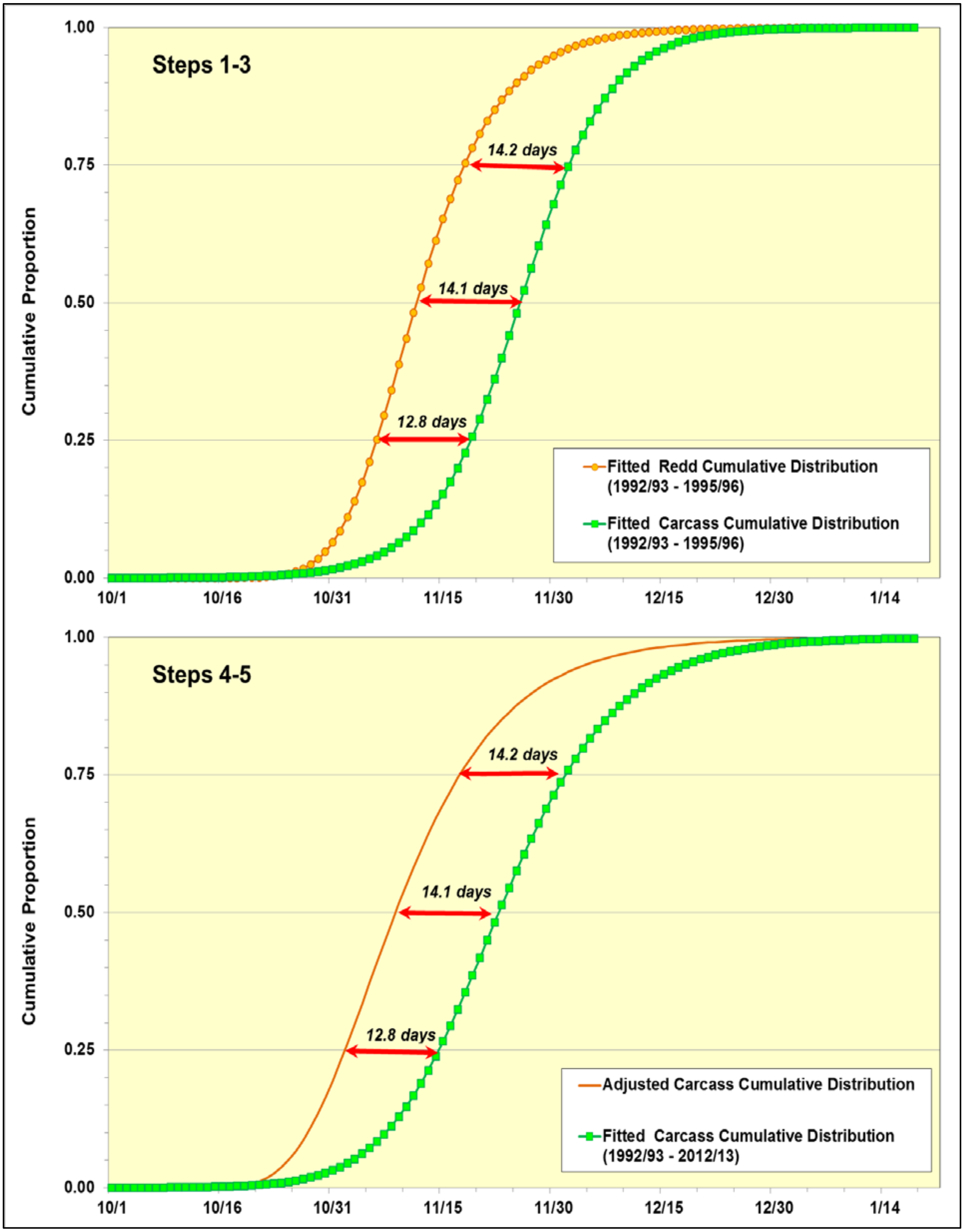

Figure 7. Asymmetric logistic curves obtained from 5-Step procedure used to describe fall-run Chinook salmon spawning timing in the lower American River during the 1992/93 - 2012/13 spawning seasons.

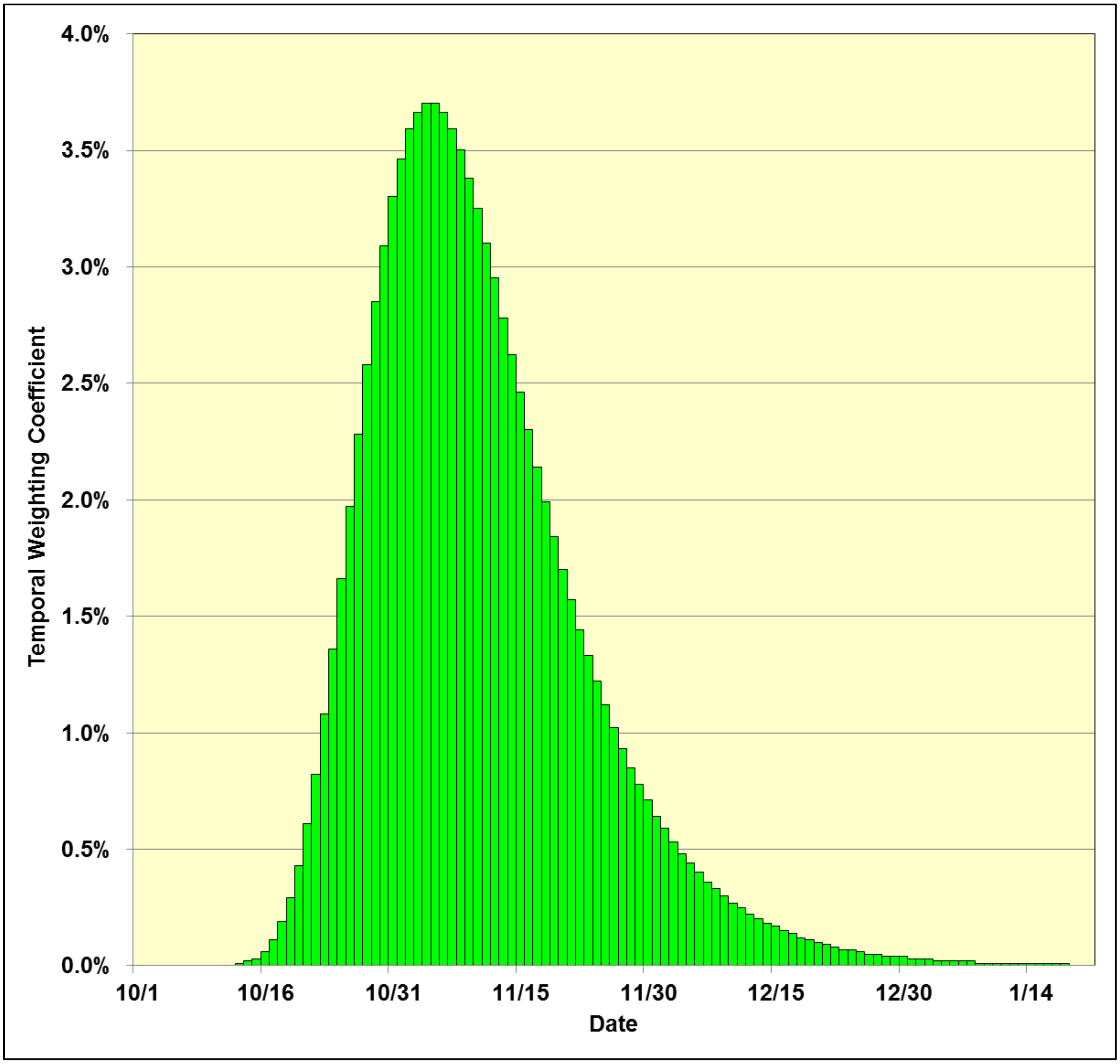

Figure 8. Daily temporal weighting coefficients used for fall-run Chinook salmon spawning in the lower American River.

Table 3. Temporal weighting coefficients used for fall-run Chinook salmon spawning in the lower American River.

Day	Lagged Carcass Fit (%)	Temporal Weighting Coefficient	Day	Lagged Carcass Fit (%)	Temporal Weighting Coefficient
10/12	0.00%	0.000000	**12/1**	0.64%	0.006403
10/13	0.01%	0.000100	**12/2**	0.59%	0.005903
10/14	0.02%	0.000200	**12/3**	0.53%	0.005303
10/15	0.03%	0.000300	**12/4**	0.48%	0.004802
10/16	0.06%	0.000600	**12/5**	0.44%	0.004402
10/17	0.11%	0.001101	**12/6**	0.40%	0.004002
10/18	0.19%	0.001901	**12/7**	0.36%	0.003602
10/19	0.29%	0.002901	**12/8**	0.33%	0.003302
10/20	0.43%	0.004302	**12/9**	0.30%	0.003002
10/21	0.61%	0.006103	**12/10**	0.27%	0.002701
10/22	0.82%	0.008204	**12/11**	0.25%	0.002501
10/23	1.08%	0.010805	**12/12**	0.22%	0.002201
10/24	1.36%	0.013607	**12/13**	0.20%	0.002001
10/25	1.66%	0.016608	**12/14**	0.18%	0.001801
10/26	1.97%	0.019710	**12/15**	0.17%	0.001701
10/27	2.28%	0.022811	**12/16**	0.15%	0.001501
10/28	2.58%	0.025813	**12/17**	0.14%	0.001401
10/29	2.85%	0.028514	**12/18**	0.12%	0.001201
10/30	3.09%	0.030915	**12/19**	0.11%	0.001101
10/31	3.30%	0.033017	**12/20**	0.10%	0.001001
11/1	3.46%	0.034617	**12/21**	0.09%	0.000900
11/2	3.59%	0.035918	**12/22**	0.08%	0.000800
11/3	3.66%	0.036618	**12/23**	0.07%	0.000700
11/4	3.70%	0.037019	**12/24**	0.07%	0.000700
11/5	3.70%	0.037019	**12/25**	0.06%	0.000600
11/6	3.66%	0.036618	**12/26**	0.05%	0.000500
11/7	3.59%	0.035918	**12/27**	0.05%	0.000500
11/8	3.50%	0.035018	**12/28**	0.04%	0.000400
11/9	3.38%	0.033817	**12/29**	0.04%	0.000400
11/10	3.25%	0.032516	**12/30**	0.04%	0.000400
11/11	3.10%	0.031016	**12/31**	0.03%	0.000300
11/12	2.95%	0.029515	**1/1**	0.03%	0.000300
11/13	2.78%	0.027814	**1/2**	0.03%	0.000300
11/14	2.62%	0.026213	**1/3**	0.02%	0.000200
11/15	2.46%	0.024612	**1/4**	0.02%	0.000200
11/16	2.30%	0.023012	**1/5**	0.02%	0.000200
11/17	2.14%	0.021411	**1/6**	0.02%	0.000200
11/18	1.99%	0.019910	**1/7**	0.02%	0.000200
11/19	1.84%	0.018409	**1/8**	0.01%	0.000100
11/20	1.70%	0.017009	**1/9**	0.01%	0.000100
11/21	1.57%	0.015708	**1/10**	0.01%	0.000100
11/22	1.44%	0.014407	**1/11**	0.01%	0.000100
11/23	1.33%	0.013307	**1/12**	0.01%	0.000100
11/24	1.22%	0.012206	**1/13**	0.01%	0.000100
11/25	1.12%	0.011206	**1/14**	0.01%	0.000100
11/26	1.02%	0.010205	**1/15**	0.01%	0.000100
11/27	0.93%	0.009305	**1/16**	0.01%	0.000100
11/28	0.85%	0.008504	**1/17**	0.01%	0.000100
11/29	0.78%	0.007804	**1/18**	0.01%	0.000100
11/30	0.71%	0.007104	**Totals**	99.95%	1

2.3 Comparison of Chinook Salmon Pre-Spawn Arrival and Spawning Temporal Distributions

Figure 9 compares the cumulative distribution of fall-run Chinook salmon spawning (orange curve) with the cumulative distribution of fall-run Chinook salmon arrival (green curve) in the lower American River in order to estimate staging duration. Estimates of staging duration are required input into the LAR Mortality Model. The red arrows indicate the time (in days) to the onset of spawning associated with particular cumulative proportions of arriving fish. The final daily temporal weighting coefficients describing the temporal distribution of adult fall-run Chinook salmon arriving in the lower American River, including the number of days until spawning for each daily cohort, are presented in **Table 4**.

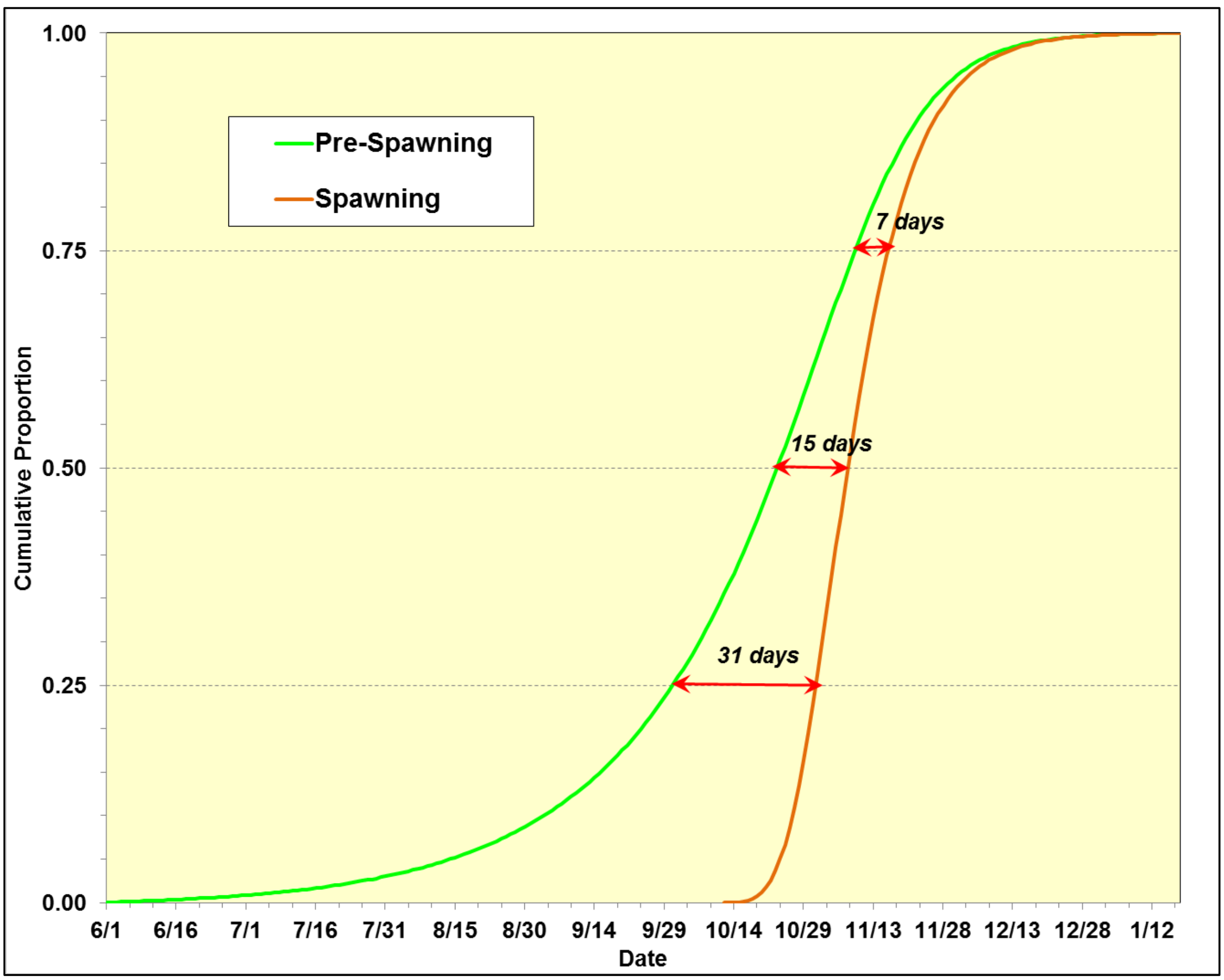

Figure 9. Comparison of the estimated cumulative temporal distributions developed for pre-spawning and spawning fall-run Chinook salmon in the lower American River.

Table 4. Temporal weighting coefficients used for adult fall-run Chinook salmon arrival in the lower American River, including the estimated days to spawning for each daily cohort.

Day	Chinook Catch Fit	Temporal Weighting	Days to Spawning	Day	Chinook Catch Fit	Temporal Weighting	Days to Spawning
6/1	0.02%	0.000201	135	7/30	0.11%	0.001106	84
6/2	0.02%	0.000201	134	7/31	0.11%	0.001106	83
6/3	0.02%	0.000201	134	8/1	0.11%	0.001106	83
6/4	0.02%	0.000201	133	8/2	0.12%	0.001207	82
6/5	0.02%	0.000201	133	8/3	0.12%	0.001207	81
6/6	0.02%	0.000201	132	8/4	0.13%	0.001307	80
6/7	0.02%	0.000201	131	8/5	0.13%	0.001307	79
6/8	0.02%	0.000201	130	8/6	0.13%	0.001307	78
6/9	0.02%	0.000201	130	8/7	0.14%	0.001408	77
6/10	0.02%	0.000201	129	8/8	0.14%	0.001408	76
6/11	0.02%	0.000201	128	8/9	0.15%	0.001508	75
6/12	0.02%	0.000201	127	8/10	0.15%	0.001508	75
6/13	0.02%	0.000201	126	8/11	0.16%	0.001609	74
6/14	0.02%	0.000201	125	8/12	0.16%	0.001609	73
6/15	0.03%	0.000302	124	8/13	0.17%	0.001710	72
6/16	0.03%	0.000302	124	8/14	0.17%	0.001710	71
6/17	0.03%	0.000302	123	8/15	0.18%	0.001810	70
6/18	0.03%	0.000302	122	8/16	0.18%	0.001810	69
6/19	0.03%	0.000302	121	8/17	0.19%	0.001911	68
6/20	0.03%	0.000302	120	8/18	0.20%	0.002011	67
6/21	0.03%	0.000302	119	8/19	0.20%	0.002011	67
6/22	0.03%	0.000302	118	8/20	0.21%	0.002112	66
6/23	0.03%	0.000302	117	8/21	0.22%	0.002212	65
6/24	0.03%	0.000302	117	8/22	0.22%	0.002212	64
6/25	0.03%	0.000302	116	8/23	0.23%	0.002313	63
6/26	0.04%	0.000402	115	8/24	0.24%	0.002414	62
6/27	0.04%	0.000402	114	8/25	0.25%	0.002514	61
6/28	0.04%	0.000402	113	8/26	0.25%	0.002514	60
6/29	0.04%	0.000402	112	8/27	0.26%	0.002615	60
6/30	0.04%	0.000402	111	8/28	0.27%	0.002715	59
7/1	0.04%	0.000402	110	8/29	0.28%	0.002816	58
7/2	0.04%	0.000402	109	8/30	0.29%	0.002916	57
7/3	0.04%	0.000402	109	8/31	0.30%	0.003017	56
7/4	0.05%	0.000503	108	9/1	0.31%	0.003117	55
7/5	0.05%	0.000503	107	9/2	0.32%	0.003218	54
7/6	0.05%	0.000503	106	9/3	0.33%	0.003319	54
7/7	0.05%	0.000503	105	9/4	0.34%	0.003419	53
7/8	0.05%	0.000503	104	9/5	0.35%	0.003520	52
7/9	0.05%	0.000503	103	9/6	0.36%	0.003620	51
7/10	0.06%	0.000603	102	9/7	0.37%	0.003721	50
7/11	0.06%	0.000603	101	9/8	0.39%	0.003922	49
7/12	0.06%	0.000603	100	9/9	0.40%	0.004023	48
7/13	0.06%	0.000603	100	9/10	0.41%	0.004123	48
7/14	0.06%	0.000603	99	9/11	0.42%	0.004224	47
7/15	0.07%	0.000704	98	9/12	0.44%	0.004425	46
7/16	0.07%	0.000704	97	9/13	0.45%	0.004525	45
7/17	0.07%	0.000704	96	9/14	0.47%	0.004726	44
7/18	0.07%	0.000704	95	9/15	0.48%	0.004827	43
7/19	0.07%	0.000704	94	9/16	0.50%	0.005028	43
7/20	0.08%	0.000805	93	9/17	0.51%	0.005129	42
7/21	0.08%	0.000805	92	9/18	0.53%	0.005330	41
7/22	0.08%	0.000805	91	9/19	0.55%	0.005531	40
7/23	0.09%	0.000905	91	9/20	0.56%	0.005632	39
7/24	0.09%	0.000905	90	9/21	0.58%	0.005833	39
7/25	0.09%	0.000905	89	9/22	0.60%	0.006034	38
7/26	0.09%	0.000905	88	9/23	0.62%	0.006235	37
7/27	0.10%	0.001006	87	9/24	0.64%	0.006436	36
7/28	0.10%	0.001006	86	9/25	0.66%	0.006637	35
7/29	0.10%	0.001006	85	9/26	0.68%	0.006838	35

Table 4 (continued). Temporal weighting coefficients used for adult fall-run Chinook salmon arrival in the lower American River, including the estimated days to spawning for each daily cohort.

