APPENDIX G-AQUA2
AQUATIC RESOURCES
METHODOLOGY

Appendix G-AQUA2 describes the processes and bases used to evaluate the No-Action Alternative, the Proposed Action, and Alternative 2 and their potential effects on aquatic and fisheries resources. Implementation of any of the alternatives is anticipated to produce two distinct types of effects: (1) direct effects related to construction activities or changes in Oroville Facilities operations; and (2) indirect effects related to changes in hydrologic conditions. The potential effects related to changes in hydrologic conditions may affect environmental resources beyond the project study area and are addressed under the cumulative analysis (see Section 5.7.4, Cumulative Effects).

Both quantitative and qualitative assessments were completed to evaluate potential effects on aquatic resources. Qualitative analyses were conducted based on a combination of literature reviews, study plan results, and the best professional judgment and experience of qualified individuals. These qualitative analyses examined potential effects associated with all of the following:

- Fish interactions (e.g., competition for food or habitat, genetic introgression, predation);
- Fisheries resources management (stocking program and disease management); and
- Potential effects on Chinook salmon spawning segregation, macroinvertebrate populations, woody debris distribution, gravel recruitment, and water quality criteria for aquatic life in relationship to aquatic resources and habitat quality.

Hydrologic and water temperature modeling was performed to provide a quantitative basis from which to assess potential effects of the alternatives on fisheries resources and aquatic habitats within the project study area.

G-AQUA2.1 HYDROLOGIC MODEL SUMMARY

Extensive hydrologic and water temperature modeling was performed to provide a quantitative basis from which to assess potential effects of each alternative on fisheries resources and aquatic habitats within the project study area. Model outputs of project operations used in the quantitative analyses of effects on aquatics and fisheries resources included reservoir water surface elevation, lower Feather River flows, and lower Feather River water temperatures. Appendix C, Modeling Tools and Results, provides a detailed discussion of the hydrologic modeling process and its application to the Oroville Facilities project analysis, including: (1) the primary assumptions and model inputs used to represent hydrologic, regulatory, structural, and operational conditions; and (2) the simulations performed from which effects were estimated.

The models used in this analysis (CALSIM II, HYDROPS™, WQRSS, and other water temperature models) have been developed for comparative planning purposes, rather than for predicting actual river and reservoir conditions at specific locations and times. Although mathematically precise, these models should be viewed as having "reasonable detection limits." Establishing reasonable detection limits is useful when analyzing the modeling output for effect assessment purposes. Additionally, interpreting model output in terms of reasonable detection limits prevents making effect determinations beyond the model's capabilities and its ability to measure changes.

Data from the models are reported to the nearest thousand acre-feet (taf) and feet in elevation above mean sea level (msl) for reservoir conditions, cubic feet per second (cfs) for instream flow, and tenths of degrees Fahrenheit (°F) for river temperatures; however, these values were rounded to the nearest reasonable value when interpreting differences for a given parameter between two modeling simulations. For example, 2 simulations having instream flows at a given location within 1 percent of each other were considered to be essentially equivalent. Differences in reservoir storage were evaluated similarly. Modeled output was similarly rounded for all output parameters to ensure that the effect assessments would be reasonable.

The methodologies used to predict comparative operational scenarios under the No-Action Alternative, the Proposed Action, and Alternative 2 are included below, along with the bases for comparison. Methods for quantitatively determining potential effects on aquatic resources related to potential changes in reservoir storage, reservoir water surface elevations, river flows, and river water temperatures are presented in Section G-AQUA2.2. Section G-AQUA2.3 describes the qualitative methods used to determine potential effects on habitat components; this description is followed by species-specific discussions for lower Feather River fish species of primary management concern (Section G-AQUA2.4). Methodology describing the synthesis of results of the analyses to identify potential effects on individual fish species is discussed in Section G-AQUA2.5, Determination of Effects.

G-AQUA2.2 QUANTITATIVE EVALUATION USING MODEL OUTPUTS

The model outputs provide a basis for comparison of the No-Action Alternative, the Proposed Action, and Alternative 2. They allow identification of the types of changes that could be expected to occur with implementation of a specified set of operational conditions. Reservoir storage, river flow and stage elevation, and water temperature output for the period modeled should not be interpreted or used as definitive absolutes depicting actual river and reservoir conditions in the future. Rather, model outputs for each alternative can be used as a basis of comparison to determine:

- Whether reservoir storage or river flows and water temperatures would be expected to change with implementation of each alternative;

- During what time periods there could be changes to reservoir storage, reservoir surface elevation, river flow, and water temperature; and

- Approximately how large, how lengthy, and how frequent such changes could be with implementation of each alternative.