Day	Chinook Catch Fit	Temporal Weighting	Days to Spawning	Day	Chinook Catch Fit	Temporal Weighting	Days to Spawning
9/27	0.70%	0.007039	34	11/25	0.69%	0.006939	3
9/28	0.72%	0.007241	33	11/26	0.65%	0.006537	3
9/29	0.75%	0.007542	32	11/27	0.60%	0.006034	3
9/30	0.77%	0.007743	31	11/28	0.56%	0.005632	3
10/1	0.79%	0.007944	31	11/29	0.52%	0.005229	3
10/2	0.82%	0.008246	30	11/30	0.48%	0.004827	3
10/3	0.84%	0.008447	29	12/1	0.45%	0.004525	3
10/4	0.87%	0.008749	28	12/2	0.41%	0.004123	2
10/5	0.89%	0.008950	28	12/3	0.38%	0.003821	2
10/6	0.92%	0.009252	27	12/4	0.35%	0.003520	2
10/7	0.95%	0.009553	26	12/5	0.32%	0.003218	2
10/8	0.97%	0.009755	25	12/6	0.30%	0.003017	2
10/9	1.00%	0.010056	25	12/7	0.27%	0.002715	2
10/10	1.03%	0.010358	24	12/8	0.25%	0.002514	2
10/11	1.06%	0.010660	23	12/9	0.23%	0.002313	2
10/12	1.09%	0.010961	23	12/10	0.21%	0.002112	2
10/13	1.12%	0.011263	22	12/11	0.19%	0.001911	2
10/14	1.15%	0.011565	21	12/12	0.18%	0.001810	2
10/15	1.18%	0.011866	21	12/13	0.16%	0.001609	1
10/16	1.20%	0.012068	20	12/14	0.15%	0.001508	1
10/17	1.23%	0.012369	19	12/15	0.13%	0.001307	1
10/18	1.26%	0.012671	19	12/16	0.12%	0.001207	1
10/19	1.29%	0.012973	18	12/17	0.11%	0.001106	1
10/20	1.32%	0.013274	17	12/18	0.10%	0.001006	1
10/21	1.34%	0.013475	17	12/19	0.09%	0.000905	1
10/22	1.37%	0.013777	16	12/20	0.08%	0.000805	1
10/23	1.39%	0.013978	15	12/21	0.08%	0.000805	1
10/24	1.42%	0.014280	15	12/22	0.07%	0.000704	1
10/25	1.44%	0.014481	14	12/23	0.06%	0.000603	1
10/26	1.46%	0.014682	14	12/24	0.06%	0.000603	1
10/27	1.48%	0.014883	13	12/25	0.05%	0.000503	1
10/28	1.49%	0.014984	13	12/26	0.05%	0.000503	1
10/29	1.50%	0.015084	12	12/27	0.04%	0.000402	0
10/30	1.51%	0.015185	12	12/28	0.04%	0.000402	0
10/31	1.52%	0.015286	11	12/29	0.04%	0.000402	0
11/1	1.52%	0.015286	11	12/30	0.03%	0.000302	0
11/2	1.52%	0.015286	10	12/31	0.03%	0.000302	0
11/3	1.52%	0.015286	10	1/1	0.03%	0.000302	0
11/4	1.51%	0.015185	9	1/2	0.02%	0.000201	0
11/5	1.50%	0.015084	9	1/3	0.02%	0.000201	0
11/6	1.49%	0.014984	8	1/4	0.02%	0.000201	0
11/7	1.47%	0.014783	8	1/5	0.02%	0.000201	0
11/8	1.44%	0.014481	8	1/6	0.02%	0.000201	0
11/9	1.42%	0.014280	7	1/7	0.02%	0.000201	0
11/10	1.39%	0.013978	7	1/8	0.01%	0.000101	0
11/11	1.35%	0.013576	7	1/9	0.01%	0.000101	0
11/12	1.31%	0.013174	6	1/10	0.01%	0.000101	0
11/13	1.27%	0.012772	6	1/11	0.01%	0.000101	0
11/14	1.23%	0.012369	6	1/12	0.01%	0.000101	0
11/15	1.19%	0.011967	5	1/13	0.01%	0.000101	0
11/16	1.14%	0.011464	5	1/14	0.01%	0.000101	0
11/17	1.09%	0.010961	5	1/15	0.01%	0.000101	0
11/18	1.04%	0.010459	5	1/16	0.01%	0.000101	0
11/19	0.99%	0.009956	4	1/17	0.01%	0.000101	0
11/20	0.94%	0.009453	4	1/18	0.01%	0.000101	0
11/21	0.89%	0.008950	4				
11/22	0.84%	0.008447	4				
11/23	0.79%	0.007944	4				
11/24	0.74%	0.007442	3	Totals	99.44%	1	

2.4 Chinook Salmon Spawning Spatial Distribution

The spatial weighting coefficients input into the LAR Mortality Model account for the proportion of fall-run Chinook salmon spawning by geographic location (river mile) in the lower American River. The original LAR Mortality Model defined the spawning spatial distribution for fall-run Chinook salmon in the lower American River based on aerial redd survey data collected by the CDFW for the 1991/92, 1992/93, and 1993/94 biological years. Since then, the CDFW has published additional aerial redd survey reports for the 1994/95 and 1995/96 biological years, providing additional data upon which the Chinook salmon spawning spatial distribution for the LAR Mortality Model can be refined.

Refined spatial weighting coefficients were derived from data collected by aerial redd surveys conducted during the 1991/92 through the 1995/96 fall-run Chinook salmon spawning seasons (Snider and McEwan 1992; Snider et al. 1993, 1996; Snider and Vyverberg 1995, 1996). Tables published in the annual Chinook salmon redd survey reports provide the number of newly-built redds by river mile (RM) observed in each annual survey (**Table 5**). A map of the lower American River indicating river miles, as measured from the confluence of the lower American and Sacramento rivers, is presented in **Figure 10** for reference.

Table 5. Number of newly built redds by river mile (RM) observed during the Chinook salmon aerial redd surveys conducted in the lower American River from 1991 through 1995.

RM \ Year	1991	1992	1993	1994	1995	1991 – 1995 Total Redds	
5-6	0	0	0	6	2	8	0.05%
6-7	12	7	20	18	15	72	0.46%
7-8	0	0	21	14	28	63	0.40%
8-9	0	0	0	1	17	18	0.11%
9-10	32	6	71	12	12	133	0.85%
10-11	6	0	4	61	39	110	0.70%
11-12	0	1	30	0	1	32	0.20%
12-13	30	1	0	15	45	91	0.58%
13-14	20	0	20	59	87	186	1.18%
14-15	33	38	49	56	115	291	1.85%
15-16	11	0	177	58	66	312	1.99%
16-17	86	123	13	83	63	368	2.34%
17-18	189	9	787	424	601	2,010	12.79%
18-19	154	96	164	297	115	826	5.26%
19-20	314	220	663	391	595	2,183	13.90%
20-21	427	266	1,587	572	1,054	3,906	24.86%
21-22	191	2	1,322	280	561	2,356	15.00%
22-23	121	369	1,277	418	560	2,745	17.47%
RM 5 – RM 23 Total Redds	1,626	1,138	6,205	2,765	3,976	15,710	100%

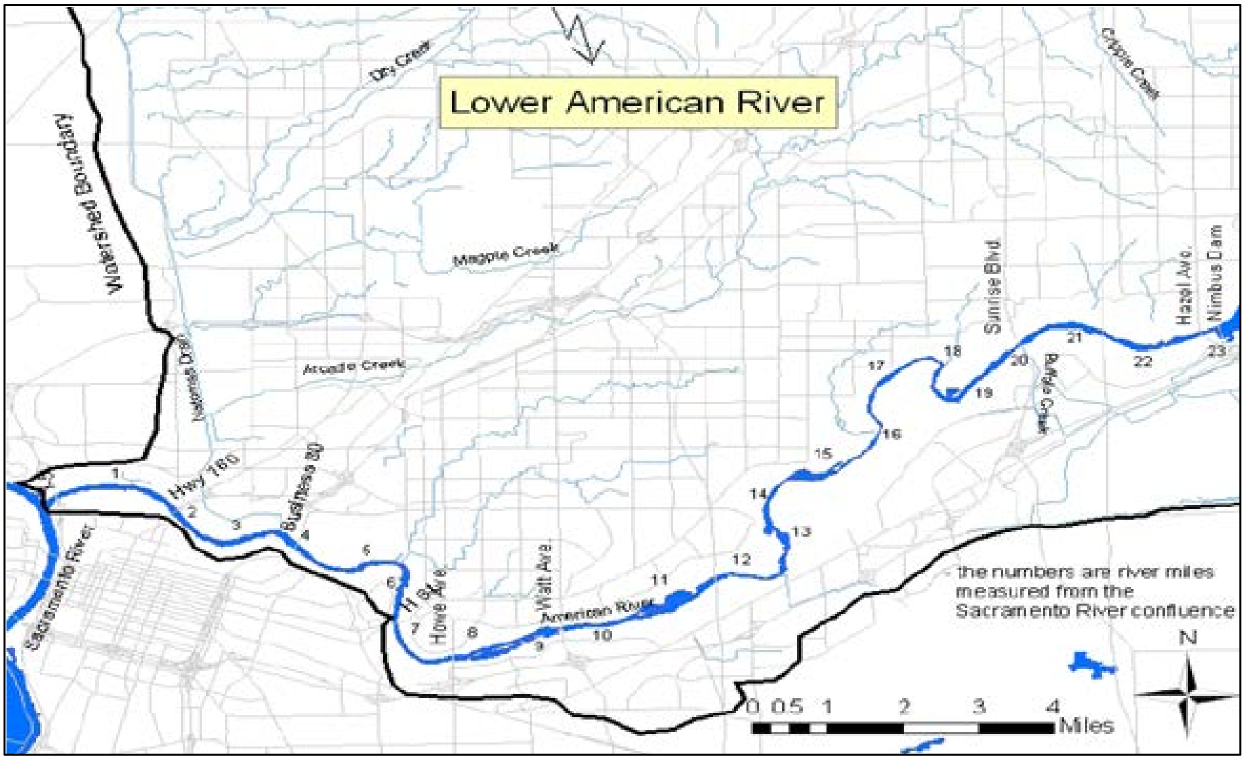

Figure 10. Map of the lower American River indicating river miles, as measured from the confluence of the lower American and Sacramento rivers (Source: Hannon and Deason 2008).

3.0 Thermally-Induced Chinook Salmon Early Lifestage Mortality Rates

3.1 Original Lower American River Mortality Model Rates

The original LAR Mortality Model utilized mortality rates for Chinook salmon fertilized eggs and pre-emergent fry for defined temperature-specific exposure durations that were originally developed by USFWS (1990). At a later date, consultation between the USBR, USFWS, and CDFW resulted in the development of different mortality rates for the pre-spawned egg lifestage (HCI 1996). These mortality rates are shown in

Table 6, **Table 7**, and **Table 8**. The LAR Mortality Model required mortality rates on a daily time-scale, so the cumulative mortality/duration data for the various lifestages were converted into daily mortality rates via Equation 7 (HCI 1996). The daily mortality rates were the rates used by the original LAR Mortality Model.

$$M_i = 1 - (1 - M_n)^{1/n} \tag{7}$$

Where: M_i = daily mortality rate (as a fraction)

M_n = mortality rate after exposure time, n (as a fraction)

n = exposure time in days

Table 6. Temperature and exposure duration-mortality relationships for pre-spawned Chinook salmon eggs (in the adult spawner). Daily mortality rates represent the pre-spawned egg criteria (PSC) used by the original LAR Mortality Model.

Water Temperature (°F)	Mortality Rate at Exposure Time (M_n) (%) [a]	Daily Mortality Rate (M_i) (%)
< 52	Natural Rate	--
52	Natural Rate	--
53	1% @ 30 days	0.034
54	5% @ 30 days	0.171
55	10% @ 30 days	0.351
56	15% @ 30 days	0.540
57	21% @ 30 days	0.783
58	29% @ 30 days	1.135
59	38% @ 30 days	1.581
60	47% @ 30 days	2.094
61	55% @ 30 days	2.627
> 62	64% @ 30 days	3.348

[a] Values listed here were calculated based on daily mortality rates, because in HCI (1996) the listed cumulative mortalities at the 30-day exposure time do not correspond to the listed M_i. The daily pre-spawned egg mortality rates shown here are listed in HCI (1996) and are programmed into the original LAR Mortality Model.

Table 7. Temperature and exposure duration-mortality relationships for fertilized-Chinook salmon eggs (in redds). Daily mortality rates represent the fertilized- egg criteria (EC) used by the original LAR Mortality Model.

Water Temperature (°F)	Mortality Rate at Exposure Time (M_n) (%)	Daily Mortality Rate (M_i) (%)
< 56	Natural Rate	--
57	8% @ 24 days	0.347
58	15% @ 22 days	0.736
59	25% @ 20 days	1.428
60	50% @ 12 days	5.613
61	80% @ 15 days	10.174
62	100% @ 12 days	31.871
63	100% @ 11 days	34.207
64	100% @ 7 days	48.205
> 64	100% @ 7 days	48.205
Source: HCI 1996.		

Table 8. Temperature and exposure duration-mortality relationships for pre-emergent Chinook salmon fry (in gravel). Daily mortality rates represent the pre-emergent fry criteria (FC) used by the original LAR Mortality Model.

Water Temperature (°F)	Mortality Rate at Exposure Time (M_n) (%)	Daily Mortality Rate (M_i) (%)
< 56	Natural Rate	--
57	Natural Rate	--
58	Natural Rate	--
59	10% @ 14 days	0.750
60	25% @ 14 days	2.034
61	50% @ 14 days	4.830
62	75% @ 14 days	9.428
63	100% @ 14 days	28.031
64	100% @ 10 days	36.904
> 64	100% @ 10 days	36.904
Source: HCI 1996.		

3.1.1 Pre-Spawned Egg Mortality Rates

USBR, USFWS, and CDFW collaborated to develop pre-spawned egg mortality rates for use in the LAR Mortality Model and, according to HCI (1996), the agencies assumed the temperature-mortality relationship for unfertilized eggs in the female Chinook salmon spawner to be the same as for fertilized eggs reaching the eyed stage. It is unclear what data the agencies relied upon to develop pre-spawned egg mortality rates, but among the studies referenced by USFWS (1990) for fertilized-egg and pre-emergent fry mortality, Hinze et al. (1956) and Hinze (1959) discussed mortality at the eyed stage for fertilized eggs. Hinze (1959) also was cited by NMFS (1997,

2000) and by USFWS (1995) as showing that the viability of *in vivo* eggs decreases when adult fish are held at temperatures greater than 60°F. These two studies are discussed further below. By convention, *in vivo* mortality is referred to herein as the egg loss due to the physiological effect of water temperature on the ability of the ovum to be fertilized and undergo normal embryo development.

Hinze et al. (1956) discussed operations at Nimbus Hatchery during July 1955 through June 1956. Excessive adult losses were reported at the hatchery in 1956. This report presented data showing the survival of fertilized eggs to the eyed stage compared to the ambient river temperatures at which eggs were harvested from adult spawners (Figure 11). The cumulative mortality (M_n) of fertilized eggs at the eyed stage (Hinze et al. 1956; Figure 11) is comparable with the original LAR Mortality Model pre-spawned egg mortality rates (Table 6). Hinze et al. (1956) discussed a number of factors that influenced egg losses at Nimbus Hatchery that season. Among these factors, high water temperatures occurred during the initial stages of egg incubation, and this alone could have caused much greater mortality than otherwise would have occurred if the same eggs had been spawned and incubated at optimal water temperatures. Furthermore, adult fish collected and held during the early period of spawning were subject not only to high temperatures, but also to low dissolved oxygen and high sulfide concentrations associated with an algal bloom in Lake Natoma the month prior to initial fish take. Therefore, the mortalities reported at Nimbus Hatchery that season cannot be definitively attributed to temperature-induced *in vivo* mortality alone.

Hinze (1959) is a report of the operations at the Nimbus Hatchery for July 1957 through June 1958. Similar to the observations made during the period 1955-56 (Hinze et al. 1956), adult mortality in the lower American River during the 1957 spawning season was high and egg survival was low (**Table 9**). As in Hinze et al. (1956), the water temperature at which eggs were collected from the adult spawners was compared to mortality of fertilized eggs at the eyed stage. Overall, fertilized-egg mortality was relatively high during 1957, even when eggs were collected and incubated at relatively optimal to slightly elevated water temperatures of 50°F to 59°F, possibly indicating that factors beside collection or incubation water temperature may have contributed to fertilized-egg mortality. Mortality data for the 55-59/50-59°F and 60-62/55-56°F egg-take/incubation temperature treatments was cited by Boles et al. (1988) as evidence that eggs exposed to 60 to 62°F water temperature *in vivo* results in lower egg survival at the eyed stage, compared to *in vivo* eggs exposed to 55 to 59°F. While *in vivo* water temperature exposure could have contributed to this mortality, the actual water temperature exposure scenario of adult spawners was not known, and eggs both harvested and incubated at lower water temperatures (50-59°F) also suffered elevated mortality.

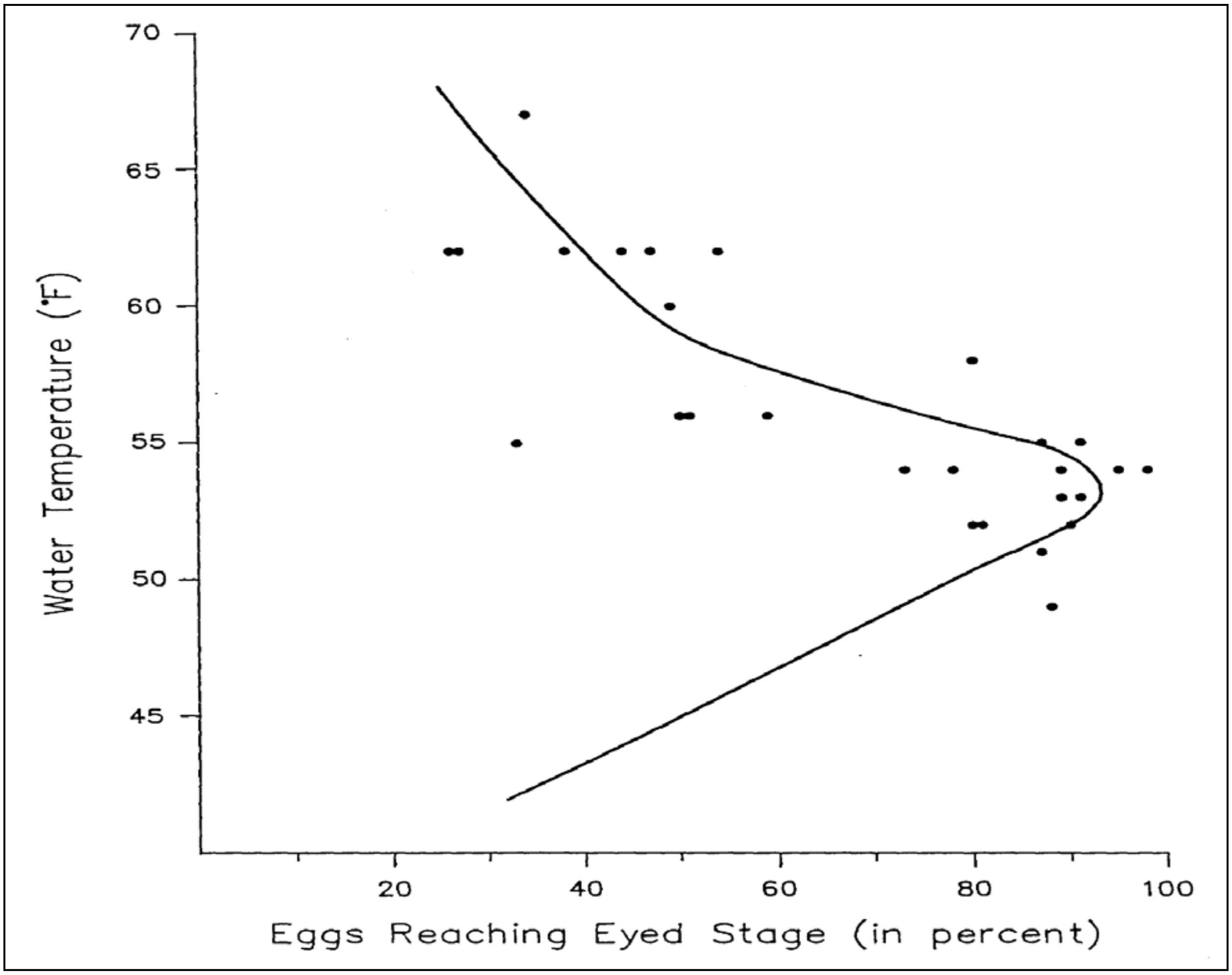

Figure 11. Relationship between water temperature at which adult fish were taken at Nimbus Hatchery during the 1955-1956 spawning season and survival of eggs to the eyed-stage (Data are originally from Hinze et al. (1956), and the figure was reproduced from Boles et al. (1988)).

Table 9. Egg-take water temperature, egg-incubation temperature, and associated mortality for Chinook salmon eggs taken from adult fish at Nimbus Hatchery during the 1957-1958 spawning season, as reported in Hinze (1959).

Egg-Take Temperature (°F)	Egg-Incubation Temperature (°F)	Mortality[a] (%)
>62	>62	100
60-62	60-62	50
55-59	50-59	20
60-62[b]	55-56	30

[a] Mortality at the eyed stage.
[b] Eggs were transferred to Moccasin Creek Hatchery, Moccasin, CA, following egg-take for cold-water incubation.

Hinze (1959) indicated that eggs collected from fish at Nimbus Hatchery when water temperatures were 60 to 62°F had been transferred to Moccasin Creek Hatchery for incubation at 55 to 56°F, but a description of egg handling and holding prior to transfer to Moccasin Creek Hatchery was not provided. If the fertilized eggs were held for any length of time at 60°F to 62°F prior to their transfer to Moccasin Creek Hatchery, this exposure could have caused water temperature-induced mortality. Also, the water temperature at which egg-take occurred during the 1957 spawning season at Nimbus Hatchery is not necessarily indicative of adult water temperature exposure. Even though the day on which egg take occurred may have had low water temperature (e.g., 50 to 59°F), pre-spawning adults could have held in the lower American River for some length of time, where water temperatures were as high as 67°F during the 1957 pre-spawn period. By contrast, some adults may have held for a minimal length of time in the lower American River prior to capture and egg take.

The early reports from Nimbus Hatchery highlight that the primary factors that influence the survival of Chinook salmon eggs are unrelated to temperature exposure of eggs *in vivo*. Mortality of adult spawners can be high due to disease and prolonged holding at elevated water temperatures, and the associated loss of *in vivo* eggs due to adult mortality can be high. Further, the survival of fertilized eggs to the eyed stage is principally affected by temperature exposure of the eggs post-fertilization. The Nimbus Hatchery reports offer little definitive evidence that survival of fertilized eggs may be affected by the *in vivo* exposure of unfertilized gametes to elevated water temperatures.

3.1.2 Fertilized-Egg Mortality Rates

Although information was limited at the time the fertilized-egg mortality rates were reported, USFWS (1990) developed the mortality rates based upon data from a number of studies including Combs and Burrows (1957), Seymour (1956) and Healey (1979). A personal communication from H. Rectenwald (formerly with CDFW) was also cited, although documentation of this communication could not be found. USFWS (1990) also cited Boles et al. (1988), in which the above referenced studies, as well as Hinze et al. (1956) and Hinze (1959), were reviewed. Another agency document contemporary with USFWS (1990), USFWS (1987), also discussed many of these same studies in the context of early lifestage Chinook salmon mortality in the Sacramento River, providing additional insight into the agency's selection of fertilized-egg mortality rates for the original LAR Mortality Model.

Review of the fertilized-egg mortality rates from the original Mortality Model shows that mortality above the natural rate begins at water temperatures of 57°F, and within 6°F, mortality reaches 100% at 62°F. USFWS (1990) stated that "*56°F is considered to be the upper limit for optimum spawning, egg incubation and sac-fry development in the Sacramento River. Information on specific impacts of temperatures exceeding 56°F on eggs and pre-emergent fry for Sacramento River salmon is limited.*" According to USFWS (1990), thermally induced egg mortality was assumed to initially occur at temperatures greater than 56°F, even though

"*Seymour (1956) observed low egg mortality at a constant temperature of 55°F and 57°F*" (USFWS 1990) and Combs and Burrows (1957) reported an optimal egg incubation temperature range of 42.5°F to 57.5°F. USFWS (1987 and 1990) did not discuss the mortality rates at 57°F, 58°F, and 59°F. However, according to USFWS (1987), 80% mortality occurs when water temperatures during egg incubation are 60°F to 61°F (citing Healey 1979) and 100% mortality occurs at temperatures greater than 62°F (citing Hinze 1959). With regard to exposure duration, USFWS (1990) also claimed that "*at a 12-day exposure to 60°F, egg mortality is 50%, and increases as exposure is prolonged,*" and although not referenced, the Nimbus Hatchery 1957/58 fiscal year report appears to have been the source of this information (Hinze 1959).

As discussed further below, data presented in the literature cited by USFWS (1987 and 1990) suggests that the fertilized-egg mortality rates used in the original LAR Mortality Model are higher than that supported by the literature.

- USFWS (1990) stated the fertilized-egg mortality rate at 60°F was 50% for a 12-day exposure. By contrast, for eggs incubated from fertilization to hatch (approximately 33 days), Seymour (1956) and Combs and Burrows (1957) reported 12-35% mortality at 60°F. Healey (1979) also reported approximately 38% cumulative mortality at hatch for eggs incubated at 60°F to 61°F. Hinze (1959) reported 50% mortality at the eyed stage (not hatch) for eggs incubated at 60°F to 62°F, but as discussed above, this report suggests that other factors affected fertilized-egg viability because eggs incubated at optimal temperatures experienced relatively high mortality (Table 9).
- USFWS (1990) stated the fertilized-egg mortality rate at 61°F was 80% for a 12-day exposure. This may have been a misinterpretation of Healey (1979), who reported 80% cumulative egg mortality through complete fry development for incubations at 60°F to 61°F. Egg-associated mortality was only 38% (Healey 1979).
- USFWs (1990) stated that the fertilized-egg mortality rate at 62°F was 100% for a 12-day exposure. Hinze (1959) reported 100% egg mortality at water temperatures *greater than* 62°F. Indeed, these eggs may have been exposed to water temperatures as high as 67°F because water temperatures in the American River at Nimbus Hatchery, where Hinze (1959) conducted the study, ranged from 63°F to 67°F during October 1957, and ranged from 56°F to 65°F during November 1957. Seymour (1956) reported 78% to 85% mortality of fertilized eggs incubated to hatch (approximately 31 days) at temperatures of 62°F.

In discussing the exposure duration values assigned to the original Mortality Model's fertilized-egg mortality rates with J.G. Smith (Project Leader, USFWS, Red Bluff, CA), who was on staff with the USFWS's Fisheries Assistance Office when the original early lifestage mortality data tables were developed, he stated the following:

> *[Previous] studies did not really develop an exposure time, but … there was a need to develop a table that did have exposure times in order to estimate mortality*

> *with varying water temperatures during incubation. I do recall that this was a weakness of the model that our studies were to address. We ran a variety of controlled temperature experiments on incubating winter-run and fall-run Chinook salmon eggs that would mimic various temperature management options (e.g. 55 degrees for XX days then 58 for XX days) that could verify, or not, the values used in Table 1 [of USFWS 1990]*. (pers. comm., January 10, 2013)

The controlled temperature experiments referred to by J.G. Smith were those published in USFWS (1998) which, along with other relevant studies, have been used to revise the early lifestage mortality rates presented in this report.

3.1.3 Pre-Emergent Fry Mortality Rates

At the time the original mortality rates were developed, there was virtually no data available on thermally-induced pre-emergent fry mortality (USFWS 1990). In general, USFWS (1990) cited Combs and Burrows (1957), Seymour (1956), Boles et al. (1988), Healey (1979), and a personal communication from H. Rectenwald (formerly with CDFW) as the basis for fertilized-egg and pre-emergent fry mortality rate development. Of these, however, none contain a rigorous study of pre-emergent fry mortality from which mortality rates could be developed. The work by Seymour (1956) provides some insight into water temperature-induced mortality of pre-emergent fry.

Seymour (1956) is a doctoral dissertation that reported on the effects of elevated water temperature exposure of fertilized-eggs on egg mortality and the physiological development of surviving fry. The results from Seymour (1956) were summarized by Boles et al. (1988): "*Incubation temperatures greater than 60°F produced high mortalities in fry able to develop past the egg stage …Though producing low egg mortality in fish from the Sacramento River, constant water temperatures in the range of 55°F to 57.5°F produced sac-fry mortalities in excess of 50 percent*." While Seymour (1956) had reported high mortality of sac-fry which had been hatched and incubated as pre-emergent fry at water temperatures from 55°F to 62°F, the 50% mortality at 55°F and 57.5°F reported by this study was not incorporated into the original pre-emergent fry mortality rates. USFWS (1990) determined that thermally-induced pre-emergent fry mortality did not initially occur until 59°F (Table 8).

Short-comings in the early lifestage mortality rates were generally recognized, as indicated by HCI (1996) and J.G. Smith (USFWS, pers. comm., January 10, 2013), including pre-emergent fry mortality data. Publication of relevant studies since the original mortality rates were developed now allows for the reliable development of pre-emergent fry mortality rates.

3.2 Refinements to Lower American River Mortality Model Rates

3.2.1 Refinements to Pre-Spawned Egg Mortality Rates

Pre-Spawned Egg Mortality Studies

A review of the available literature has shown that to date, few experiments have been published which specifically address *in vivo* egg mortality. Because pre-spawned egg losses are also incurred due to pre-spawn adult mortality, the water temperature-exposure-mortality relationship for adult Chinook salmon also is reviewed. A number of qualitative conclusions can be drawn from the available studies and reports.

Berman (1990) published results of an experiment that measured Chinook salmon *in vivo* egg mortality due to elevated water temperature. Adult spring-run Chinook salmon from the Yakima River, Washington, were initially subject to prolonged holding in hatchery ponds at 66.2°F. At this water temperature, no eggs were obtained due to heavy adult losses after 38 days of exposure (88% adult mortality). Because *F. columnaris* caused excessive disease-related adult mortality at 66.2°F, one-half of the fish from the control-temperature ponds (57°F) were transferred to and held in the elevated-temperature ponds (66.2°F). Adult fish held in the control-temperature ponds (52 days at 57°F) and those held at elevated water temperatures (14 days at 66.2°F) were spawned, and fertilized eggs were incubated until hatch at 49.1°F. Average mortality of eggs from the elevated water temperature treatments was 0.85%, while mortality of eggs from the control treatment was 0.10%. Egg and alevin size were also slightly lower for the elevated water temperature treatment, but fertilization rate and number of eggs produced were similar between treatment and control. Berman (1990) could not properly analyze the experimental results with statistics due to the low number of fish surviving the initial exposure at 66.2°F.

In a similar unpublished experiment, North State Resources (NSR) held spring-run Chinook salmon at constant water temperatures ranging from 55.4°F to 69.8°F (K. Marine, Principal Scientist at NSR, pers. comm., April 23, 2013). Adult fish held at 69.8°F suffered complete mortality, and few adults survived for 30 days at 61°F to 66°F. Adult mortalities were a result of bacterial infection, and most occurred within the first 12 days of exposure. The few fish that survived 30 days at temperatures of 61°F to 66°F, and those surviving at lower temperatures were spawned, and eggs were incubated at optimal temperatures. Egg survival to hatch was high among all temperature treatments, and no differences in mortality could be discerned between the eggs from females exposed to the elevated and low temperature treatments.

Jenson et al. (2006) held adult summer-run Chinook salmon from the Puntledge River, British Columbia in Puntledge Hatchery tanks with elevated daily water temperatures ranging from 66°F to 72°F. The complete mortality of adult fish held for up to six weeks at these temperatures was attributed to a number of factors, including elevated total gas pressure, abrupt switching of water sources, poor water quality related to elevated algal levels, and elevated water temperatures. Because fish in the experimental treatment ponds did not survive, Jenson et al. (2006) compared survival of fertilized eggs (determined at hatch) from fish held in the hatchery raceways and from fish held at an off-site coldwater hatchery. Daily average water temperatures during the adult holding period in the Puntledge hatchery raceways were greater than 68°F for 30 days. Because fish were not tagged upon their arrival, a definitive accounting of each adult's exposure duration was not available. Nonetheless, adults holding in the raceways were exposed to elevated water temperatures for days to weeks. Adult mortality of fish held in the hatchery raceways was estimated to be greater than 47%, and mortality of fertilized eggs (at hatch) from adult fish surviving the raceways was 11.8% to 13.4%. Mortality of adults held at the cold-water site was 8%, and mortality of fertilized eggs from the coldwater site was 3.1%. Based on these results, the difference in percent mortality of fertilized eggs collected from adults at the cold-water site versus the warm-water hatchery raceways was 8.7–10.3%, while the difference is percent mortality of adults was >39%.

Mann and Peery (2005) fitted adult pre-spawn fall-run Chinook salmon from the Snake River with external temperature loggers, and released them into the river to complete their migration. Of the returning fish that migrated to and were spawned at the time of their natural arrival at one of three hatcheries on the river, twelve had retained their temperature loggers. Eggs from these fish were subject to normal hatchery operations. Mortality for each lot of eggs was assessed at hatch and at complete yolk-sac absorption. Adult temperature exposures were calculated as "degree days greater than 20°C." Adults exposed to daily average water temperatures ≤ 20°C (68°F) were given a value of 0 degree days above 20°C. For fish exposed to daily average temperatures > 20°C, 20 was subtracted from each daily average temperature greater than 20°C, and the sum of all such calculations for a particular fish was the number of degree days above 20°C. For example, an adult exposed to three days of daily average water temperatures of 22°C would have incurred 6 degree days above 20°C.

Mann and Peery (2005) observed high variability in the mortality of fertilized eggs (at hatch) from the returning adults. The fish which yielded the highest fertilized-egg mortality (19%) was exposed to 0 days greater than 20°C. The other five adults yielding the next highest fertilized-egg mortalities (4% to 9%) had been exposed to the greatest number of degree days above 20°C (2 to 7 days). Six fish exposed to < 2 degree days above 20°C yielded fertilized-egg mortalities of 1% to 3%.

In 2003 (July through September), Leaburg Hatchery (Leaburg, OR) observed increased spring-run Chinook salmon adult and egg mortalities related to elevated water temperatures during adult holding and fertilized-egg incubation periods. Construction upstream of the hatchery in 2003 resulted in monthly average water temperatures of approximately 64°F in July and August, approximately 6°F greater than observed during other years (**Figure 12**). Annual adult and fertilized-egg mortalities and monthly temperature statistics were obtained from the hatchery for the years 2003, 2005, 2007, 2008, 2009, and 2011 (K. Kremers, Leaburg Hatchery Manager,

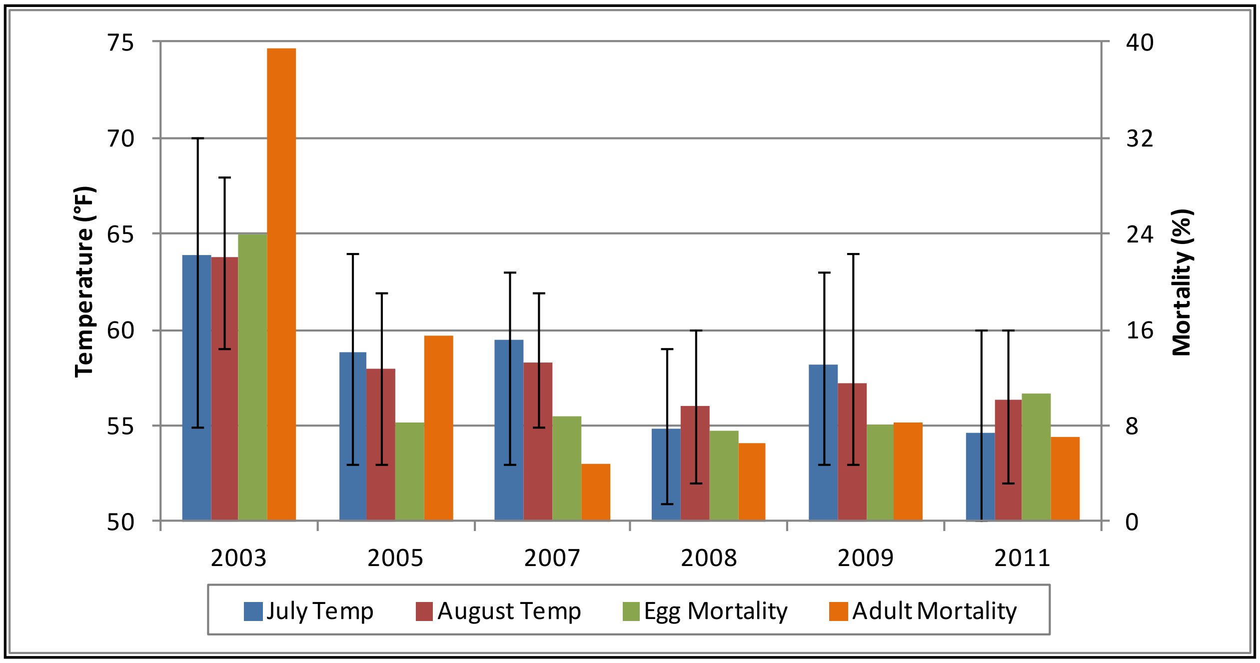

Figure 12. Monthly average water temperatures in hatchery ponds during July and August, and annual spring-run Chinook salmon adult and fertilized-egg mortality at Leaburg Hatchery (Leaburg, OR). Error bars correspond to the daily minimum and maximum temperatures observed during that month.

pers. comm., April 24, 2013). Adult and fertilized-egg mortality in 2003 was 39% and 24%, respectively (Figure 12). Annual average adult and fertilized-egg mortality was 8% and 9%, respectively, for the years 2005, 2007, 2008, 2009, and 2011. Thus, an additional 31% adult mortality and 15% fertilized-egg mortality was observed in 2003. The hatchery attributed the additional 15% fertilized-egg mortality observed in 2003 to prolonged exposure of pre-spawn adults to elevated water temperate because daily average water temperatures during egg incubation were typically well below 60°F.

Temperature-induced adult mortality presents a problem for generating the experimental data needed to address the effects of temperature on *in vivo* egg viability and subsequent survival upon fertilization. Of the studies discussed above, the most pertinent experiments are Berman (1990) and the unpublished work from NSR (K. Marine, pers. comm., April 23, 2013) because these studies held adults for a known duration at constant temperature. Although these studies reported a high proportion of adult mortality due to disease and infection, data from surviving adults indicated that egg survival is undiminished by exposure of pre-spawn adults to water temperatures up to 66°F. Mann and Peery (2005) also showed that there was no relationship between temperature exposure of adult fish and subsequent egg survival. In contrast, observations from Leaburg Hatchery and Puntledge Hatchery suggest that egg mortality could be slightly elevated (by 8–15%) due to prolonged *in vivo* exposures greater than 66–68°F, yet affects on *in vivo* egg viability could also have been related to stress on adult fish from other physical and chemical water characteristics (see discussion of Jensen et al. 2005 above).

Cumulatively, data from these studies are insufficient to determine whether fertilized-egg loss rates are increased (for a given egg incubation temperature) if the adult female (and her *in vivo* eggs) is exposed to temperatures in the mid to upper 60°F range (or even higher) and survives to spawn. However, these studies indicate that pre-spawn adult losses, due to prolonged holding at elevated temperatures or other factors such as disease, result in a much greater proportion of *in vivo* egg loss relative to any decrease in the viability of *in vivo* eggs in surviving adults that spawn, if there is such an effect at all.

Pre-Spawn Adult Mortality Studies

Although the studies and reports reviewed above do not provide sufficient information to determine the temperature-exposure-mortality relationship for *in vivo eggs*, data are available to determine the temperature exposure-survival relationship for adult Chinook salmon (Coutant 1970; Strange 2010; Garman 2014).

Over a 3-year period (1967 to 1969), Coutant (1970) performed experiments that held fall-run Chinook salmon jacks from the Columbia River (Richland, WA) in experimental tanks at constant temperatures ranging from 68°F to 86°F and determined their survival time. Experiments during 1968 utilized 5 to 10 fish per treatment, with fish densities of 6.6 to 13.2 fish/m^3, and incubation temperatures of 78.8°F to 86.0°F. Experiments during 1969 utilized 10 to 15 fish per treatment, with fish densities of 6.6 to 13.2 fish/m^3, and holding temperatures of 71.6°F to 78.8°F. Coutant (1970) reported geometric mean survival time for his experiments. Were the survival times reported as *arithmetic* means, that survival time would correspond to the time when 50% of fish had succumbed to death. Mathematically, however, the *geometric* mean is always less than the *arithmetic* mean. Thus, at the *geometric* mean survival time for a particular incubation temperature more than 50% of the adult fish could have been alive.

The geometric mean survival times for the 1968 and 1969 tests are shown in **Figure 13**. In 1968 the geometric mean survival time for jacks held at 78.8°F was approximately 200 min, compared to approximately 900 min in the 1969 test. Based on the detailed information collected ahead of the tests, Coutant (1970) ruled out differences in acclimation temperatures and fish sizes as explanations of the difference in interannual jack survival times. Coutant (1970) indicated that one possible contributing factor was the use of larger fish tanks in the 1969 test, which would have resulted in lower fish density and lower stress during the high temperature exposures.

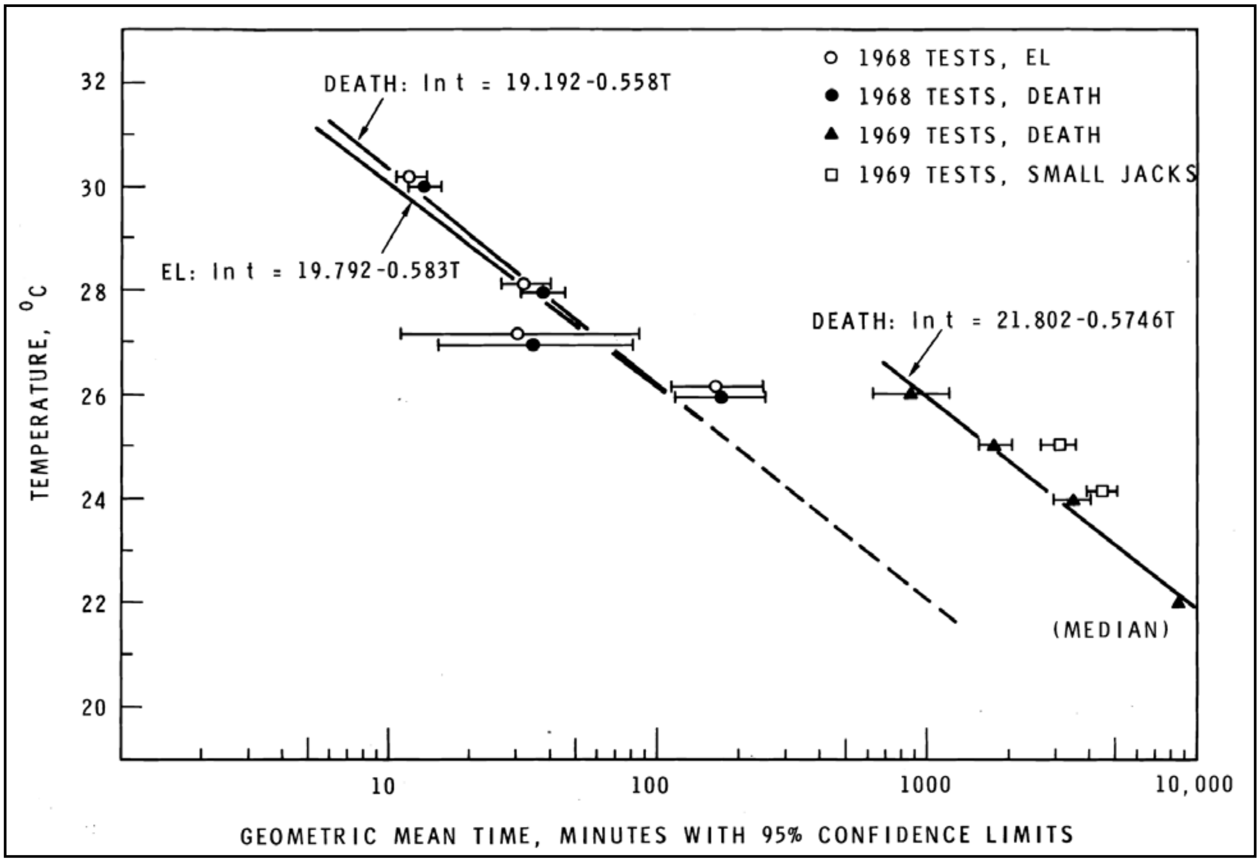

Figure 13. Geometric mean times (t) to equilibrium loss (EL) and death of jack Chinook salmon, 1968 and 1969, with 95% confidence limits. Figure reproduced from Coutant (1970).

Mann and Peery (2005) identified 20°C (68°F) as the upper incipient lethal temperature (UILT) for salmon, although they used a definition of UILT as the water temperature at which theoretically half of the population would survive with permanent exposure. By contrast, the incipient lethal temperature (defined as 50% mortality after 7 days of exposure) of adult Chinook salmon is considered to be approximately 72°F (McCullough 1999), which is in good agreement with the incipient lethal temperature of 71°F to 72°F reported by Coutant (1970) for the tests conducted in 1969.

Strange (2010) reported results of a study in which 16 spring-run and two fall-run Chinook migrating up the Klamath River were tagged with locaters and temperature loggers during the spawning seasons of 2004 and 2005. Of the 18 fish, 16 fish were recovered – four were caught by anglers, ten reached hatcheries or spawned, and two were never recovered. Temperature loggers were recovered from ten fish. Although three fish were caught by anglers early in the migration, data for the other seven fish indicated that mean weekly average body temperature (MWAT) of the fish ranged 70.3–72.7°F during the first week of the migration (weekly average MWAT of 71.4°F) and 62.6–69.4°F during the second week of migration (weekly average MWAT of 66.9°F). Combining data for the first two weeks of the migration, the average MWAT among all fish was 69.2°F. These seven fish survived well past the first two weeks of their migration, eventually reaching spawning areas, showing up in hatcheries, or being caught. Thus, data from Strange (2010) indicate high survival (i.e., 100%) of adult fish migrating during a period in which they were exposed to an average temperature of 69.2°F for 14 days.

Butte Creek, CA, spring-run Chinook pre-spawn holding mortality has been monitored since approximately 2001. Monitoring occurs from early June through spawning in mid-September. Ward et al. (2004c) and Garman (2015) identified an extended period of average daily temperatures above approximately 66-67°F (19–19.4°C), measured at Quartz Bowl (top of the holding reach), as corresponding to the onset of significant pre-spawn mortalities in 2002 and 2003 (21% and 64%, respectively) (note that disease and crowding were also factors) and increased mortality for several weeks in 2014. Temperatures exceeded 67°F a total of 16 days in 2002 and 11 days in 2003. During most other years (2001, 2004–2013), when there was minimal pre-spawn mortality (≤5.4%), daily average water temperature at Quartz Bowl exceeded 67°F only a few days (Ward et al. 2004a; Ward et al. 2006; Ward et al. 2007; McReynolds and Garman 2008; McReynolds and Garman 2010). During 2014, however, water temperature exceeded 67°F a total of 16 days and overall mortality was relatively low (4.4%), but the highest daily mortality rates occurred during and immediately following an 11 day period when temperature each day exceeded 67°F (40 mortalities of 5,083 holding fish, daily mortality rate of 0.072%; Garman 2015). These data from Butte Creek indicate that an index temperature of approximately 66–67°F as measured at Quartz Bowl corresponds to relatively low mortality rate and that temperatures above this correspond to higher mortality.