Modeling output provided hourly values for each year of the hydrologic simulation period modeled for reservoir storage and water surface elevation, river flows, and water temperatures. Daily mean values of these model outputs were used as the basis of comparison for the aquatic resource assessments associated with each alternative.

Modeling results were evaluated quantitatively against criteria that are indicators of biological effects associated with changes in Oroville Facilities operations, including changes in reservoir surface elevations, lower Feather River flows, and lower Feather River water temperatures. These evaluation criteria were developed for each species of primary management concern and were based on review of available literature and study plan results. Evaluation criteria used in the analysis are described in detail in Section G-AQUA2.2.1, Operations-related Effects on Reservoir Fish Species; Section G-AQUA2.2.2, Flow-related Effects on Lower Feather River Fish Habitat; and Section G-AQUA2.2.3, Water Temperature–related Effects on Lower Feather River Fish Habitat, of this appendix.

G-AQUA2.2.1 Operations-related Effects on Reservoir Fish Species

Implementation of the No-Action Alternative, the Proposed Action, or Alternative 2 could result in alterations to storage volumes and water surface elevations within Oroville Facilities reservoirs. Day-to-day operations and changes in runoff patterns could result in changes in the timing and magnitude of reservoir drawdown. The resulting fluctuation of the reservoirs could potentially affect recreationally important reservoir fish species of primary management concern. Methods used to determine potential effects on reservoir fish species within Lake Oroville and other project reservoirs are discussed below.

The analysis of aquatic biological resources focuses on how reductions and fluctuations in the coldwater pools and water surfaces of Oroville Facilities reservoirs could affect coldwater and warmwater fish habitat and aquatic resources. For example, the seasonal timing and rate of reductions in reservoir water surface elevation during the black bass spawning period determines the proportion of bass nests that potentially could be dewatered. Bass populations reportedly require approximately 60 percent nest success to remain self-sustaining (Friesen 1998; Goff 1996; Hunt and Annett 2002; Hurley 1975; Knotek and Orth 1998; Kramer and Smith 1962; Latta 1956 in Steinhart 2004; Lukas and Orth 1995; Neves 1975; Philipp et al. 1997; Raffetto et al. 1990; Steinhart 2004; Turner and MacCrimmon 1970). Reservoir coldwater pool volume is affected by project releases and coldwater pool is required for coldwater fish habitat. Changes in the proportion of available coldwater pool volume are an indicator of the potential changes in the amount of available coldwater fish habitat.

Extensive sediment deposits, or sediment wedges, were identified in all four major tributaries of the Feather River at approximately 720 feet msl and below during field investigations conducted during October and December 2002. Sediment wedges are subject to periodic exposure events when the reservoir surface elevation drops below the elevations at which the wedges occur. Such exposure events may inhibit or prohibit the movement of fish from the reservoir to tributaries upstream of Lake Oroville.

Currently, the upper Feather River watershed is reportedly producing high sediment loads because of accelerated erosion. The Natural Resources Conservation Service's East Branch North Fork Feather River Erosion Inventory Report estimated that 90 percent of the erosion in the 1,209-square-mile study area was accelerated erosion (NRCS 1998). Accelerated erosion is a soil loss greater than natural geologic conditions, which can reduce reservoir capacity, degrade water quality, and harm fish and wildlife.

The presence or absence of exposed sediment wedges is a potentially important factor to be considered in the analysis of project operations on aquatic resources. If sediment wedges are exposed during large portions of the upstream migration periods of spring-run Chinook salmon, fall-run Chinook salmon, or steelhead, access to upstream spawning habitat could be affected substantially. In contrast, if the sediment wedges are not exposed for large portions of the migration periods of anadromous salmonids, it is likely that upstream migration would not be affected substantially by sediment wedge exposure. Additionally, the absence of exposed sediment wedges may allow for the undesirable upstream migration of stocked salmonid species or warmwater species currently in Lake Oroville.

As reported in Study Plan Report SP-G1, sediment wedges are dynamic and mobilize differently based on different hydrologic conditions in tributaries and reservoirs. If the reservoir elevation is greater than the uppermost elevation of the wedge, lentic conditions predominate and wedge material does not move appreciably. If the reservoir elevation is lower than the wedge material, fluvial conditions predominate and typical stream processes transport wedge materials downstream. Because of the dynamic nature of the sediment wedges in the upper Feather River/Lake Oroville interface, it is difficult to assess the frequency, magnitude, and duration of sediment wedge exposure over time and its resulting effect on fisheries interactions in the reservoir and upstream tributaries. Further, the ability to determine that an exposed sediment wedge is a potential fish migration barrier depends on a number of conditions that are variable and cannot be reliably predicted. Therefore, a qualitative evaluation of the potential effects of sediment wedge exposure and resulting fish migration conditions was performed for the No-Action Alternative, the Proposed Action, and Alternative 2.

G-AQUA2.2.1.1 Warmwater Reservoir Fish Species of Primary Management Concern

Warmwater fish species present in Lake Oroville (including largemouth bass, smallmouth bass, spotted bass, green sunfish, crappie, and catfish) use the warm upper layer of the reservoir and nearshore littoral habitats throughout most of the year. Therefore, seasonal changes in reservoir storage, as they affect reservoir water surface elevation, and the rates at which the water surface elevation changes during specific periods of the year, can directly affect the reservoir's warmwater fisheries resources. Reduced water surface elevations can potentially reduce the availability of nearshore littoral habitats used by warmwater fish for spawning and rearing, thereby reducing spawning and rearing success and subsequent year-class strength. In addition, decreases in reservoir water surface elevation during the primary spawning period for warmwater fish nest building may result in reduced initial year-class strength as a result of nest "dewatering."

Spawning and Initial Rearing

A two-phased approach was used to assess potential effects of changes in reservoir water surface elevation on warmwater fish in Lake Oroville and Thermalito Afterbay. First, the magnitude of change (feet msl) in reservoir water surface elevation during each month of the primary spawning period for nest-building fish (March through June) was determined for each alternative, then compared to that modeled for the basis of comparison. Review of available literature suggests that, on average, self-sustaining black bass populations in North America experience a rate of nest success (i.e., the nest produces swim-up fry) of 60 percent or more (Friesen 1998; Goff 1996; Hunt and Annett 2002; Hurley 1975; Knotek and Orth 1998; Kramer and Smith 1962; Latta 1956 in Steinhart 2004; Lukas and Orth 1995; Neves 1975; Philipp et al. 1997; Raffetto et al. 1990; Steinhart 2004; Turner and MacCrimmon 1970).

A study by the California Department of Fish and Game (DFG), which examined the relationship between rates of fluctuation in reservoir water surface elevation and nesting success for black bass, suggests that a reduction rate of approximately 6 feet per month or less would result in 60 percent nest success for largemouth bass and smallmouth bass (Lee 1999). Therefore, a decrease in reservoir water surface elevation of 6 feet or more per month was selected as the threshold beyond which spawning success of nest-building, warmwater fish could potentially result in long-term population declines. To evaluate effects on largemouth bass, smallmouth bass, and spotted bass, the number of times that reservoir reductions of 6 feet or more per month could occur under the Proposed Action was compared to the number of occurrences that were modeled.

Criteria for reservoir elevation increases (nest flooding events) have not been developed by DFG. Because of overall reservoir fishery benefits (e.g., an increase in the availability of littoral habitat for warmwater fish rearing), greater reservoir surface elevations that would be associated with rising water levels would offset negative effects caused by nest flooding (Lee 1999). Therefore, the effects on spawning warmwater fishes from increases in reservoir water surface elevations are not addressed for reservoir fisheries. A qualitative assessment of the availability of littoral habitat for juvenile bass rearing was conducted for both Lake Oroville and Thermalito Afterbay. Additionally, a qualitative assessment was conducted of the potential effects of changes in reservoir surface elevations, drawdown rate and timing, and habitat enhancement programs on stocking and fish interactions (competition for food and habitat, genetic introgression, predation, and disease).

G-AQUA2.2.1.2 Coldwater Reservoir Fish Species of Primary Management Concern

During the period when Lake Oroville is thermally stratified (April through November), coldwater fish within the reservoir reside primarily within the reservoir's metalimnion and hypolimnion, where water temperatures remain suitable. Reduced reservoir storage during this period could reduce the reservoir's coldwater pool volume, thereby reducing the quantity of potential habitat available to coldwater fish species. The size of the reservoir coldwater pool generally decreases as reservoir storage decreases, although not always in direct proportion because of the influence of reservoir basin morphometry and management of water temperature releases from the reservoir.