Because Butte Creek spring-run Chinook salmon hold downstream of Quartz Bowl, the corresponding average daily temperature for the river reach where the largest percentage of fish hold (typically above the Centerville Powerhouse) is actually higher than the Quartz Bowl index temperature (66–67°F). The average temperature of the reach (Quartz Bowl to Pool 4) is 1.4°F higher than the temperature at Quartz Bowl (based on July 2002 and 2003 average Quartz Bowl and Pool 4 temperatures). The reach index temperature, therefore, that corresponds to a relatively low mortality rate is approximately 67.5–68.2°F. An index temperature of 67.5°F and cumulative mortality of 1% after 7 days (0.143% daily mortality) was used as a stringent approach to address this variability.

Revised Pre-Spawned Egg Mortality Rates

As previously discussed in this report (see Section 3.1.1), *in vivo* egg mortality is defined as "*the egg loss due to the physiological effect of water temperature on the ability of the ovum to be fertilized and undergo normal embryo development*." Relevant information related to decreased ovum viability was compiled and reviewed for this report, and the most pertinent experimental information on ovum viability due to adult exposure to high temperature is from Berman (1990) and unpublished work by NSR (K. Marine, pers. comm., April 23, 2013). These sources indicated that decreased ovum viability is minimal compared to adult loss. Although relevant hatchery information also was reviewed, the hatchery studies could not separate pre-spawned egg losses from fertilized-egg losses, because elevated temperatures occurred during both stages, or the studies did not present sufficient data to fully determine if decreased ovum viability was due to factors besides temperature. The same hatchery studies indicated that adult mortality was far greater than decreased ovum viability or fertilized egg mortality that could be attributed to *in vivo* exposure. Therefore, this report relied upon the results from Berman (1990) and NSR as a basis for developing the pre-spawned egg mortality rates on the assumption that adult losses will outweigh any decrease in *in vivo* egg viability.

Temperature-induced pre-spawned adult mortality rates were developed using data from Coutant (1970) to characterize the temperature range that causes elevated mortality of adult Chinook salmon, and using data from Berman (1990), Strange (2010), and Garman (2015) to characterize the range of temperatures and exposure known to be survived by pre-spawn adult salmon (**Table 10**). In using data from Coutant (1970), it was assumed that the temperature-survival time relationship for pre-spawned Chinook salmon in the lower American River is equivalent to the temperature-survival time relationship for jack Chinook salmon derived by Coutant (1970) for the experiments conducted in 1969. The 1969 experimental results were used instead of the 1967 and 1968 results because: (1) Coutant (1970) conjectured that the shorter survival times of the 1967 and 1968 experiments were due to higher fish densities in his experimental tanks relative to 1969; and (2) the lower American River, with adequate flow and space to obviate the influence of confinement, would be better represented by the 1969 results. Berman (1990) reported that healthy adult Chinook salmon survived when held for 14 days at 66.2°F. Data from Garman (2015) indicated high survival of adult Chinook salmon holding 7 days at 67.5°F (daily mortality rate of 0.143%). Strange (2010) reported complete survival of migrating adult Chinook salmon exposed to a weekly average temperature of 69.2°F for 14 days. Because survival to exposures of 66.2–69.2°F was high, a 1% cumulative mortality was assumed for these temperatures (Table 10**)**. A natural background daily mortality rate of 0.003% was also assumed based upon data from Butte Creek (McReynolds and Garman 2012) that shows that mortality is essentially non-existent for healthy adult fish when water temperatures are optimal.

Table 10. Literature-derived Chinook salmon adult mortality data.

Water Temperature (°F)	Cumulative Mortality M_n (%)	Exposure Duration *n* (days)	Daily Mortality Rate M_i (%)	Reference
66.2	1	14	0.072	Berman 1990
67.5	1	7	0.143	Garman 2015
69.2	1	14	0.072	Strange 2010
71.6	50	5.83	11.218	Coutant 1970
75.2	50	2.36	25.447	Coutant 1970
77.0	50	1.21	43.507	Coutant 1970
78.8	50	0.58	69.799	Coutant 1970

Regression analysis was used to fit a three-parameter exponential function to the daily mortality and temperature exposure data for adult Chinook salmon (Table 10). A three-parameter exponential function was chosen because it facilitates the characterization of the low daily mortality rates that occur below 69°F in comparison to a two parameter exponential function, as was used in the refinement of the fertilized-egg and pre-emergent fry mortality rates. The three-parameter exponential function is shown in Equation 8 and relates average daily temperature in degrees Fahrenheit (T_F) to the daily mortality of adult Chinook salmon as a fraction. Equation 8 is applicable at water temperatures greater than 67.1°F and less than or equal to 80.3°F. At water temperatures less than 67.1°F, Equation 8 produces daily mortality rates less than the natural background mortality rate (0.003%); thus, the daily mortality rate was set at 0.003% for temperatures lower than 67.1°F. At water temperatures greater than 80.3°F, Equation 8 produces daily mortality rates in excess of 100%; thus, the daily mortality rate was set at 100% for temperatures greater than 80.3°F.

$$M_i = -0.042763 + (3.2319 \times 10^{-9}) \times e^{(0.24428 \times T_F)} \qquad \textbf{(8)}$$

As previously discussed, Equation 8 also represents the daily pre-spawned egg mortality rate at various temperatures. Daily mortality rates for pre-spawned eggs calculated using Equation 8 are compared (as a percentage) to the original rates in **Figure 14** and **Table 11**. Equation 8 replaces the original LAR Mortality Model's pre-spawned egg criteria (PSC), and is intended to be used to directly calculate the daily pre-spawned egg mortality (PSM) using the average daily water temperature for a given reach.

There were two compelling reasons for extending the range of average daily water temperatures and corresponding daily mortality rates. First, as previously discussed, for the pre-spawned egg lifestage, the 1995 LAR Mortality Model held the daily mortality rate constant for all water temperatures exceeding 62ºF. However, examination of available water temperature monitoring data at the Fair Oaks Gage (USGS 11446500) from October 30, 1998 through August 26, 2015 indicate that water temperatures frequently exceed 62ºF during the pre-spawned egg lifestage period. The pre-spawned egg lifestage extends from June 1 through mid-January.

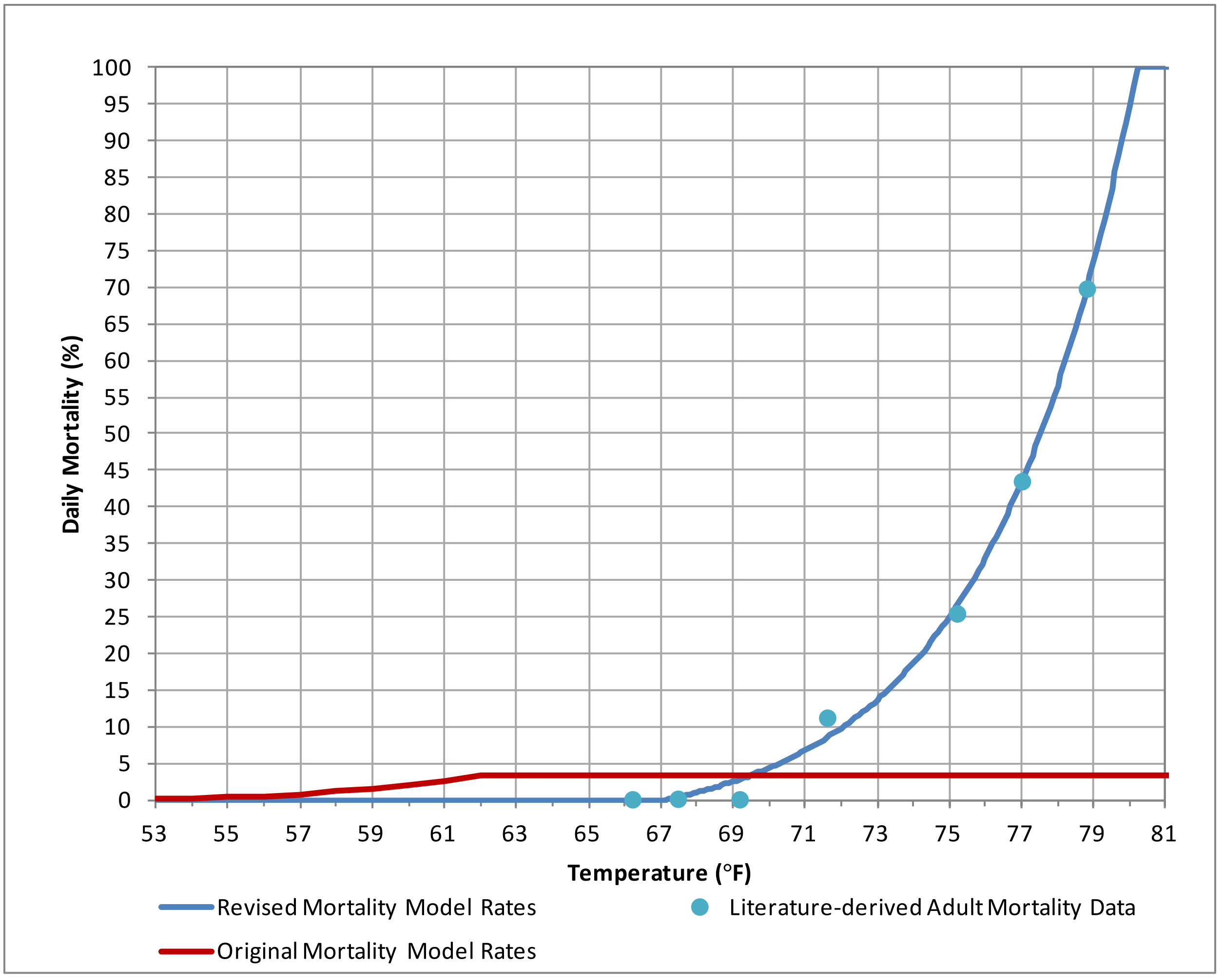

Figure 14. Original 1995 LAR Mortality Model and revised Chinook salmon pre-spawned egg daily mortality rates versus exposure temperature. Revised rates were developed assuming that pre-spawned egg loss is derived solely from temperature-induced mortality of pre-spawned adults.

For the 16 years encompassing this time period, 62°F was exceeded each of those years during the pre-spawned egg lifestage, and typically for much of the duration of the lifestage during most years (**Figure 15**). Considering each of the days corresponding with the pre-spawned egg lifestage for the 16 years during which water temperature monitoring data were available, water temperatures exceeded 62°F 39.9% of the days.

Second, the range of average daily water temperatures and corresponding daily mortality rates was extended in Figure 14 and Table 10 for presentation purposes. The average daily water temperature-daily mortality rate for the pre-spawned egg lifestage is a continuous function, and can be presented for any desired range. In Figure 14 and Table 10 the function was presented such that a daily mortality rate was provided for every corresponding water temperature value until a daily mortality rate approaching 100% was obtained, to illustrate the entire range of the function.

Table 11. Original 1995 LAR Mortality Model and revised Chinook salmon pre-spawned egg daily mortality rates.

Temperature (°F)	Daily Mortality Rate M_i (%)	
	Original Model	**Revised Model**
52	Natural Rate	0.003
53	0.034	0.003
54	0.171	0.003
55	0.351	0.003
56	0.540	0.003
57	0.783	0.003
58	1.135	0.003
59	1.581	0.003
60	2.094	0.003
61	2.627	0.003
62	3.348	0.003
63	3.348	0.003
64	3.348	0.003
65	3.348	0.003
66	3.348	0.003
67	3.348	0.003
68	3.348	1.013
69	3.348	2.477
70	3.348	4.346
71	3.348	6.731
72	3.348	9.777
73	3.348	13.666
74	3.348	18.630
75	3.348	24.968
76	3.348	33.060
77	3.348	43.391
78	3.348	56.580
79	3.348	73.419
80	3.348	94.917
81	3.348	100.000

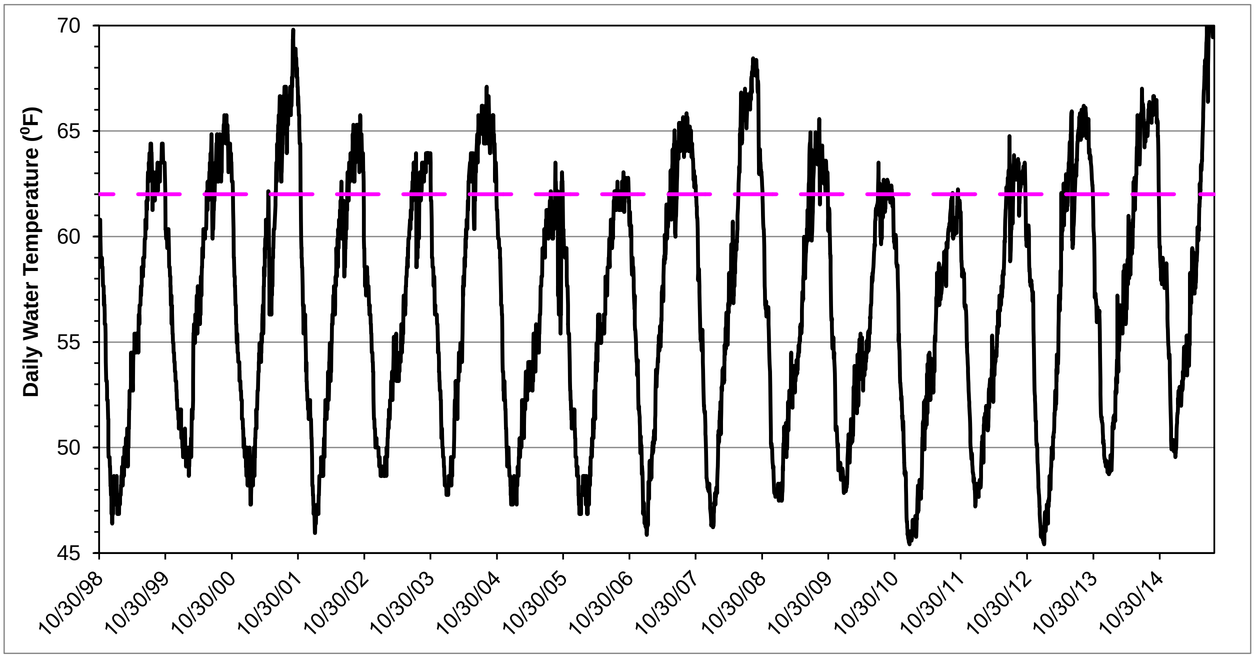

Figure 15. Daily water temperature at the USGS Fair Oaks Gage from October 30, 1998 through August 26, 2015 with the pre-spawned egg period indicated as horizontal lines at 62^{0}F.

3.2.2 Refinements to Fertilized-Egg and Pre-Emergent Fry Mortality Rates

Fertilized Egg and Pre-Emergent Fry Mortality Studies

The fertilized-egg and pre-emergent fry experiments reviewed were those that used constant exposure temperatures, controlled experimental conditions (e.g., replicates, light, water source, dissolved oxygen, etc.), similar experimental methods among studies, and those which had explicitly reported exposure duration.

Seymour (1956) generated data from incubations of Chinook salmon fertilized eggs at constant temperatures between 34°F and 67.5°F, by assessing mortality in weekly intervals through hatch and through yolk-sac absorption. Two experiments were run in consecutive years, each utilizing a single set of parents from the Green River, Washington. Embryos were divided into eight lots and incubated at specified temperatures. The first experiment averaged 547 eggs per lot, while the second averaged 518 eggs per lot. Seymour (1956) reported the duration to 50% hatch, but did not report any exposure durations associated with lots that did not survive to hatch, nor were any exposure durations reported for pre-emergent fry. A fraction of fertilized-eggs survived through 50% hatch at temperatures up to 64.6°F, while complete mortality occurred sometime prior to hatch at temperatures of 64.8°F and 67.5°F. Fertilized-eggs incubated and surviving to hatch at temperatures of 60°F to 62.5°F did not survive further exposures at the same elevated temperatures as pre-emergent fry. Fertilized eggs incubated and surviving to hatch at temperatures of 55°F to 57.5°F produced sac-fry mortalities in excess of 50% upon further exposure to the same temperatures.

Murray and McPhail (1988) conducted constant-temperature incubations of Chinook salmon fertilized-eggs and pre-emergent fry at five different temperatures ranging from 35.6°F to 57.2°F. Adult Chinook salmon were taken from Babine River, British Columbia. Pre-emergent fry were those that survived the constant temperature incubations as eggs, and duration to and mortality at 50% hatch and 50% emergence were reported. Each incubation lot consisted of approximately 240 eggs. At 57.2°F, the mortality of fertilized eggs was 52% and the mortality of pre-emergent fry was 3%.

Beacham and Murray (1989) took Chinook salmon adults from three different salmon stocks in British Columbia and subjected eggs and pre-emergent fry to four constant-temperature treatments ranging from 39°F to 59°F. Incubations of each stock were similar in egg count, which ranged from 750 to 1900 eggs per temperature incubation. Duration to and mortality at 50% hatch and 50% emergence were reported. At 59°F, mortality among the three stocks for fertilized eggs was 4.3% to 8.7% and for pre-emergent fry was 4.8% to 39.4%.

Jensen and Groot (1991) obtained eggs and milt from five female and five male Chinook salmon from Nanaimo, British Columbia. Upon activation of pooled gametes, fertilized eggs were incubated in small groups (approximately 30 per group), with two groups per temperature treatment. Fertilized eggs were incubated at six water temperatures between 50.4°F and 68.4°F. For incubations in which a portion of eggs survived, egg mortalities were monitored until 50% hatch or until complete mortality was observed. Pre-emergent fry mortality was monitored for eggs which had survived incubation at the same treatment temperature. Mortality of pre-emergent fry was monitored until complete emergence, until the yolk-sac was no longer visible, or until complete mortality occurred.

Complete mortality of fertilized eggs occurred prior to hatch in the 64.4°F and 68.4°F constant temperature treatments, while complete mortality of pre-emergent fry occurred prior to yolk-sac absorption in the 61.5°F constant temperature treatment. Although Jensen and Groot (1991) reported the time to the end of the temperature exposure treatments, there was insufficient information presented in the study to verify that the time to the end of the experiment corresponded to the actual date that complete egg mortality occurred. Data for pre-emergent fry from the 61.5°F treatment were considered suspect for the following reason. The exposure duration of pre-emergent fry in the 61.5°F treatment (31 days), calculated as the difference between the time of the end of the experiment less the time to 50% hatch, was longer than the duration to complete emergence or yolk sac absorption at temperatures of 53.0–57.2°F (27 days). These results are counterintuitive from a developmental perspective, as the time to yolk sac absorption decreases with increasing temperature (see Section 4).

USFWS (1998) reported results from a study of thermally-induced, winter and fall-run Chinook salmon egg and pre-emergent fry mortality. Fall-run Chinook salmon eggs and pre-emergent fry from the Sacramento River were incubated at seven constant temperatures ranging from 50°F to

62°F, while winter-run eggs and pre-emergent fry were subject to five temperature treatments in the range of 56°F to 64°F. Five replicates of fall-run and three replicates of winter-run eggs and pre-emergent fry were utilized for each incubation temperature. Each replicate consisted of 80–100 eggs. Mortality was measured at the end of four development stages as determined by the number of ATUs: cleavage eggs (450 ATU), embryo (900 ATU), eleutheroembryo (1350 ATU) and pre-emergent alevin (1800 ATU). The USFWS (1998) embryo threshold of 900 ATU agrees reasonably well with the average 936 ATUs required for fertilized eggs to reach 50% hatch. However, an average 713 ATUs are additionally required for pre-emergent fry to reach emergence, and this developmental threshold is nearly mid-way between the USFWS (1998) eleutheroembryo and pre-emergent alevin end-points. Incubations of both winter- and fall-run showed that a fraction of eggs and pre-emergent fry survived through all developmental stages at temperatures of 50°F to 62°F, and complete mortality occurred sometime within the first 450 ATUs (14.1 days) exposure of winter-run pre-emergent fry to 64°F.

Additional incubations were performed by USFWS (1998) to determine the influence of egg incubation temperature on pre-emergent fry mortality. Fall- and winter-run eggs incubated for the first 900 ATUs at a control temperature of 56°F, were then incubated through the next 900 ATUs as pre-emergent fry at temperatures of 60°F or 62°F. In comparison to mortality when both fertilized-eggs and pre-emergent fry were incubated at the elevated temperature, pre-emergent fry survival was significantly greater when eggs had been incubated at 56°F. These results show that pre-emergent fry mortality is greater when, as eggs, they were exposed to elevated temperatures. This would often be the situation in the lower American River and other spawning reaches of Central Valley rivers, where river temperatures are warmer during fertilized-egg incubation periods and cooler during the pre-emergent fry lifestage.

Revised Fertilized-Egg Mortality Rates

Calculation of daily mortality rates requires cumulative mortality data and the exposure duration associated with mortality. From the studies described above (Seymour 1956; Murray and McPhail 1988; Beacham and Murray 1989; Jensen and Groot 1991; and USFWS 1998), cumulative mortality and days to 50% hatch or days to 900 ATUs (USFWS 1998) were compiled where data was available. These conditions were met for eggs incubated within the temperature range of 35°F to 64.6°F. Using data from treatments in which a fraction of eggs survived to hatch integrated the effects of the temperature exposure over the entire lifestage. Duration for USFWS (1998) cumulative mortality was calculated as the number of degree days required to achieve 900 ATUs at the specified incubation temperature. These duration estimates were verified using the weekly ATU summaries for incubating eggs provided in Appendix 1 and Appendix 2 of USFWS (1998). Data for temperature treatments of 64.4°F and 68.4°F in Jenson and Groot (1991) and 67.5°F in Seymour (1956) were not used because the exact duration that resulted in complete mortality in these treatments was uncertain.

Cumulative mortality and exposure duration were used to calculate daily mortality rate for fertilized eggs. Literature-derived cumulative mortality, exposure duration, and daily mortality rates for fertilized eggs are given in **Table 12**.

Regression analysis was used to fit a two-parameter exponential function to the fertilized-egg daily mortality and temperature exposure data (Table 12). This function is shown in Equation 9 and relates average daily temperature in degrees Fahrenheit (T_F) to the daily mortality of Chinook salmon fertilized eggs as a fraction. Equation 9 is applicable at water temperatures less than or equal to 67.9°F. At water temperatures greater than 67.9°F, Equation 9 produces daily mortality rates in excess of 100%, thus it is assumed that the daily mortality rate is 100% at temperatures greater than this threshold.

$$M_i = 6.451 \times 10^{-19} e^{(0.61669 \times T_F)} \tag{9}$$

Equation 9 is plotted (as a percentage) along with the literature-derived, fertilized-egg mortality data and the original Mortality Model rates in **Figure 16**. **Table 13** also shows the daily mortality rates for fertilized eggs estimated with Equation 9. Equation 9 replaces the original model's fertilized egg criteria (EC) at water temperatures less than or equal to 67.9°F, and at water temperatures greater than this threshold EC is assumed to be 100%. The refined EC values are intended to be used to directly calculate the daily fertilized-egg mortality (EM) using the average daily water temperature for a given reach.

As with the pre-spawned egg lifestage, there were two compelling reasons for extending the range of average daily water temperatures and corresponding daily mortality rates for the fertilized egg lifestage. The 1995 LAR Mortality Model held the daily mortality rate constant for all water temperatures exceeding 64°F for the fertilized egg lifestage. Examination of available water temperature monitoring data at the Fair Oaks Gage (USGS 11446500) from October 30, 1998 through August 26, 2015 indicate that water temperatures exceed 64°F during half (8) of the years encompassing the fertilized egg lifestage (mid-October through mid-March), although not for many days each year **(Figure 17**). Considering each of the days corresponding with the fertilized egg lifestage for the 16 years during which water temperature monitoring data were available, water temperatures exceeded 64°F 2.5% of the days.