The water temperature criterion used in the analysis of potential effects on coldwater fish habitat is based on the most stringent criteria recommended by the U.S. Environmental Protection Agency (USEPA) for protection of aquatic life and for growth of adult and juvenile salmonids. The criterion chosen was based on the weekly maximum average water temperature because no monthly criterion is recommended by USEPA for protection of aquatic life. USEPA suggests two types of criteria for water temperature for coho salmon:

- Maximum weekly average water temperature for growth of juvenile and adult coho salmon (18 degrees Celsius [°C] or 64.4°F); and

- Maximum weekly average water temperature for survival of juvenile and adult coho salmon (24°C or 75.2°F) (USEPA 2002).

Eighteen degrees Celsius was chosen as the water temperature defining the upper layer of the usable coldwater salmonid habitat, for two reasons: (1) 18°C (64.4°F) was a more protective estimate than the 24°C (75.2°F) water temperature criterion for survival of juvenile and adult coho salmon; and (2) of all the salmonids for which specific criteria are recommended, coho salmon had the most stringent water temperature recommendations. Additionally, coho salmon have recently been stocked in Lake Oroville. For the purpose of this analysis, water with a temperature less than 18°C (64.4°F) was considered usable coldwater salmonid habitat.

Coldwater fish habitat also requires dissolved oxygen (DO) concentrations at or above 6.5 milligrams per liter (mg/L), based on USEPA criteria for sustainable coldwater fisheries, as well as a food base appropriate for coldwater fisheries. No characterizations of DO or food base are available from project modeling results, so the relative proportion of change in the coldwater pool volume was used as an indicator of the potential change in the quantity of coldwater fish habitat.

End-of-month storage modeled for each year of the 72-year period of record under each alternative was compared to end-of-month storage under the basis of comparison for each month of the April-through-November period. Substantial reductions in reservoir storage were considered to result in substantial reductions in coldwater pool volume and, therefore, habitat availability for coldwater fish.

Coldwater pool volume was not modeled for Thermalito Afterbay. The water temperature regime for Thermalito Afterbay is dynamic and is controlled by Oroville Facilities water temperature releases, peaking and pumpback operations, and rates of agricultural diversions and afterbay releases. Sections 5.4.1.2 and 5.4.2.2 provide information relating to the characteristics of coldwater conditions in Thermalito Afterbay.

Therefore, project-related changes were qualitatively assessed for their potential effects on coldwater fish habitat in Thermalito Afterbay.

Additionally, qualitative assessments were conducted of potential changes in reservoir surface elevations, drawdown rate and timing, and effects of habitat enhancement programs on stocking and fish interactions (competition for food, habitat, introgression, predation, and disease).

G-AQUA2.2.2 Flow-related Effects on Lower Feather River Fish Habitat

Changes in flow affect water surface elevations based on site-specific stage discharge relationships in the river. Changes in water surface elevations, in turn, potentially change the suitability of water depth for some species with minimum or maximum water depth requirements, of water depth for inundation of habitat, and of water velocity for some fish species and life stages.

Flows in the Low Flow Channel of the Feather River, which extends from the Fish Barrier Dam to the Thermalito Afterbay Outlet, are governed by a 1983 agreement between the California Department of Water Resources (DWR) and DFG (DWR and DFG 1983). The agreement specifies that DWR "…shall release into the Feather River from the Thermalito Diversion Dam for fishery purposes a flow of 600 cfs…" (DWR and DFG 1983). With implementation of one of the alternatives, flow in this reach of the river could potentially change from the basis of comparison, 600 cfs. Total releases to the lower Feather River below the Thermalito Afterbay Outlet would not change, nor would the minimum flow requirements for the lower Feather River change. As a result of the potential flow changes in the Low Flow Channel and High Flow Channel with implementation of the No-Action Alternative, the Proposed Action, or Alternative 2, both the quantitative and qualitative analyses evaluate the Low Flow Channel and High Flow Channel separately for flow-related effects on aquatic resources. See Chapter 3.0, Proposed Action and Alternatives, for additional information describing flows.

Quantitative analyses were conducted to determine the relationship between flow changes and the quantity and distribution of fish habitat. These analyses were based on site-specific stage-discharge relationships developed to characterize the availability of habitat for the spawning life stage of Chinook salmon and steelhead. See Section G-AQUA2.4.1 and Section G-AQUA2.4.2, respectively, of this appendix for additional information about how Weighted Useable Area (WUA) indices from the Physical Habitat Simulation (PHABSIM) model were used in the effect analyses to evaluate the relationship of flows to availability of spawning habitat for Chinook salmon and steelhead. Quantitative analyses were also conducted to determine the relationship of flow to the availability of spawning and initial rearing habitat for Sacramento splittail (see Section G-AQUA2.4.8 of this appendix).

For each of the alternatives, qualitative analyses of flow changes and their potential effects were conducted for fish species and life stages for which specific, quantified flow-habitat relationships have not been established. Qualitative analyses of flow changes occurring with implementation of the alternatives were conducted to characterize the type of effects expected on the relative quality and quantity of fish habitat for all of the following fish species and life stages:

- American shad adult immigration and spawning;
- Chinook salmon adult immigration and holding;
- Chinook salmon juvenile rearing and downstream movement;
- Steelhead/rainbow trout adult immigration and holding/residence;
- Steelhead/rainbow trout juvenile rearing and downstream movement;
- Steelhead smolt emigration; and
- Striped bass adult spawning.

Flow changes were evaluated qualitatively to determine the relative changes to habitat with respect to water depth, water velocity, and the amount of inundated habitat area compared to the known distribution and relative abundance for each species and life stage evaluated.

G-AQUA2.2.3 Water Temperature–related Effects on Lower Feather River Fish Habitat

The process used to evaluate potential water temperature–related effects on habitat for fish species of primary management concern in the lower Feather River is divided into three steps, each with multiple elements. The first part of this analytical approach was to combine the available information about fish habitat in the lower Feather River with the water temperature distribution information from the model outputs. Based on this information, a comprehensive evaluation was made of the total relative quantity and quality of fish habitat by species and life stage. Finally, the amount of change in fish habitat and aquatic resources with the No-Action Alternative, the Proposed Action, and Alternative 2, was determined, relative to the basis of comparison.

Fish species and life stages evaluated using the water temperature index value process described in the following sections include:

- American shad adult immigration and spawning;
- Black bass spawning;
- Chinook salmon adult immigration and holding;
- Chinook salmon adult spawning and embryo incubation;
- Chinook salmon juvenile rearing and downstream movement;

- Green sturgeon adult immigration;
- Green sturgeon adult spawning and embryo incubation;
- Green sturgeon juvenile rearing;
- Hardhead spawning;
- River lamprey spawning;
- Sacramento splittail spawning;
- Steelhead/rainbow trout adult immigration and holding/residence;
- Steelhead/rainbow trout adult spawning and embryo incubation;
- Steelhead/rainbow trout fry and fingerling rearing and downstream movement;
- Steelhead smolt emigration; and
- Striped bass adult spawning.

The following generalized example illustrates the benefits of using this integrated approach to evaluate the No-Action Alternative, the Proposed Action, and Alternative 2.

Chinook salmon spawning occurs from September through December, and habitat component requirements include suitable spawning substrate (gravel), water depth (0.8 foot–3.3 feet), mesohabitat (riffle or run), and water temperatures (index values of 56°F, 58°F, 60°F, and 62°F). If an alternative results in colder water temperatures, but at a time and/or location in which the habitat component requirements for Chinook salmon spawning are not present, then the species and life stage has not benefited from the colder water temperatures; the overall habitat suitability index value calculated for this species life stage will not reflect any change. Conversely, water temperatures may be more suitable, or may be suitable over a longer portion of the spawning period, at the locations in which all of the required suitable habitat components are present. In such a case, the overall habitat suitability index value calculated would proportionately increase to reflect the improvement in conditions and the benefit to this species and life stage.

In the case of the Chinook salmon spawning life stage, water temperature index values used for the evaluation are reported in available literature to be associated with specific types of biological effects. By evaluating water temperature changes that are biologically relevant to the suitability of habitat to the fish species and life stage, it is possible to learn the potential nature of the changes and potential biological effects associated with the alternatives.