Second, the average daily water temperature-daily mortality rate for the fertilized egg lifestage is a continuous function, and can be presented for any desired range. In Figure 16 and Table 13 the function was presented such that a daily mortality rate was provided for every corresponding water temperature value until a daily mortality rate approaching 100% was obtained, to illustrate the entire range of the function.

Table 12. Literature-derived Chinook salmon fertilized-egg mortality data.

Water Temperature (°F)	Cumulative Mortality M_n (%)	Exposure Duration n (days)	Daily Mortality Rate M_i (%)	Reference
38.8	2.1	125.6	0.017	Beacham & Murray 1989
39	30.3	132.5	0.272	Beacham & Murray 1989
39	4.1	128.5	0.033	Beacham & Murray 1989
46.2	0.4	71.1	0.006	Beacham & Murray 1989
46.2	1.1	68.9	0.016	Beacham & Murray 1989
46.4	0.3	70.6	0.004	Beacham & Murray 1989
53.6	0.8	44.1	0.018	Beacham & Murray 1989
53.6	2.2	44.1	0.05	Beacham & Murray 1989
53.8	0.6	42.2	0.014	Beacham & Murray 1989
59	6.9	36.1	0.198	Beacham & Murray 1989
59	4.3	34.1	0.129	Beacham & Murray 1989
59.4	8.7	34.3	0.265	Beacham & Murray 1989
50.4	21.3	51.2	0.467	Jensen & Groot 1991
53.1	28.7	43.1	0.782	Jensen & Groot 1991
57.2	21.3	35.7	0.669	Jensen & Groot 1991
61.5	64.3	32.1	3.158	Jensen & Groot 1991
35.6	86	202	0.969	Murray & McPhail 1988
41	17	101.5	0.183	Murray & McPhail 1988
46.4	6	67.1	0.092	Murray & McPhail 1988
51.8	10	46.9	0.224	Murray & McPhail 1988
57.2	52	38.4	1.893	Murray & McPhail 1988
39.8	6	128.6	0.048	Seymour 1956
44.7	6	79.1	0.078	Seymour 1956
45.2	1	73.4	0.014	Seymour 1956
50.2	2	50.9	0.04	Seymour 1956
50.6	13	50.2	0.277	Seymour 1956
54.6	2	38.8	0.052	Seymour 1956
55.1	5	40	0.128	Seymour 1956
57.8	2	34	0.059	Seymour 1956
59.8	35	32.1	1.333	Seymour 1956
60.2	22	34	0.728	Seymour 1956
62	85	30.7	5.992	Seymour 1956
62.4	78	31.4	4.708	Seymour 1956
64.6	99	28	15.166	Seymour 1956
50	6	50	0.124	USFWS 1998
52	8	45	0.185	USFWS 1998
54	11	40.9	0.284	USFWS 1998
56	10	37.5	0.281	USFWS 1998
56	14	37.5	0.401	USFWS 1998
58	16	34.6	0.502	USFWS 1998
58	14	34.6	0.435	USFWS 1998

Table 12 (continued)				
60	15	32.1	0.504	USFWS 1998
60	14	32.1	0.468	USFWS 1998
62	37	30	1.528	USFWS 1998
62	22	30	0.825	USFWS 1998
64	74	28.1	4.677	USFWS 1998

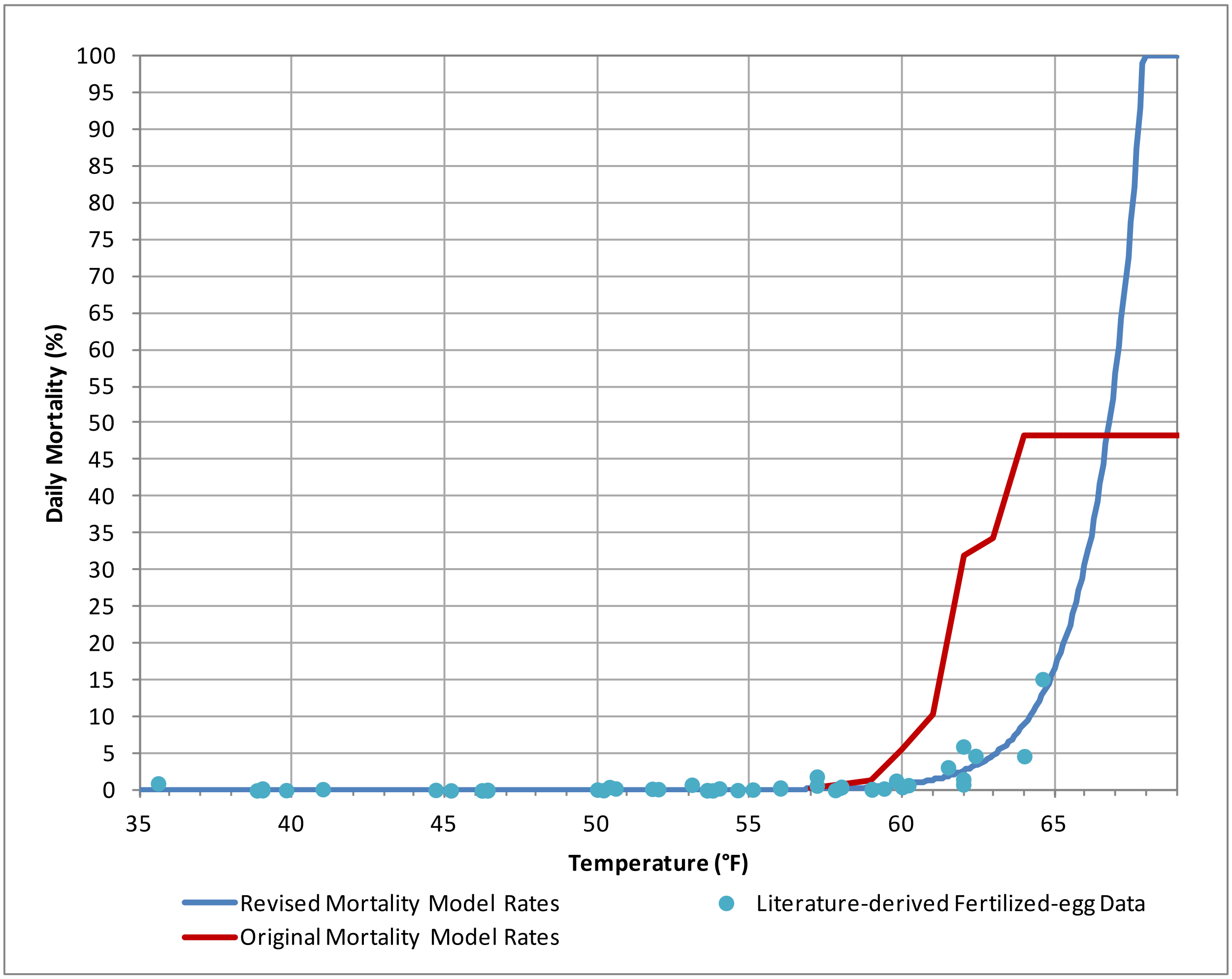

Figure 16. Original 1995 LAR Mortality Model and revised Chinook salmon fertilized-egg daily mortality rates versus exposure temperature. Data used for non-linear regression modeling for the revised Chinook salmon fertilized-egg daily mortality rates are presented for comparison.

Revised Pre-Emergent Fry Mortality Rates

Revised pre-emergent fry mortality rates were derived using data from Murray and McPhail (1988), Beacham and Murray (1989), Jensen and Groot (1991), and USFWS (1998). From these studies, the cumulative mortality and exposure duration data was compiled for pre-emergent fry that had survived the same incubating temperature as eggs. Overall, pre-emergent fry mortality and duration data were available for water temperatures from 35°F to 62°F.

Table 13. Original 1995 LAR Mortality Model and revised Chinook salmon fertilized-egg daily mortality rates.

Water Temperature (°F)	Daily Mortality Rate M_i (%)	
	Original Model	Revised Model
56	Natural Rate	0.064
57	0.347	0.119
58	0.736	0.221
59	1.428	0.409
60	5.613	0.757
61	10.174	1.403
62	31.871	2.599
63	34.207	4.815
64	48.205	8.922
65	48.205	16.530
66	48.205	30.627
67	48.205	56.746
68	48.205	100.00
≥69	48.205	100.00

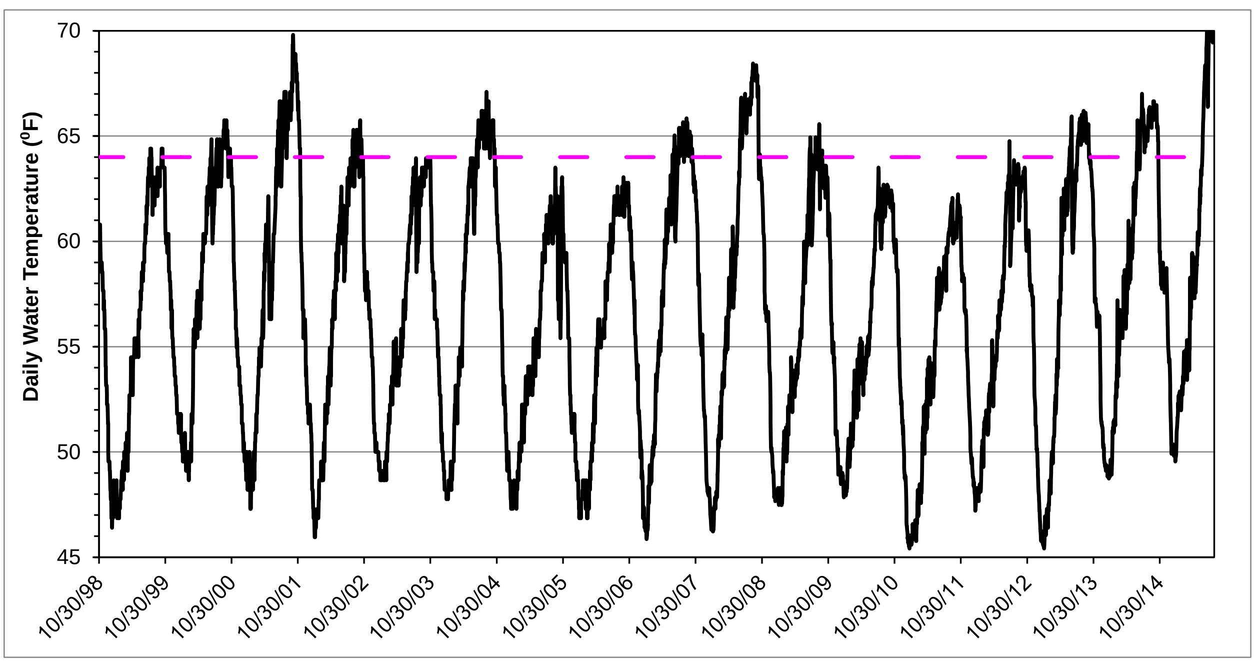

Figure 17. Daily water temperature at the Fair Oaks Gage from October 30, 1998 through August 26, 2015 with the fertilized egg period (mid-October through mid-March) indicated as horizontal lines at 64°F.

The duration of exposure used to calculate daily mortality rates was slightly different depending on the study. Duration of exposure was equivalent to: (1) the duration required to accrue 900 ATUs in USFWS (1998); (2) the duration associated with emergence and/or yolk-sac absorption in Jensen and Groot (1991); and (3) the duration between 50% hatch and 50% emergence in Murray and McPhail (1988) and Beacham and Murray (1989). Data derived from USFWS (1998) was for cumulative mortality through what the study called the "pre-emergent alevin" lifestage, which ended 900 ATUs after the fertilized-egg lifestage (i.e., the cleavage embryo and embryo stages). USFWS (1998) reported cumulative egg mortality at the end of each lifestage, which required calculation of the mortality that occurred specifically during the pre-emergent fry lifestage. To do so, cumulative egg mortality was subtracted from the combined egg and pre-emergent fry mortality, and the resulting difference was divided by the fraction of eggs which survived the egg lifestage. In the case of the 64°F incubation in USFWS (1998), complete mortality occurred sometime within 450 ATU (14.1 days). Because the precise duration of exposure at which complete mortality occurred in the 64°F treatment was not reported, data from this incubation was not used. For the same reasons, data for temperature treatments of 64.4°F and 68.4°F in Jenson and Groot (1991) were not used because the exact duration that resulted in complete mortality in these treatments was uncertain.

Cumulative mortality and exposure duration were used to calculate daily mortality rate. Literature-derived cumulative mortality, exposure duration, and the associated daily mortality rates for pre-emergent fry are given in **Table 14**. Regression analysis was used to fit a two-parameter exponential function to the pre-emergent fry daily mortality and temperature exposure data. The function is shown in Equation 10 and relates average daily temperature in degrees Fahrenheit (T_F) to the daily mortality of Chinook salmon pre-emergent fry as a fraction. Equation 10 is applicable at water temperatures less than or equal to 66.1°F. At water temperatures greater than 66.1°F, Equation 10 produces daily mortality rates in excess of 100%, thus it is assumed that the daily mortality rate is 100% at temperatures greater than this threshold.

$$M_i = 3.268 \times 10^{-19} e^{(0.64334 \times T_F)} \qquad \textbf{(10)}$$

Equation 10 is plotted (as a percentage) along with the literature-derived pre-emergent fry mortality data and the original 1995 LAR Mortality Model rates in **Figure 18**. **Table 15** also shows the daily mortality rates for pre-emergent fry calculated with Equation 10. Equation 10 replaces the original 1995 LAR Mortality Model's pre-emergent fry criteria (FC) at water temperatures less than or equal to 66.1°F, and at water temperatures greater than this threshold, FC is assumed to be 100%. The refined FC values are intended to be used to directly calculate the daily pre-emergent fry mortality (FM) using the average daily water temperature for a given reach.

Table 14. Literature-derived Chinook salmon pre-emergent fry mortality data.

Water Temperature (°F)	Cumulative Mortality M_n (%)	Exposure Duration (days)	Daily Mortality Rate M_i (%)	Reference
38.8	0.8	85.7	0.009	Beacham & Murray 1989
39.0	0.0	87.5	0.000	Beacham & Murray 1989
39.0	2.2	82.9	0.027	Beacham & Murray 1989
46.2	0.8	45.0	0.018	Beacham & Murray 1989
46.2	0.0	46.4	0.000	Beacham & Murray 1989
46.4	0.1	56.1	0.002	Beacham & Murray 1989
53.6	0.7	34.1	0.021	Beacham & Murray 1989
53.6	2.3	32.7	0.071	Beacham & Murray 1989
53.8	0.3	33.9	0.009	Beacham & Murray 1989
59.0	39.4	26.7	1.858	Beacham & Murray 1989
59.0	6.3	27.6	0.235	Beacham & Murray 1989
59.4	4.8	27.6	0.178	Beacham & Murray 1989
50.4	0.0	35.5	0.000	Jensen & Groot 1991
53.1	0.0	27.4	0.000	Jensen & Groot 1991
57.2	3.8	27.1	0.143	Jensen & Groot 1991
35.6	0.0	114.0	0.000	Murray & McPhail 1988
41.0	0.0	89.5	0.000	Murray & McPhail 1988
46.4	5.0	47.9	0.107	Murray & McPhail 1988
51.8	4.0	37.1	0.110	Murray & McPhail 1988
57.2	3.0	24.6	0.124	Murray & McPhail 1988
52.0	5.4	45.0	0.123	USFWS 1998
54.0	5.6	40.9	0.141	USFWS 1998
56.0	5.6	37.5	0.154	USFWS 1998
56.0	3.5	37.5	0.095	USFWS 1998
58.0	19.0	34.6	0.607	USFWS 1998
58.0	14.0	34.6	0.433	USFWS 1998
60.0	20.0	32.1	0.692	USFWS 1998
60.0	74.4	32.1	4.153	USFWS 1998
62.0	84.1	30.0	5.945	USFWS 1998
62.0	91.0	30.0	7.723	USFWS 1998

In comparison to the revised LAR Mortality Model fertilized-egg mortality rates (Table 13), the revised pre-emergent fry mortality rates are slightly greater. This may result from the physiological sensitivity of pre-emergent fry which have had a history of high incubation temperatures as eggs (USFWS 1998), or it may truly reflect a greater susceptibility of pre-emergent fry to extreme temperatures, as shown by short-duration (1-8 hour) experiments at temperature greater than 71.5°F (Neitzel and Becker 1985).

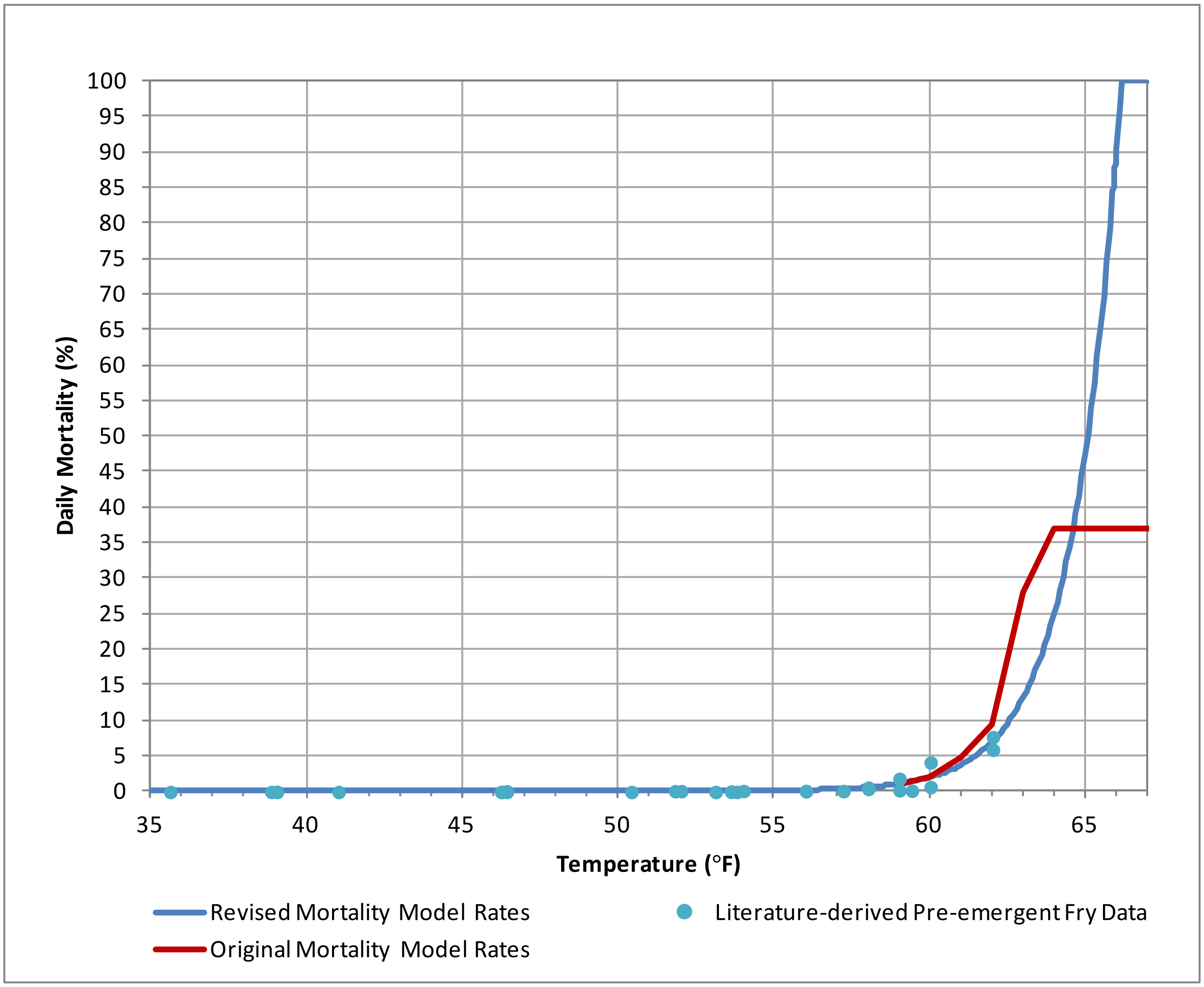

Figure 18. Revised Chinook salmon pre-emergent fry daily mortality rates versus incubation temperature. Data used for non-linear regression modeling and the original Lower American River Mortality Model rates are presented for comparison.

By contrast with the pre-spawned egg and fertilized egg lifestages, examination of average daily water temperatures monitored at the Fair Oaks Gage (USGS 11446500) from October 30, 1998 through August 26, 2015 indicate that water temperatures during the pre-emergent fry lifestage (mid-November through mid-April) did not exceed 64ºF (**Figure 19**). The revised pre-emergent fry water temperature-daily mortality rate function approached 100% at 67ºF, which represented the upper range depicted in Figure 18 and Table 14.

Table 15. Original and revised Chinook salmon pre-emergent fry daily mortality rates.

Water Temperature (°F)	Daily Mortality Rate M_i (%)	
	Original Model	**Revised Model**
56	Natural rate	0.145
57	Natural rate	0.275
58	Natural rate	0.524
59	0.750	0.997
60	2.034	1.898
61	4.830	3.612
62	9.428	6.872
63	28.031	13.077
64	36.904	24.883
65	36.904	47.348
66	36.904	90.095
≥67	36.904	100.00

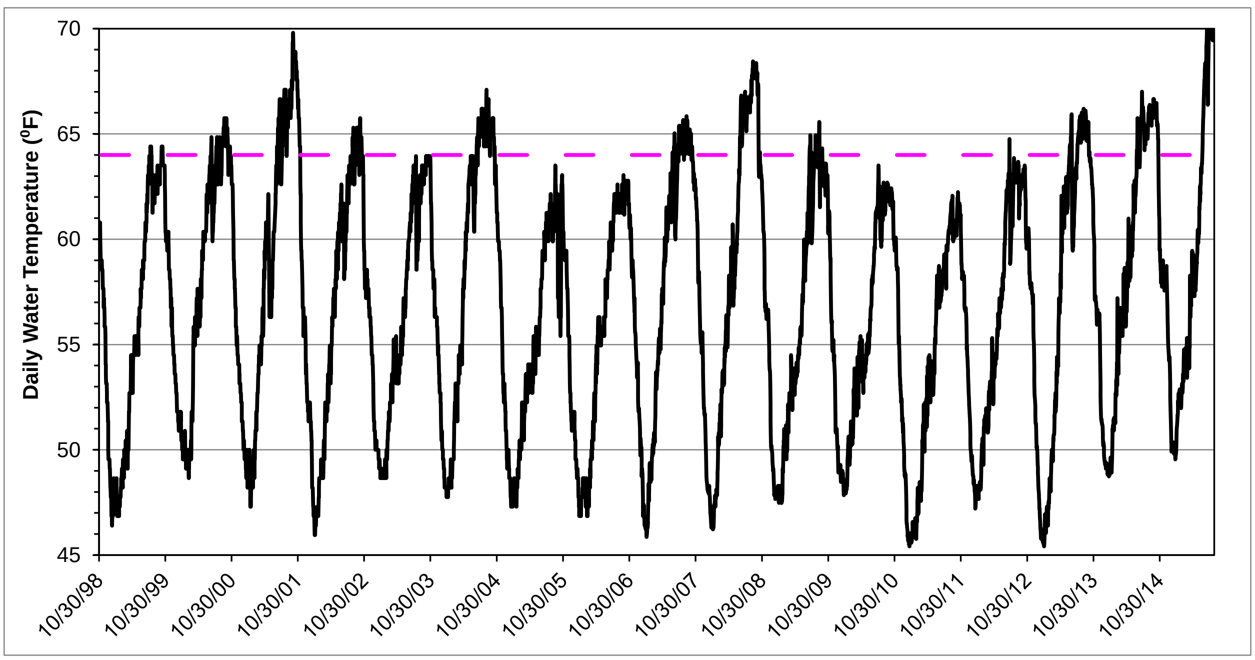

Figure 19. Daily water temperature at the Fair Oaks Gage from October 30, 1998 through August 26, 2015 with the pre-emergent fry period (mid-November through mid-April) indicated as horizontal lines at 64^{0}F.