Current criteria for managing water temperatures in the lower Feather River were established in the 1983 agreement between DFG and DWR, which stated that:

(1) water temperatures below the Thermalito Afterbay Outlet must be suitable for fall-run Chinook salmon after September 15; (2) water temperatures below the Thermalito Afterbay Outlet must be suitable for American shad, striped bass, and other warmwater fish from May through August; and (3) daily average temperatures for water supplied to the Feather River Fish Hatchery must not exceed the following:

- 60°F from June 16 through August 15;
- 58°F from August 16 through August 31;
- 56°F from June 1 through June 15;
- 55°F from December 1 through March 31, and May 16 through May 31;
- 52°F from September 1 through September 30; and
- 51°F from October 1 through November 30, and April 1 through May 15.

(A deviation of plus or minus 4°F for these average daily water temperatures is allowed between April 1 through November 30 [DWR 2001a].)

With implementation of the Proposed Action or the No-Action Alternative, the current water temperature criteria for management of aquatic resources in the lower Feather River would remain in place. Alternative 2 would modify the water temperature targets at Robinson Riffle. No alternative would modify hatchery water supplies such that water temperature management constraints for the lower Feather River would change. However, flow change in the Low Flow Channel from 600 cfs (Proposed Action and No-Action Alternative) to 800 cfs (Alternative 2) also would alter the water temperature regime in the lower Feather River. See Chapter 3.0, Proposed Action and Alternatives, for further definition of the water temperature management and flow standards proposed under the No-Action Alternative, the Proposed Action, and Alternative 2.

The three steps of the water temperature analysis illustrated in Figure G-AQUA2.2-1 include: (1) identifying potentially suitable fish habitat for each fish species and life stage to be evaluated; (2) evaluating the suitability of water temperatures against the requirements of these fish species and life stages; and (3) for each alternative, comparing the results for each of the fish species and life stages to the basis of comparison to identify the proportion of total change and quality of change in the fish habitat.

The first step in developing the index to show the proportion of relative habitat suitability was to identify the location and distribution of potentially suitable fish habitat for each species and life stage selected for analysis. Suitable habitat requirements for each species and life stage evaluated were defined using the matrices from SP-F3.2, Task 2, *Literature Review of Fish Life History and Habitat Requirements for Feather River Fish Species*, which were produced from a comprehensive literature review, as well as from the results of other study plan reports. Fish habitat component requirements included