4.0 Chinook Salmon Early Lifestage Developmental Thresholds

HCI (1996) stated that a key model assumption is "*Development from fertilized egg to hatching requires 750 (°F) temperature units, and another 750 (°F) temperature units from hatching to emergent fry (32mm), for a total of 1500 (°F) temperature units from egg to emergent fry*". An ATU is defined as degrees Fahrenheit above 32°F, accumulated during a 24-hour period (CDFG 1998). CDFG (1998) states "*From the time of egg fertilization a cumulative total of 1550 temperature units …are required for an egg to hatch and fry to emerge (Armour 1991)*". Additionally, Armour (1991) states that… "*Development from fertilization to hatching requires 850 daily temperature units (DTU's), and an additional 700 units are required from hatching to beginning of emergence.*" Because citations for the original 1995 LAR Mortality Model assumption were not provided, the use of the thermal units approach was further examined.

As shown in **Figure 20** and **Figure 21**, the ATUs corresponding to median hatch (50% hatch) and to median emergence (50% emergence) were calculated for fertilized eggs and pre-emergent fry data from studies used in the revision of early lifestage mortality rates (Seymour 1956; Beacham and Murray 1989; and Murray and McPhail 1988; Jensen and Groot 1991). A non-linear relationship between developmental rate, as shown by ATUs to reach the end of the lifestage, and temperature is evident by the downward trend in the ATUs associated with 50% hatch or 50% emergence at temperatures less than 40°F. As discussed by Alderdice and Velsen (1978), the deviation of this relationship from linearity restricts the use of the ATU approach as a satisfactory estimate of the length of the egg incubation period to temperatures greater than 40°F. A similar observation can be made for pre-emergent fry (Figure 21).

The available data from the USGS Fair Oaks Gage (USGS 11446500) presented in Figure 17 and Figure 19, spanning the period from October 30, 1998 through August 26, 2015, show that water temperatures in the lower American River are never below 45.5°F during the fertilized egg lifestage (mid-October through mid-March), and never below 45.4°F during the pre-emergent fry lifestage (mid-November through mid-April). Based upon the foregoing discussing, the thermal units approach will produce satisfactory estimates of the length of the incubation period for fertilized eggs and pre-emergent fry at temperatures relevant to the lower American River. Thus, the use of an average ATU threshold to mark the transition between the egg/pre-emergent fry and pre-emergent fry/post-emergent fry lifestages has been retained in the LAR Mortality Model. The average ATU thresholds used in this update of the LAR Mortality Model are as follows. For fertilized eggs, the average ATUs to 50% hatch is 936, which was calculated using data at temperatures greater than 45.5°F shown in Figure 20. For pre-emergent fry, the average ATUs to 50% emergence is 713, which was calculated using data at temperatures greater than 45.4°F shown in Figure 21.

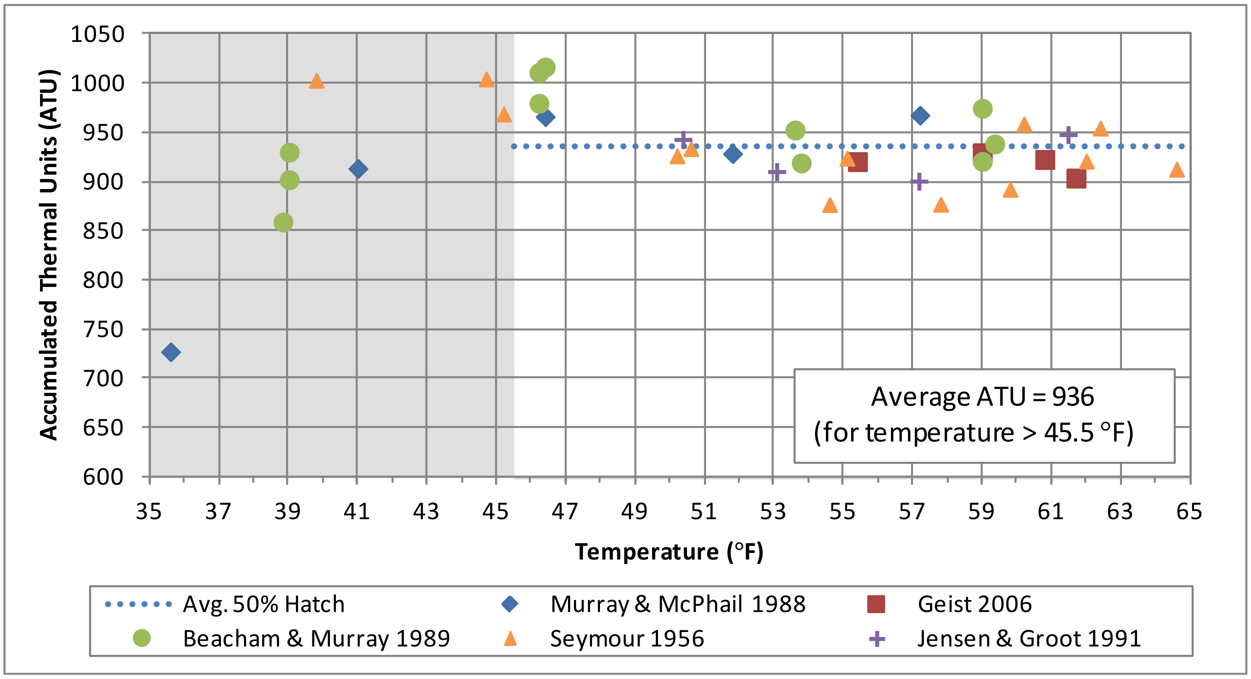

Figure 20. Literature-derived accumulated thermal units (ATUs) required for fertilized eggs to reach 50% hatch at various temperatures. Average ATUs to reach 50% hatch was calculated for temperatures greater than 45.5°F, the minimum temperature that has historically occurred in the lower American River during the egg incubation period of the year.

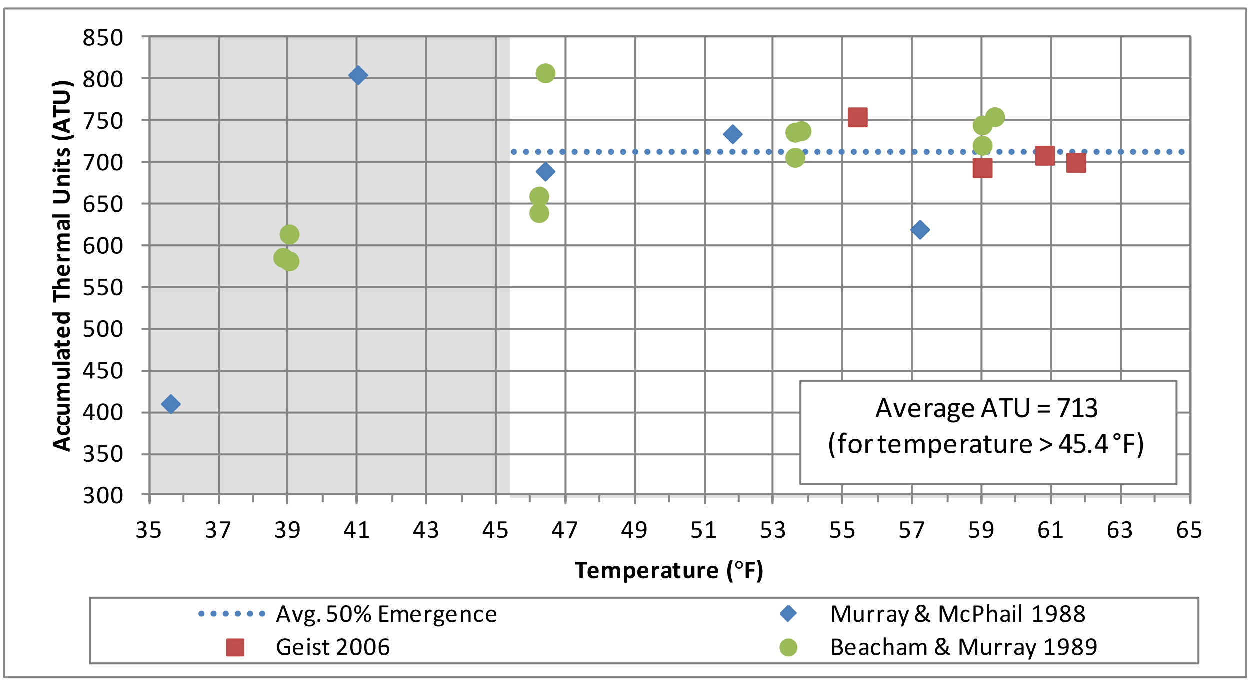

Figure 21. Literature-derived accumulated thermal units (ATUs) required for pre-emergent fry to reach 50% emergence at various temperatures. Average ATUs to reach 50% emergence was calculated for temperatures greater than 45.4°F, the minimum temperature that has historically occurred in the lower American River during the pre-emergent fry development period of the year.

5.0 Model Code Corrections, Programming Language Conversion, and Update

The following sections of this Memorandum describe changes and updates that were made to the original 1995 LAR Mortality Model associated with: (1) identified errors in the coding of the original model; and (2) updated biological and physiological information related to fall-run Chinook salmon in the lower American River.

Before any coding updates were made to the original 1995 model, the coding of the original model in FORTRAN was converted to Visual Basic for Applications (VBA) / Microsoft Excel. After the original FORTRAN model was converted to VBA and it was confirmed that the VBA version produced the same results as the FORTRAN version, the VBA version was then corrected for model coding errors and updated to reflect updated biological and physiological information for fall-run Chinook salmon in the lower American River.

5.1 FORTRAN Code Corrections

Review of the original 1995 Lower American River Salmon Mortality Model resulted in the identification of errors related to five primary components of the original model, including: (1) temporal arrival distribution; (2) the methodology applied to interpolate daily water temperatures based on average monthly water temperatures; (3) calculation of pre-spawned egg mortalities at particular water temperatures; (4) calculation of early year (January and February) early lifestage mortalities; (5) pre-spawn and spawning distributions; and (6) front loading of mortality in each lifestage.

In the process of updating the LAR Mortality Model, the original FORTRAN model was reviewed for errors or inconsistencies. Beyond the updates discussed in previous sections, six areas of concern with the original FORTRAN model were identified: (1) temporal arrival distribution; (2) temperature interpolation; (3) calculation of pre-spawn mortalities; (4) calculation of early year (January and February) mortalities; (5) pre-spawn and spawning temporal distributions; and (6) front loading of mortality in each lifestage.

5.1.1 Temporal Arrival Distribution

In reviewing the FORTRAN code of the original 1995 salmon mortality model and the 1996 *Water Forum Issue Paper* (HCI 1996), it became apparent that the temporal arrival distribution (i.e., weekly mean percentages of the annual fall-run Chinook salmon run arriving in the lower American River) used in the original 1995 FORTRAN model were not consistent with the reported values in the 1996 *Water Forum Issue Paper* (HCI 1996). After converting the 1995 FORTRAN model to VBA, the weekly mean percentages of the annual fall-run Chinook salmon run arriving in the lower American River from the original 1995 FORTRAN model were used.

While converting the model to a different programming language, Visual Basic for Applications (VBA), it was identified that the temporal arrival distribution (also termed: mean percentage of run arriving) used in the original FORTRAN model did not agree with the values provided in the *Water Forum Issue Paper* (Table 4 of HCI 1996) as shown in **Table 16**. When conducting the sensitivity analysis the values from the original FORTRAN model were used, however as the model was updated, the new temporal arrival distribution was used.

Table 16. Temporal arrival distribution from the FORTRAN model and the Water Forum Issue Paper.

Week	Days	Mean Percentage of Run Arriving	
		FORTRAN Model Values	Water Forum Issue Paper Values
Sept (wk 1)	7	2.9%	3.0%
2	8	2.9%	3.0%
3	7	4.3%	4.2%
4	8	2.2%	2.2%
Oct (wk 1)	7	5.4%	5.6%
2	8	5.0%	5.0%
3	8	4.9%	5.0%
4	8	8.4%	8.4%
Nov (wk 1)	7	8.3%	8.4%
2	8	18.8%	19.0%
3	7	16.3%	16.3%
4	8	12.4%	12.4%
Dec (wk 1)	7	2.0%	2.0%
2	8	2.7%	2.4%
3	8	1.0%	1.0%
4	8	2.5%	2.2%

5.1.2 Temperature Interpolation

The original 1995 LAR Mortality Model used average monthly water temperatures to calculate daily mortality rates for fall-run Chinook salmon. In the original model, monthly water temperatures were converted to a daily format by linearly interpolating from the middle of one month (i.e., the 15th of the month) to the middle of the next month. Two problems were identified related to interpolating water temperatures using this method. First, there is no interpolation for the first 15 days of the year (i.e., 1/1 – 1/15) or for the last 16 days (i.e., 12/15 – 12/31) of the year (**Figure 18**). Instead of interpolating water temperatures based on the month before the first month of the year and based on the month after the last month of the year, the original model used the monthly average. Second, when the model's interpolated water temperature values are converted back to a monthly average there could be more than a one degree (°F) of difference between the monthly average water temperatures based on the interpolation method and the actual monthly average water temperatures (**Figure 22** – see comparison of the dashed red line (i.e., monthly average water temperatures derived from interpolation) and the solid green line (i.e., actual average monthly water temperatures). By converting the original model to utilize average daily water temperatures, this problem associated with interpolation of water temperatures was eliminated.

The original FORTRAN model used average monthly temperatures and interpolated these monthly values to daily temperature in order to calculate daily mortality for each lifestage. Monthly temperatures were converted to a daily timestep by linearly interpolating from the middle of one month (the 15th) to the middle of the next month. There were two problems with interpolating the temperatures in this manner. First, there was no interpolation performed for the first 15 days (1/1 – 1/15) and the last 16 days (12/15 – 12/31) of the calendar year (Figure 22). Instead of interpolating with the month before and after the year being run, the model simply used the monthly average. Second, when model interpolated values were converted back to a monthly average value, there could be more than a degree of difference from the initial or actual monthly averages (Figure 22 – comparison of the dashed red and solid green lines). In other words, the FORTRAN model was not maintaining thermal mass through the interpolation process it was using. By converting the model to read average daily temperatures this problem was eliminated.

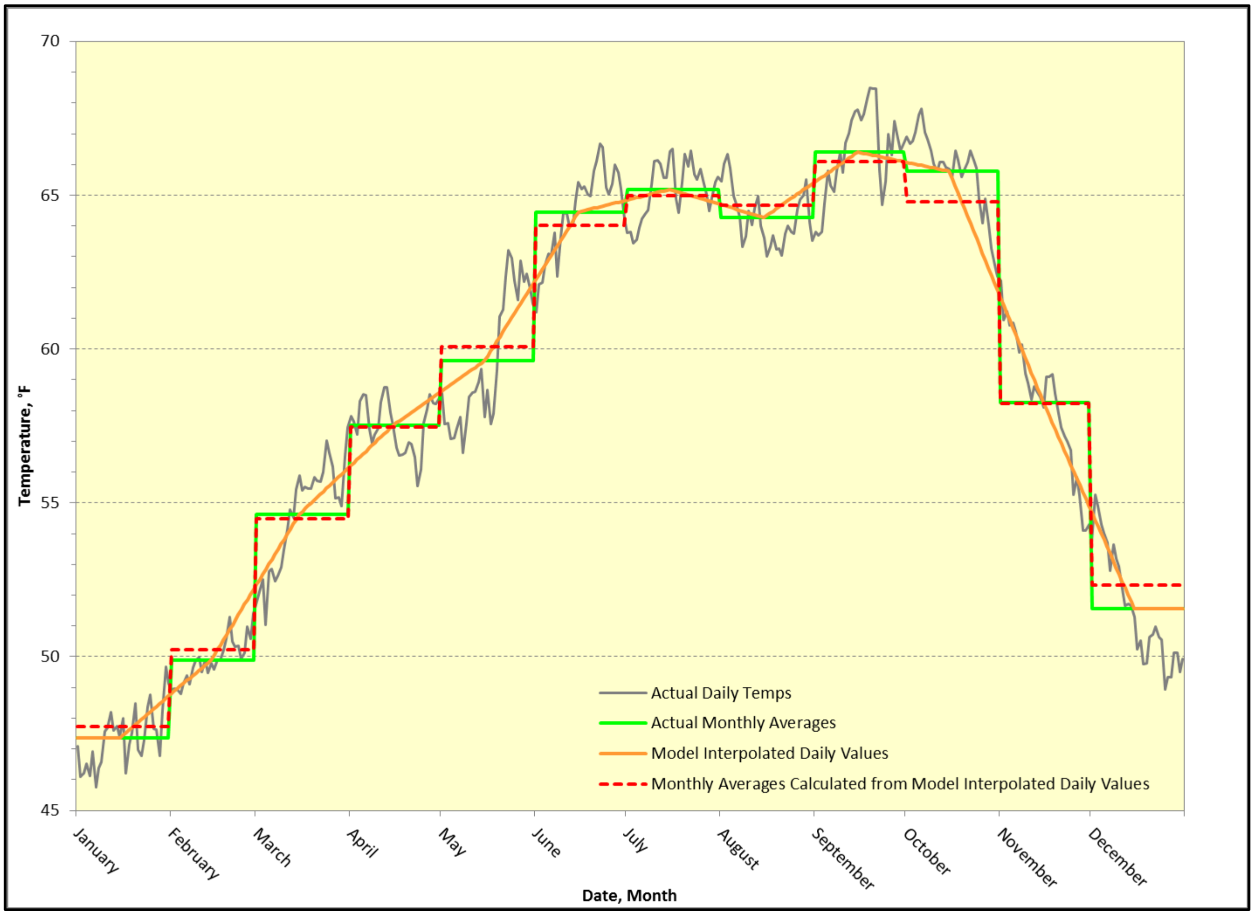

Figure 22. Graph showing problem with FORTRAN model interpolation from monthly to daily temperatures.

5.1.3 Pre-Spawned Mortalities

The original 1995 FORTRAN mortality model "reads" Table 1 from the 1996 Water Forum Issue Paper (i.e., water temperature and exposure duration-mortality rates for pre-spawned Chinook salmon eggs), and uses the mortality rates to interpolate daily mortality rates between whole degrees Fahrenheit. However, manual calculations performed to review the model's performance of interpolating daily mortality rates between whole degrees indicated that the original 1995 model was improperly interpolating daily mortality rates when the daily water temperature was between 60 and 61°F. The original 1995 model was improperly referring to the wrong line of code to calculate the daily pre-spawn mortality rate. The coding error occurred on line 147 (numeric label 97) and was referring to numeric label 95 instead of 99. Once this coding error was corrected, the original 1995 model appeared to run properly. The resultant modeled annual mortalities associated with this code correction were slightly different from the results produced from the original model.

The mortality model used the pre-spawn mortality rates shown in Tables 6-8, and used those values to interpolate daily rates between the integer values provided. However, after hand calculations were performed, it was found that the model was improperly interpolating daily mortality rates when the daily temperature was between 60 and 61°F. The model was incorrectly referencing the wrong line of code to calculate the pre-spawn mortality rate. The error was on line 147 (numeric label 97) and was pointing to numeric label 95 instead of 99. Once fixed, the model ran properly and the yearly losses were slightly different than the original FORTRAN model.

5.1.4 Calculation of Early Year Mortalities

Review of the coding employed in the original 1995 salmon mortality model to calculate daily early lifestage mortality during January and February indicated a potential error in the water temperatures used to calculate early lifestage mortality during January and February.

The original 1995 FORTRAN model "looped back" on itself within the same year to calculate early year (i.e., January and February) Chinook salmon early lifestage mortality. The original 1995 model would store daily water temperatures for one calendar year at a time and then calculate mortalities for that year before deleting the water temperatures and storing the water temperatures for the next year. The original 1995 model would start the annual mortality calculation process on September 1st (day 244). When the original 1995 model steps to day 366 it loops back to January 1st (day 1) of the same year and calculates mortalities using January 1 water temperatures and December 31 inputs. Therefore, the original mortality model may potentially have been applying water temperatures from January and February of the year prior to the year that it was supposed to be calculating early lifestage mortalities for (e.g., calculating early lifestage mortalities for January and February 1923 using water temperatures for January and February 1922). However, it is possible that the water temperatures input to the original 1995 model were formatted in such a way that this methodology was correct (e.g., water temperature data sequenced as Jan 1923, Feb 1923,…Aug 1923, Sep 1922, Oct 1922, Nov 1922, Dec 1922). Regardless, because the original mortality model was updated to calculate annual early lifestage mortality over a "spawning year" (i.e., June 1 – May 31), the potential errors associated with calculating annual early lifestage mortality over a calendar year are removed from the updated mortality model.

The original FORTRAN model used incorrect monthly temperature inputs to calculate daily temperatures in the early part of the calendar year (i.e., January and February). The model would create and store daily temperatures one calendar year at a time and then calculate mortalities for that year before deleting the temperature values and storing the temperature values for the following calendar year. The model would start the mortality calculation process on September 1st (day 244). When the model steps to day 366 (January 1 of the next calendar year) it would loop back to January 1 (day 1) of the same year and calculate mortalities using January 1 temperatures and December 31 inputs.

The only way this was not a mistake was if the input monthly temperature file was created with modified water year temperatures in a calendar year format (i.e., Jan 1923, Feb, 1923, ..., Aug

1923, Sept 1922, Oct 1922, Nov 1922, Dec 1922) which is not the way temperature inputs are typically provided to the original FORTRAN model. It was more likely that the original author of the model used this logic as a work around to use calendar years but still calculate mortalities for a whole spawning season. Examination of the results showed that although there was some issue to be taken with this logic, it likely had little effect on the final result. Temperatures are typically cold enough in January and February that there is very little mortality. If, however, higher temperatures were inputted into the model then losses could be recorded in the early year. Converting the model to use a spawning year format (i.e., June 1 - May 31) eliminated this problem.

5.1.5 Pre-Spawning Adult and Spawning Temporal Distributions

The original 1995 FORTRAN model had some apparent problems with regards to how it handled the pre-spawning and spawning distributions. Specifically, the original model had an accounting error with respect to the total pre-spawn distribution. After the 60°F spawning threshold was passed and spawning was initiated in the original model, the pre-spawn population quickly drops to zero even, despite the fact there were still fall-run Chinook salmon arriving to spawn in the lower American River. As documented below, the 60°F spawning threshold was removed from the updated mortality model, and pre-spawning and spawning temporal distributions were applied in order to define the number of days to spawning for pre-spawning adults that arrived in the lower American River on any given day, removing the error associated with the accounting of the pre-spawning adult and spawning distributions in the original mortality model. The problem was that the model was adjusting the pre-spawn distribution with population losses (both pre-spawn mortality and transition to the egg lifestage), but was not adjusting the spawning distribution (i.e., the percent of the population on a given day transitioning from the pre-spawn lifestage to the egg lifestage) in the same manner. Thus the model was accounting for a larger spawning population which caused the pre-spawn population to drop to zero. As an example, on a given day the spawning distribution specifies 8% should transition from pre-spawning to egg; however, between arrival and spawning the pre-spawn population incurred 2% mortality. Therefore only 6% of the spawning distribution on that day (a fraction of the total pre-spawn population on that day) would transition to the egg lifestage.

The original FORTRAN model had some problems with regards to how it handled the pre-spawn and spawning temporal distributions. The model had an accounting error with respect to the total pre-spawn distribution. After the 60°F spawning threshold was reached, and spawning was allowed to begin, the pre-spawn population would quickly drop to zero even though there were still arrivals. The problem was that the model was adjusting the pre-spawn distribution with population losses (both pre-spawn mortality and transition to the egg lifestage), but was not adjusting the spawning distribution (i.e., the percent of the population on a given day transitioning from the pre-spawn lifestage to the egg lifestage) in the same manner. Thus the model was accounting for a larger spawning population which caused the pre-spawn population to drop to zero. As an example, on a given day the spawning distribution specifies 8% should transition from pre-spawning to egg; however, between arrival and spawning the pre-spawn population incurred 2% mortality. Therefore only 6% of the spawning distribution on that day (a fraction of the total pre-spawn population on that day) would transition to the egg lifestage.

5.1.6 Mortality Frontloading and Daily Cohort Tracking

For each lifestage in the model there were periods where one lifestage and the subsequent lifestage did and did not overlap. Mortalities incurred in the FORTRAN model during periods of no overlap were translated to the beginning of the subsequent lifestage. This is referred to as a "frontloading" of mortalities. For example, if mortalities were incurred two weeks after the initial arrival of pre-spawned adults and before the initiation of any spawning, then it should be assumed that all two weeks' worth of the population that were present in the river would incur some level of loss proportional to the arrival distribution. However, the FORTRAN model was assuming that the fish holding the longest (i.e., the first arrivals) would incur all of the mortality. Thus, the front end of the subsequent lifestage (for this example it would be the egg distribution) would experience all of the loss incurred prior to the initiation of spawning. This issue was resolved when the model was converted to track daily cohorts, and then mortality was distributed across all preceding days of a particular lifestage, not just isolated to the front end of that lifestage.

To overcome issues with mortality frontloading and to accommodate earlier run arrivals, the model was converted to track each individual daily cohort through each of the three lifestages with a spawning year format, starting on June 1. Originally, the FORTRAN model would compute mortality one lifestage at a time. This model framework led to the mortality frontloading issue. Instead, the updated model tracks each daily cohort individually which allows for properly distributed mortalities. Furthermore, this update eliminates the issues concerning early year mortalities (see Section 5.1.4) since model calculations begin on June 1st and carry through consecutively (on a daily basis) through the end of each spawning year.

5.2 Model Conversion to VBA/Excel

As previously mentioned, before any updates were made the original 1995 model, the 1995 model was converted to VBA/Excel in order to operate the model in the same way as the original FORTRAN model was operated. During the conversion process any errors discovered in the FORTRAN code were either fixed or documented. The original 1995 FORTRAN model was converted to VBA/Excel for several reasons. First, Excel is widely used and accessible to potential users. It provides the user with a familiar and user-friendly environment for changing variables and examining results. Secondly, VBA is a more modern language and easier to write than FORTRAN. Furthermore, de-bugging and testing the model is easier with VBA than FORTRAN, reducing the risk of programming errors. The drawbacks of using VBA/Excel are that the file sizes are larger and run times are longer than in FORTRAN. However, the additional increase in file sizes and run times are generally negligible with modern computers.

Extensive testing was performed for all stages of early lifestage mortality modeling to ensure that the VBA/Excel model and FORTRAN models were calculating the same resultant mortality values. Additionally, all input variables were adjusted for both models and tested for congruity. FORTRAN and VBA/Excel models both calculated the same total annual early lifestage Chinook salmon losses when provided the same inputs.

Before any updates were made, the model was converted to VBA/Excel to operate the same as the original FORTRAN model. During the conversion process any errors discovered in the FORTRAN code were either fixed or documented. The choice to convert the model to VBA/Excel was made for several reasons. First, Excel is widely used and accessible, and provides the user with a familiar and user-friendly environment for changing variables and examining results. Second, VBA is a more modern language that code is easier to write, de-bug and test, as compared to FORTRAN, which reduced the risk of programming errors. The drawbacks of using VBA/Excel are that the file sizes are larger and model run times are longer. However, with modern computing systems these differences are negligible.

Extensive testing was performed for all stages of mortality prediction to ensure that the VBA/Excel model and FORTRAN models were calculating the same values. In addition, all input variables were adjusted for both models and tested for agreement. FORTRAN and base VBA/Excel models both calculated the same total yearly salmon losses when given the same inputs.

5.3 Model Update

After initial review of the original 1995 FORTRAN model, it became apparent that certain aspects of the original model needed to be updated in order to better reflect an updated understanding of biological and physiological characteristics of fall-run Chinook salmon in the lower American River. Updated biological and physiological information used to update the original mortality model related to: (1) fall-run Chinook salmon pre-spawning arrival and spawning spatial and temporal distributions in the lower American River; (2) the physiological spawning response to water temperature in the lower American River; (3) the ATUs associated with the end of the fertilized-egg and pre-emergent fry lifestages; and (4) pre-spawned egg, fertilized egg, and pre-emergent fry mortality-water temperature relationships.

In addition to updating the original mortality model to reflect updated biological and physiological information, the model also was updated to reflect a more accurate application of water temperature-mortality relationships for the three early lifestages of fall-run Chinook salmon, and include modeling of early lifestage mortality in 18 reaches within the lower American River instead of 9 reaches in the original mortality model.

The updates described in this section refer to version 2.5 of the updated Lower American River Salmon Mortality Model. In addition to the correction of coding errors previously described, there were seven key updates made to the original 1995 model: (1) allow the model to compute annual early lifestage mortalities based on the spawning year (i.e., starting on June 1) instead of the calendar year; (2) convert the model to track individual daily cohorts; (3) update the fall-run Chinook salmon spawning spatial distribution and water temperatures with an 18 reach distribution; (4) update the fall-run Chinook salmon run arriving to the lower American River from weekly values starting in September to daily values starting in June with associated holding times until spawning; (5) replace the 60°F spawning distribution threshold with calculated days from arrival to the lower American River until spawning (based on fall-run Chinook salmon pre-spawning and spawning temporal distributions); (6) replace interpolated lifestage-specific mortality values with continuous mortality equations; and (7) change the ATUs associated with the end of the fertilized-egg and pre-emergent fry lifestages. Most of these revisions are justified and discussed in earlier sections of this technical memorandum.

5.4 Summary of Model Updates

After initial review, it was decided that certain aspects of the model needed to be updated. There were eight key updates made to the model:

1.) Correct coding errors as needed.

2.) Convert model from a calendar year format to a spawning year (i.e., 6/1 - 5/30) format.

3.) Convert the model to track individual daily cohorts (revised code provided in Appendix A).

4.) Expand from 9 reaches to 18 reaches and update spatial spawning distribution.

5.) Update temporal arrival distribution from weekly values starting in September to daily arrivals starting in June.

6.) Replace 60°F spawning initiation threshold with a specified days till spawning independent of water temperature.

7.) Replace interpolated life-stage mortality values with continuous mortality equations.

8.) Change life-stage accumulated temperature unit (ATU) values.

6.0 Effect of Model Refinements

The effect of the various model refinements upon predicted mortalities for each lifestage were evaluated with a progressive sensitivity analysis. Refinements were implemented stepwise, one piece at a time, where each refinement built upon the earlier refinements. The evaluation was carried out over 15 spawning years. To provide input data for the evaluation of the model refinements, mean daily water temperatures for each of 18 reaches were computed using the HEC-RAS water quality model for the lower American River developed for the Water Forum.

6.1 Water Temperature Modeling

The lower American River HEC-RAS water quality model was used to simulate water temperature in each of the 18 reaches for the period of record where input data were available (i.e., June 1999 – May 2014). River flow (i.e., Nimbus Dam release), upstream water temperature, diversions, and downstream stage data at the confluence with the Sacramento River were acquired from CDEC, USGS, Carmichael Water District, and the City of Sacramento. Meteorological conditions were acquired from CIMIS gage #131 in Fair Oaks.

The HEC-RAS model was executed with a sub-hourly time step and the results averaged to produce mean daily water temperatures. Water temperatures were extracted from river segments that spanned the half river-miles (i.e., RM 5.5, RM 6.5,…, RM 21.5, RM 22.5) and were used to represent water temperatures in the 18 reaches of the Mortality Model. The locations of the half river miles used are based upon the river mile locations specified by the USGS.

6.2 Progressive Model Sensitivity Analysis

The following components were progressively implemented (i.e., in a stepwise manner) in the order listed to demonstrate the effects of each major refinement on the final results:

1.) Correct coding errors, include daily cohort tracking, and increase the number of reaches to 18

2.) Use average daily water temperatures

3.) Update adult arrival temporal distribution, implement number of days until spawning and remove 60°F spawning threshold

4.) Add new pre-spawn mortality rate equation

5.) Add new egg mortality rate equation

6.) Add new fry mortality rate equation

7.) Use new egg ATU threshold

8.) Use new fry ATU threshold yielding the New Model

Each sensitivity item on the list includes the updates from all previous items. For example, the results for Adjustment 4 (adding the new pre-spawn mortality rate equation) included the model updates listed in Adjustments 1, 2, and 3.

6.3 Progressive Sensitivity Analysis Results

Total annual mortalities for each lifestage (i.e., pre-spawn, egg, and pre-emergent fry) are the primary output of the LAR Chinook Salmon Early Lifestage Mortality Model. Annual mortalities of each lifestage were averaged across the 15 years simulated to demonstrate the effect each revision had on the model results (**Table 16** and **Figure 23**). The new model showed an 11.49% decrease in total average annual mortality compared to the FORTRAN model. The difference results from a large decrease in pre-spawn losses and a smaller increase in egg losses.

The progressive sensitivity analysis showed that Adjustments 1 through 5 had the largest impacts on model results. Adjustment 1 resulted in increased average mortalities, mostly in the pre-spawn lifestage, due largely to the corrected calculation of the pre-spawn and spawning temporal distributions, as described earlier. Adjustment 2, the utilization of average daily water temperatures, also showed an increase in mortalities, mostly due to increased egg mortality. Daily averaged water temperatures had individual days with water temperatures in excess of the monthly interpolated averages where the population experienced higher mortality rates.

Adjustment 3, updated arrival distribution with days until spawning and removal of the 60°F spawning threshold, showed a dramatic increase in pre-spawn mortalities due to significantly earlier arrivals (June 1 vs. September 1) and longer adult holding times. Additionally, without the 60°F spawning threshold, spawning generally occurred earlier in the season when water temperatures were higher. Earlier spawning in turn led to an increase in egg mortalities as well as this lifestage was generally present earlier in the season and subject to higher water temperatures.

Adjustment 4, incorporation of the new pre-spawn mortality rate equation, led to a very large reduction in pre-spawn mortalities compared to the results of Adjustment 3. New pre-spawn mortality rates essentially eliminated pre-spawn losses for water temperatures less than 67.5°F. In many years (12 of the 15 used in the sensitivity analysis), water temperatures rarely exceeded 67.5°F during adult holding periods and pre-spawn losses were therefore negligible. Decreased pre-spawn mortality resulted in a larger egg population (i.e., fewer pre-spawn losses left a larger number of fertilized eggs). A larger egg population, that was present earlier in the season when temperatures were warmer, led to a large increase in egg mortalities.

Adjustment 5, incorporation of the new egg mortality equation, led to a large decrease in egg mortality when compared to the results of Adjustment 4. For water temperatures between 58°F and 66°F, the new egg mortality rates were up to 35% lower than the mortality rates in the FORTRAN model. This decrease in mortality rates is why there was a decrease in average egg mortality from Adjustment 4 to 5. Conversely, Adjustment 5 has more egg mortality than the FORTRAN model, due to the elimination of the 60°F spawning threshold and decreased pre-spawn losses. These differences resulted in earlier spawning in larger quantities, which led to an increase in egg mortality over the FORTRAN model. Although there was a very small increase in fry mortalities, generally, the model showed very low sensitivity to Adjustments 6 through 8.

In addition to total mortality and mortality for each lifestage, the model provides cumulative daily survival plots for each lifestage as well as for the timing of spawning. Three representative spawning years were selected to demonstrate the differences in predictions between the FORTRAN model and the new model. The three years serve to represent an average mortality year (2004-2005, **Figure 24**), a low mortality year (2011-2012, **Figure 25**), and a high mortality year (2001-2002, **Figure 26**). Daily average water temperatures for both the FORTRAN model and the new model are provided as grey lines in all plots. The FORTRAN interpolated, monthly average temperatures were reasonably correlated with the new model's daily average water temperatures from June until December 15. After December 15, the FORTRAN model's interpolation issues and calendar year framework caused the interpolated, average water temperatures to diverge from the intended values.

The new model's tendency to have lower pre-spawn mortalities is apparent in the top-left plot (blue lines in **Figure 24, Figure 25** and **Figure 26**). Even in high mortality years (2001-2002) the new model's pre-spawn cumulative survival was markedly higher than the FORTRAN model (new – 88% vs. FORTRAN – 67%). A sharp increase at the front end of the FORTRAN model's spawning distribution in the top-right plots was caused by the 60°F spawning threshold. Egg mortality can be interpreted by differencing the final value of the green line in the bottom-left plot with the final value of the blue line in the top-left plot. The difference for the new model (dashed line) is greater than the difference of the FORTRAN model (solid line). The model's insensitivity to fry mortality rates (i.e., the survival rate for the fry lifestage is roughly equal to the survival rate for the egg lifestage) was due primarily to cold water temperatures and was apparent when comparing the final egg survival (green line in the bottom-left plot) with the fry survival (purple line in the bottom-right plot).

Overall, low and average mortality years saw an increase in survival (i.e., a decrease in mortality) with the new model compared to the FORTRAN model. High mortality years, on the other hand, saw a decrease in survival with the new model compared to the FORTRAN model. These differences were due in part to how the new pre-spawn mortality rate equation behaved at low and high temperatures in addition to increased egg mortalities. At lower water temperatures, the new pre-spawn mortality equation is relatively insensitive. Water temperatures in critical reaches (i.e., the reaches where a majority of the spawning is predicted) in most years were below the 67.5°F threshold, yielding virtually no mortality for the pre-spawn lifestage. Alternatively, in years with high water temperatures, the new pre-spawn mortality rate is higher than the original pre-spawn mortality rate and therefore higher pre-spawn losses were predicted. This tendency of the new pre-spawn mortality equation means that only in years with high water temperatures will pre-spawn mortality be noticeable. Moderate pre-spawn losses and increased egg losses in high water temperature years combined and led to total annual mortalities in excess of FORTRAN model predictions.

Table 17. Progressive sensitivity analysis results - average annual mortality for each lifestage, total, and difference from original FORTRAN model.

Adjustment Number	Model Adjustment	Average Annual Mortality				
		Pre-Spawn	Egg	Fry	Total	Difference from FORTRAN Model
-	**Original FORTRAN Model**	20.41%	3.33%	0.00%	**23.74%**	-
1	Correct coding errors, daily cohort tracking, increase to 18 reaches	23.34%	3.37%	0.00%	**26.71%**	2.97%
2	Use average daily water temperatures	24.09%	7.25%	0.01%	**31.34%**	7.61%
3	Update arrival distribution and used new days till spawning metric	38.87%	11.89%	0.00%	**50.76%**	27.02%
4	Add new pre-spawn mortality rate equation	1.34%	33.13%	0.00%	**34.47%**	10.73%
5	Add new egg mortality rate equation	1.34%	10.41%	0.04%	**11.79%**	-11.95%
6	Add new fry mortality rate equation	1.34%	10.41%	0.71%	**12.46%**	-11.28%
7	Use new egg ATU threshold	1.34%	10.60%	0.31%	**12.25%**	-11.49%
8	Use new fry ATU threshold - **New Model**	1.34%	10.60%	0.30%	**12.25%**	-11.49%

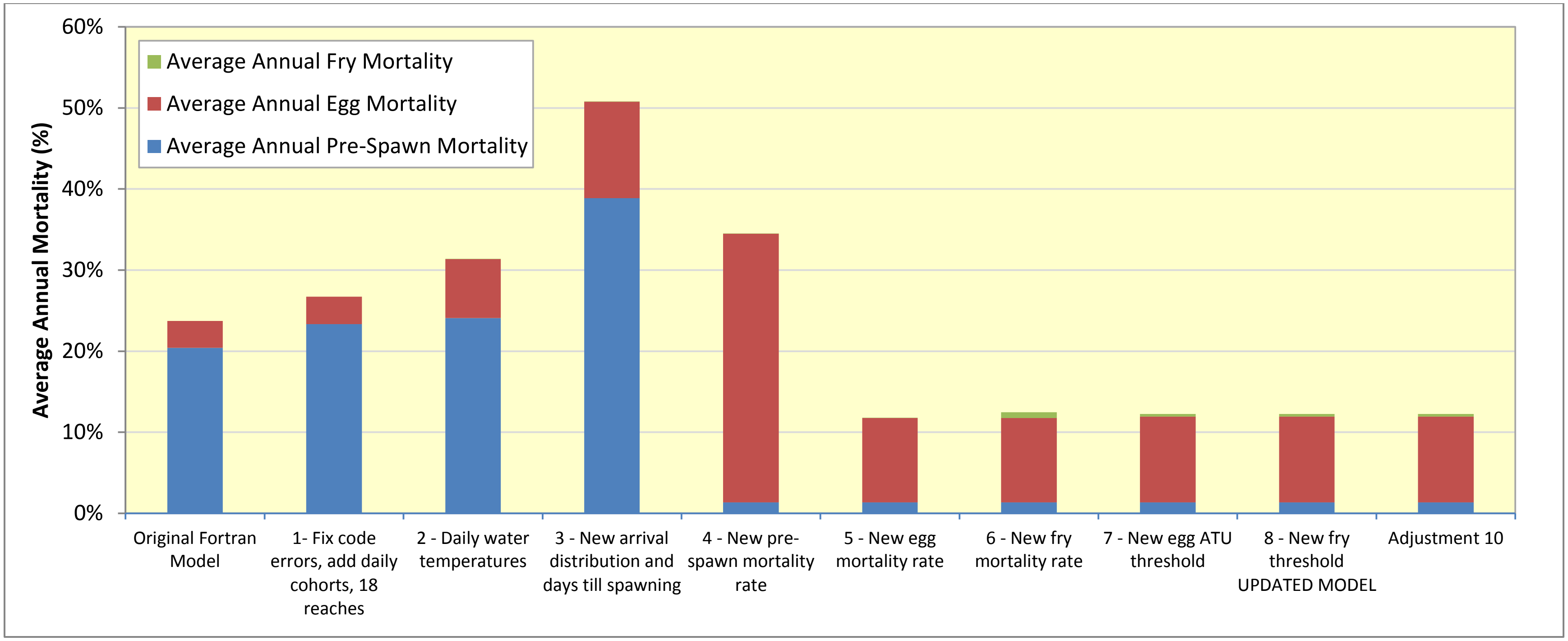

Figure 23. Plot of progressive sensitivity results showing total average annual mortality for each model adjustment.

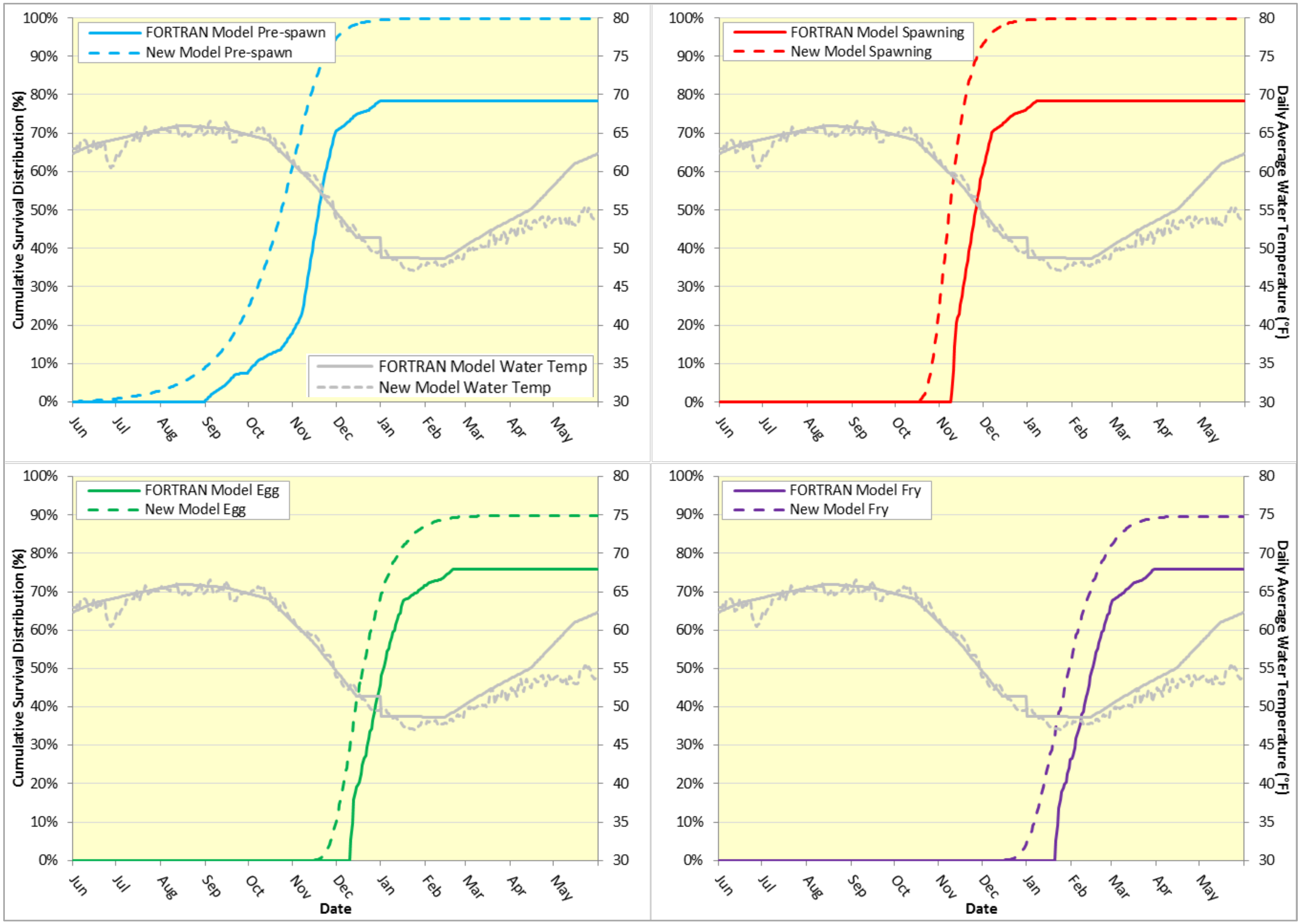

Figure 24. Total annual mortality for an average mortality year (spawning year 2004-2005) – Total Mortality: FORTRAN Model = 24.2%, New Model = 10.4%.

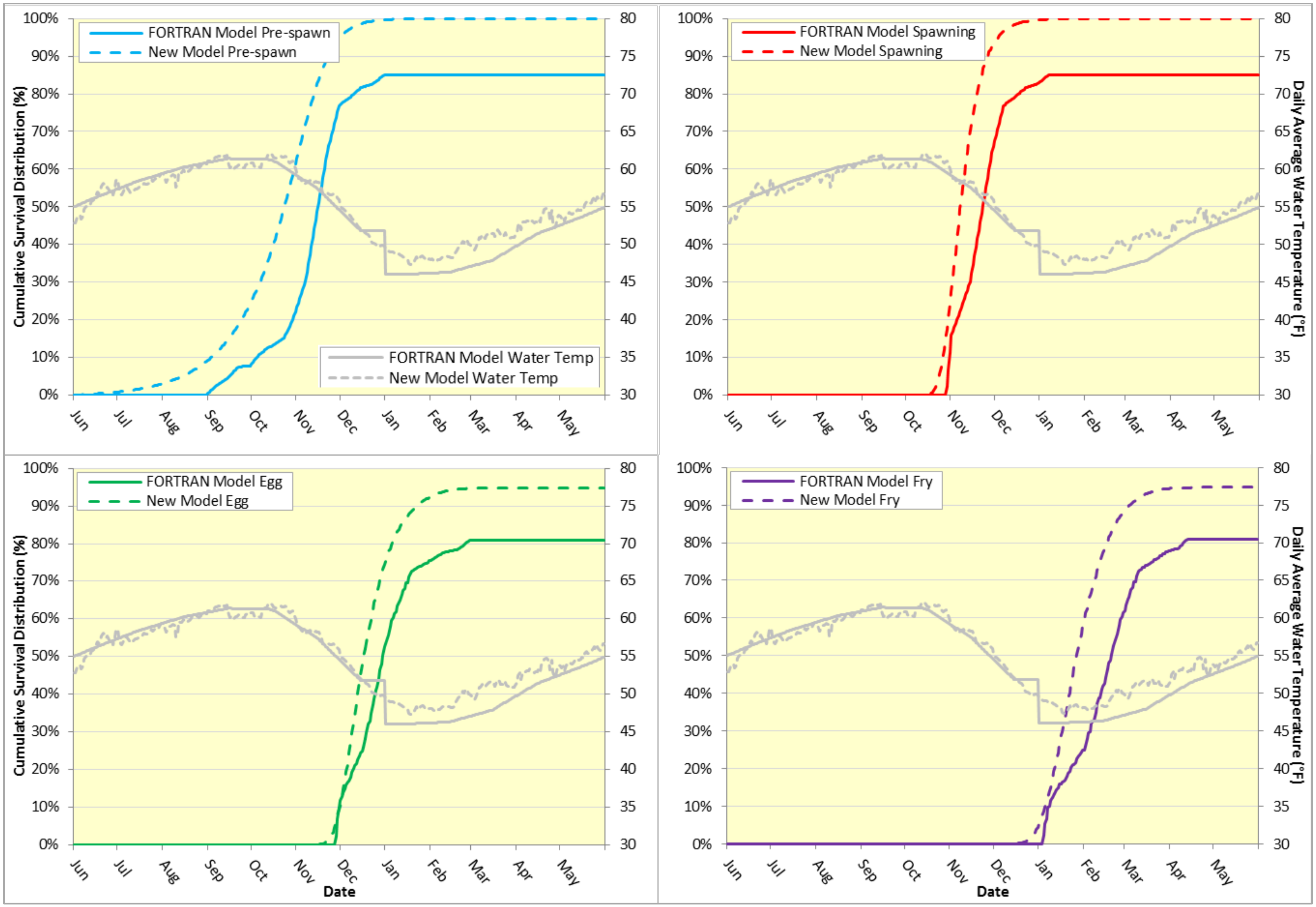

Figure 25. Total annual mortality for a low mortality year (spawning year 2011-2012) – Total Mortality: FORTRAN Model = 19.0%, New Model = 5.3%.

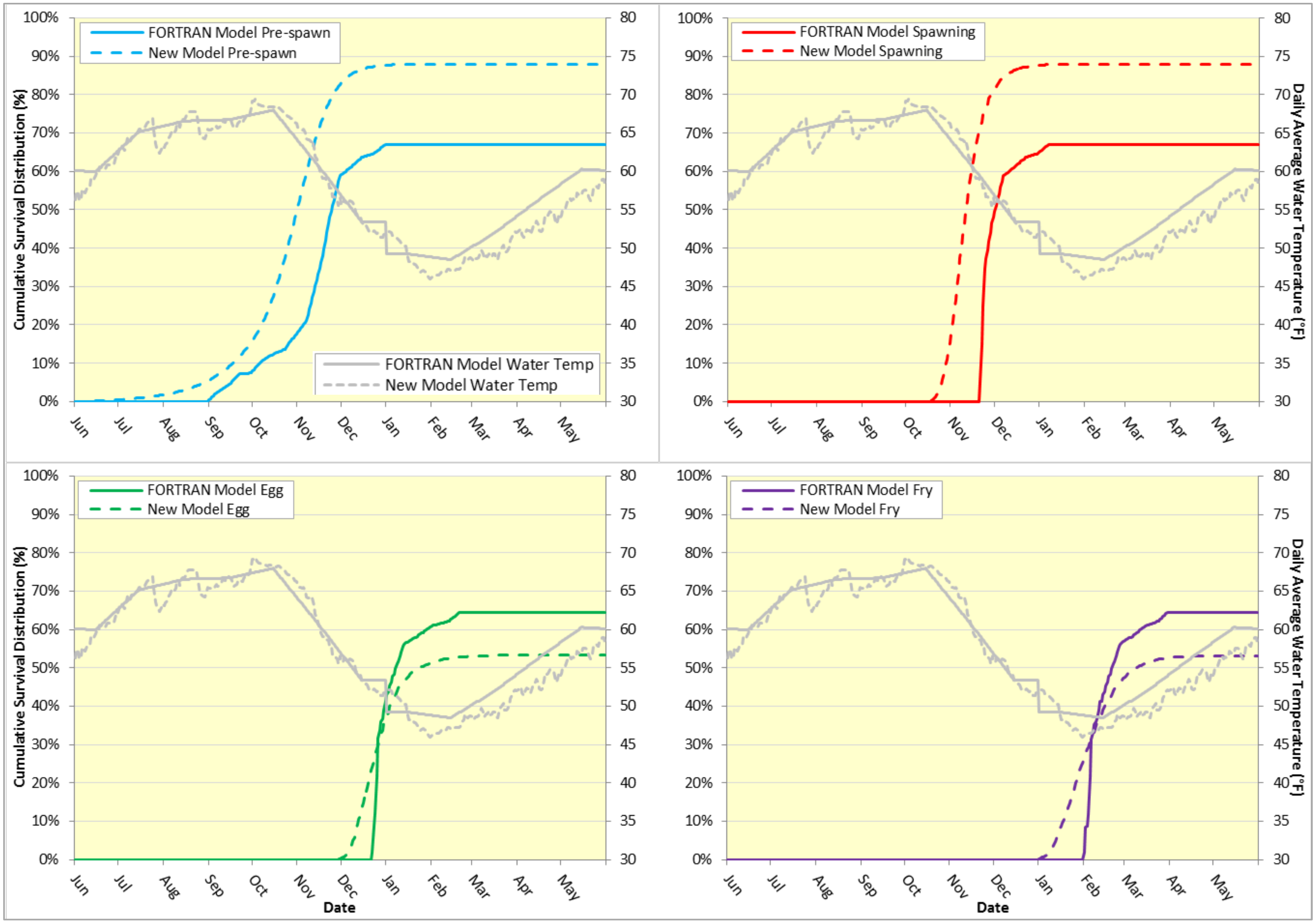

Figure 26. Total annual mortality for a high mortality year (spawning year 2001-2002) – Total Mortality: FORTRAN Model = 35.6%, New Model = 46.9%.

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APPENDIX A

REVISED MORTALITY MODEL VBA CODE

```
Sub RunMortality()

'prespawn and spawn variables

    Dim i As Long

    Dim J As Long

    Dim PreSpwnStartDay(1 To 82) As Integer

    Dim PreSpwnEndDay(1 To 82) As Integer

    Dim SpwnStartDay(1 To 82) As Integer

    Dim SpwnEndDay(1 To 82) As Integer

    Dim PreSpwnDist(2 To 34000, 19) As Double

    Dim PreSpwnMort(2 To 34000, 18) As Double

    Dim PreSpwnMortC(2 To 34000, 18) As Double

    Dim PreSpwnMortCumul(2 To 34000, 19) As Double

    Dim PreSpwnMortTime(2 To 34000, 19) As Double

    Dim SpwnDist(2 To 34000, 19) As Double

    Dim spwnday(2 To 34000) As Double



'egg variables

    Dim EggMort(2 To 34000, 18) As Double

    Dim EggMortC(2 To 34000, 18) As Double

    Dim EggMortCumul(2 To 34000, 19) As Double

    Dim EggMortTime(2 To 34000, 19) As Double

    Dim EggDist(2 To 34000, 18, 2) As Double

    Dim EggDistCumul(2 To 34000, 19) As Double

    Dim DegDay(2 To 34000) As Double

    Dim TemperatureF(2 To 34000, 18) As Double

    Dim Eggstart(2 To 34000) As Long

    Dim Eggend(2 To 34000) As Long


'fry variables

    Dim FryMort(2 To 34000, 18) As Double

    Dim FryMortC(2 To 34000, 18) As Double

    Dim FryMortCumul(2 To 34000, 19) As Double

    Dim FryMortTime(2 To 34000, 19) As Double

    Dim FryDist(2 To 34000, 18, 2) As Double

    Dim FryDistCumul(2 To 34000, 19) As Double

    Dim DegDayf(2 To 34000) As Double


'temporary variable

    Dim TempVar As Double

'    Dim TempVar2(2 To 34000, 18) As Double
```

```
'reach variables
   Dim Rch As Integer
   Dim Rchs As Integer
   Dim RchPerct(1 To 18) As Double
   Dim RchFlag As Integer

'year variables
   Dim Yr As Integer
   Dim FirstYr As Integer

'prespawn and spawn settings
   PreSpwnStartDay(1) = 79
   PreSpwnEndDay(1) = 288 '444
   SpwnStartDay(1) = 233
   SpwnEndDay(1) = 295

'egg settings
   EggDegDayConst = 931

'fry settings
   FDegDayconst = 686

'reach setting
   Rchs = 18
   RchFlag = 1     '1 turns the reach weighting on and zero turns it off

'*********************************************
'        Set Calculation and Updating off
'*********************************************
Application.Calculation = xlCalculationManual
Application.ScreenUpdating = False
'*********************************************
'       Set prespawning and spawning start and end dates (rows)
'*********************************************
Application.StatusBar = "Set prespawn and spawn start and end dates"
'Sheets("StartEndDays").Select
For i = 1 To 81
   PreSpwnStartDay(i) = Sheets("StartEndDays").Cells(i + 2, 9).Value
   PreSpwnEndDay(i) = Sheets("StartEndDays").Cells(i + 2, 10).Value
   SpwnStartDay(i) = Sheets("StartEndDays").Cells(i + 2, 11).Value
   SpwnEndDay(i) = Sheets("StartEndDays").Cells(i + 2, 12).Value
Next
```

```
For Rch = 1 To Rchs
   RchPerct(Rch) = Sheets("StartEndDays").Cells(Rch + 9, 3).Value
Next

'*********************************************
'       Read in the Data
'*********************************************
Application.StatusBar = "reading data"
'Sheets("Fishdata").Select

For Yr = 1 To 81
     FirstYr = (PreSpwnStartDay(Yr) - PreSpwnStartDay(1))
   If Yr = 1 Then
     For i = PreSpwnStartDay(1) To PreSpwnEndDay(1)
       spwnday(i) = Sheets("Fishdata").Cells(i, 6).Value
       PreSpwnDist(i, 0) = Sheets("Fishdata").Cells(i, 3).Value
     Next
   Else
     For i = PreSpwnStartDay(Yr) To PreSpwnEndDay(Yr)
       spwnday(i) = spwnday(i - FirstYr) + FirstYr
       PreSpwnDist(i, 0) = PreSpwnDist(i - FirstYr, 0)
     Next
   End If
Next

For Rch = 1 To Rchs
   For i = 2 To 34000
      PreSpwnDist(i, Rch) = PreSpwnDist(i, 0)
   Next
Next

Sheets("WaterTemperature").Select
For Rch = 1 To Rchs
  For i = 2 To 34000
   TemperatureF(i, Rch) = Cells(i + 25, Rch + 1).Value
   PreSpwnMort(i, Rch) = (1 - 0.5 ^ (1440 / (Exp(21.802 - 0.5746 * (TemperatureF(i, Rch) - 32) / 1.8))))
   EggMort(i, Rch) = 1.404 * (10 ^ -10) * Exp(0.31584 * TemperatureF(i, Rch))
   FryMort(i, Rch) = 6.688 * (10 ^ -17) * Exp(0.56446 * TemperatureF(i, Rch))
  Next
Next
```

```
'*************************************************
'Reach Loop Calculation
'*************************************************
For Rch = 1 To Rchs

    '*********************************************
    '        Adjust Pre Spawning Mortality
    '*********************************************
    Application.StatusBar = "Adjusting PreSpawn Mortality"

    For Yr = 1 To 81
     For J = PreSpwnStartDay(Yr) To PreSpwnEndDay(Yr)                              'Loop through PreSpawn Temporal Distribution
        For i = J To PreSpwnStartDay(Yr) Step -1                                   'Step back through to calculate mortality on fish already in the river
            If (spwnday(i) >= J) Then                                              'Only calculate mortality on fish that have not already spawned
              TempVar = PreSpwnDist(i, Rch) * PreSpwnMort(J, Rch)
              If TempVar > PreSpwnDist(i, Rch) Then TempVar = PreSpwnDist(i, Rch)
              PreSpwnDist(i, Rch) = PreSpwnDist(i, Rch) - TempVar
              PreSpwnMortCumul(i, Rch) = PreSpwnMortCumul(i, Rch) + TempVar
              PreSpwnMortTime(J, Rch) = PreSpwnMortTime(J, Rch) + TempVar
                'Range("l" & i).Value = PreSpwnDist(i)
            End If
        Next
     Next
    Next

    '*********************************************
    '        Calculate the Spawning Distribution
    '*********************************************
    Application.StatusBar = "Calculating the Spawning Distribution"

    For Yr = 1 To 81
     For J = SpwnStartDay(Yr) To SpwnEndDay(Yr)                                    'Loop through Spawning Temporal Distribution
        For i = J To PreSpwnStartDay(Yr) Step -1                                   'Step back through PreSpawn Fish to accumulate the number of fish that will spawn on each day
          If (spwnday(i) = J) Then                                                 'Only accumulate spawning for day J
            SpwnDist(J, Rch) = SpwnDist(J, Rch) + PreSpwnDist(i, Rch)
            'Range("m" & J).Value = SpwnDist(J)
          End If
        Next
     Next
    Next

    '**********************************************
```

```
'         Calculate the Egg and Fry Distributions
'*********************************************
For Yr = 1 To 81
   Application.StatusBar = "Calculating the Egg and Fry Distributions " & Yr
 For J = SpwnStartDay(Yr) To SpwnEndDay(Yr)                                   'Track Spawning Cohorts through egg and fry emergence
   EggDist(J, Rch, 1) = SpwnDist(J, Rch)                                     'Transfer Spawning Distribution (after mortality) to Egg Distribution
   i = J                                                                     'Increment Counter to start on day J (spawning cohort j)
   DegDay(J) = TemperatureF(J, Rch) - 32#                                    'Initiate Degree Day calculation

   '******************************************
   '       Egg Distribution
   '******************************************
   Do While DegDay(J) < EggDegDayConst                                       'For each egg cohort loop through each day until the day before hatching
      TempVar = EggDist(J, Rch, 1) * EggMort(i, Rch)
      If TempVar > EggDist(J, Rch, 1) Then TempVar = EggDist(J, Rch, 1)         'If the egg distribution goes negative set to "zero"
      EggDist(J, Rch, 1) = EggDist(J, Rch, 1) - TempVar                      'Adjust the egg distribution for cohort j based on daily temperature mortality
      EggMortC(J, Rch) = EggMortC(J, Rch) + TempVar

      EggMortTime(i, Rch) = EggMortTime(i, Rch) + TempVar

      i = i + 1                                                              'Increment the counter for the next day
      DegDay(J) = DegDay(J) + TemperatureF(i, Rch) - 32#                     'Accumulate degree days for the next day
   Loop

      EggDist(J, Rch, 2) = i - 1                                             'Track the day for the last day of egg cohort j
      EggDistCumul(i - 1, Rch) = EggDistCumul(i - 1, Rch) + EggDist(J, Rch, 1)    'Accumulate egg distributions the final day before hatching
      EggMortCumul(i - 1, Rch) = EggMortCumul(i - 1, Rch) + EggMortC(J, Rch)

   '******************************************
   '        Fry Distribution
   '******************************************
   FryDist(J, Rch, 1) = EggDist(J, Rch, 1)                                   'Start the fry distribution

   Do While DegDay(J) < (EggDegDayConst + FDegDayconst)                      'For each egg cohort loop through each day until the day before fry emergence
      TempVar = FryDist(J, Rch, 1) * FryMort(i, Rch)
      If TempVar > FryDist(J, Rch, 1) Then TempVar = FryDist(J, Rch, 1)         'If the fry distribution goes negative set to "zero"
      FryDist(J, Rch, 1) = FryDist(J, Rch, 1) - TempVar                      'Adjust the fry distribution for cohort j based on daily temperature mortality
      FryMortC(J, Rch) = FryMortC(J, Rch) + TempVar

      FryMortTime(i, Rch) = FryMortTime(i, Rch) + TempVar

      i = i + 1                                                              'Increment the counter for the next day
```

```
        DegDay(J) = DegDay(J) + TemperatureF(i, Rch) - 32#                    'Accumulate degree days for the next day
      Loop

        FryDist(J, Rch, 2) = i - 1                                'Track the day for the last day of fry cohort j
        FryDistCumul(i - 1, Rch) = FryDistCumul(i - 1, Rch) + FryDist(J, Rch, 1)    'Accumulate egg distributions the final day before emergence
        FryMortCumul(i - 1, Rch) = FryMortCumul(i - 1, Rch) + FryMortC(J, Rch)

    Next
   Next

Next

'**********************************************
'    Write Out Data With (flag =1) or Without (flag = 0) Reach Weighting
'**********************************************

For Rch = 1 To 18
 If RchFlag <> 1 Then RchPerct(Rch) = 1#

 For i = 2 To 34000
   PreSpwnDist(i, Rch) = PreSpwnDist(i, Rch) * RchPerct(Rch)
    PreSpwnDist(i, 19) = PreSpwnDist(i, 19) + PreSpwnDist(i, Rch)

   SpwnDist(i, Rch) = SpwnDist(i, Rch) * RchPerct(Rch)
    SpwnDist(i, 19) = SpwnDist(i, 19) + SpwnDist(i, Rch)

   EggDistCumul(i, Rch) = EggDistCumul(i, Rch) * RchPerct(Rch)
    EggDistCumul(i, 19) = EggDistCumul(i, 19) + EggDistCumul(i, Rch)

   FryDistCumul(i, Rch) = FryDistCumul(i, Rch) * RchPerct(Rch)
    FryDistCumul(i, 19) = FryDistCumul(i, 19) + FryDistCumul(i, Rch)

   PreSpwnMortCumul(i, Rch) = PreSpwnMortCumul(i, Rch) * RchPerct(Rch)
    PreSpwnMortCumul(i, 19) = PreSpwnMortCumul(i, 19) + PreSpwnMortCumul(i, Rch)

   PreSpwnMortTime(i, Rch) = PreSpwnMortTime(i, Rch) * RchPerct(Rch)
    PreSpwnMortTime(i, 19) = PreSpwnMortTime(i, 19) + PreSpwnMortTime(i, Rch)

   EggMortCumul(i, Rch) = EggMortCumul(i, Rch) * RchPerct(Rch)
    EggMortCumul(i, 19) = EggMortCumul(i, 19) + EggMortCumul(i, Rch)

   EggMortTime(i, Rch) = EggMortTime(i, Rch) * RchPerct(Rch)
```

```
      EggMortTime(i, 19) = EggMortTime(i, 19) + EggMortTime(i, Rch)

    FryMortCumul(i, Rch) = FryMortCumul(i, Rch) * RchPerct(Rch)
      FryMortCumul(i, 19) = FryMortCumul(i, 19) + FryMortCumul(i, Rch)

    FryMortTime(i, Rch) = FryMortTime(i, Rch) * RchPerct(Rch)
      FryMortTime(i, 19) = FryMortTime(i, 19) + FryMortTime(i, Rch)

  Next
Next

'Sheets("PreSpwnDist").Select
Sheets("PreSpwnDist").Range("b2:u34000").Value = PreSpwnDist
'Sheets("SpwnDist").Select
Sheets("SpwnDist").Range("b2:u34000").Value = SpwnDist
'Sheets("EggDist").Select
Sheets("EggDist").Range("b2:u34000").Value = EggDistCumul
'Sheets("FryDist").Select
Sheets("FryDist").Range("b2:u34000").Value = FryDistCumul
'Sheets("PreSpwnMort").Select
Sheets("PreSpwnMort").Range("b2:u34000").Value = PreSpwnMortCumul
'Sheets("PreSpwnMortTime").Select
Sheets("PreSpwnMortTime").Range("b2:u34000").Value = PreSpwnMortTime
'Sheets("EggMort").Select
Sheets("EggMort").Range("b2:u34000").Value = EggMortCumul
'Sheets("EggMortTime").Select
Sheets("EggMortTime").Range("b2:u34000").Value = EggMortTime
'Sheets("FryMort").Select
Sheets("FryMort").Range("b2:u34000").Value = FryMortCumul
'Sheets("FryMortTIme").Select
Sheets("FryMortTIme").Range("b2:u34000").Value = FryMortTime
Sheets("PS_Mort_Rate").Range("b2:t34000").Value = PreSpwnMort
Sheets("Egg_Mort_Rate").Range("b2:t34000").Value = EggMort
Sheets("Fry_Mort_Rate").Range("b2:t34000").Value = FryMort
'temp write out for testing
'Sheets("junktest").Select
'Range("b2:t34000").Value = TempVar2
Sheets("Model Results").Select
Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic
Application.StatusBar = "Model Execution Complete"
End Sub
```