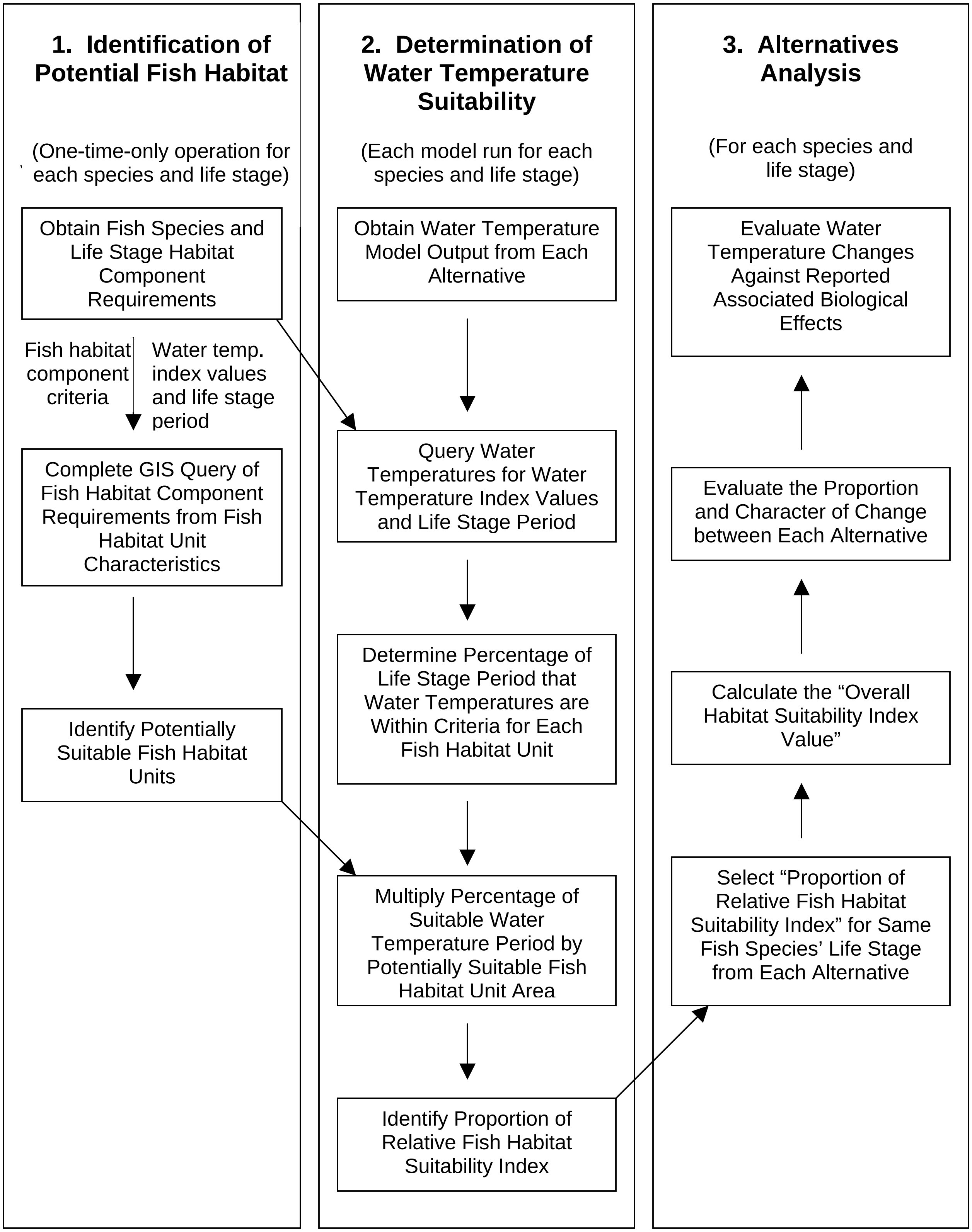

Figure G-AQUA2.2-1. Water temperature/habitat suitability analysis flow diagram.

mesohabitat (generalization of hydraulic conditions, i.e., glide, pool, riffle, run), substrate type, and water depth. Fish habitat component distribution in the lower Feather River was mapped in SP-G2 and was used as the basis of the SP-F3.2, Task 4 report, *Comparison of Fish Distribution to Habitat Distribution and Maps (by species)*. Appendix G-AQUA1, Affected Environment, provides summaries of the aquatic resources study plan reports, and Appendix G-AQUA2.4, Lower Feather River Fish Species of Primary Management Concern, identifies habitat component requirements for specific species and life stages.

Fish habitat requirements by species and life stage were evaluated against the characteristics and distribution of fish habitat components in the lower Feather River to identify those locations that meet the habitat requirements of each species and life stage. The locations meeting the requirements of a fish species and life stage were identified as “potential habitat” and were used in the second step of the process during evaluation of the water temperature suitability of the habitat units. This identification of potential fish habitat was conducted for the lower Feather River from the Fish Barrier Dam to the confluence with the Sacramento River for each fish species and life stage of primary management concern identified in Section 5.5.1, Aquatic Resources Affected Environment.

Figure G-AQUA2.2-2 (in the separate figures volume) illustrates the geographic distribution of potential fish habitat for an example fish species for the Low Flow Channel of the lower Feather River. The map legend lists habitat criteria used to identify locations meeting the fish habitat requirements and includes a pie chart depicting the amount and proportion of potentially suitable fish habitat identified for the river reach depicted. Those locations that did not meet the requirements for physical habitat components for a fish species and life stage were eliminated from the index value calculation; regardless of the potential water temperature suitability of these areas, they do not contribute to the quantity of habitat available to each species and life stage.

The second step in the water temperature suitability analysis used output from the water temperature models to further refine the relative quantity of potentially suitable habitat available for each species and life stage evaluated. During the second step, an overall habitat suitability index value was calculated based on the results of the modeled water temperatures throughout the lower Feather River under each alternative during the specific time periods defined for each species and life stage. Each of the 101 locations of water temperature output nodes from the water temperature model for the lower Feather River were defined using geographic information systems (GIS). Modeled water temperature results were coded relative to their respective habitat units. The query of the model output returned the proportion of time during which water temperatures met the criteria for the water temperature index in the time period associated with each species and life stage for each fish habitat unit. The percentage of time during which the water temperatures are suitable, compared to the water temperature index value for the period that the species and life stage is present, is multiplied by the amount of area for each respective fish habitat unit. These amounts are summed for the entire lower Feather River to determine the overall habitat suitability index value (OHSIV). Figure G-AQUA2.2-3 illustrates the GIS query process for calculating the index value.

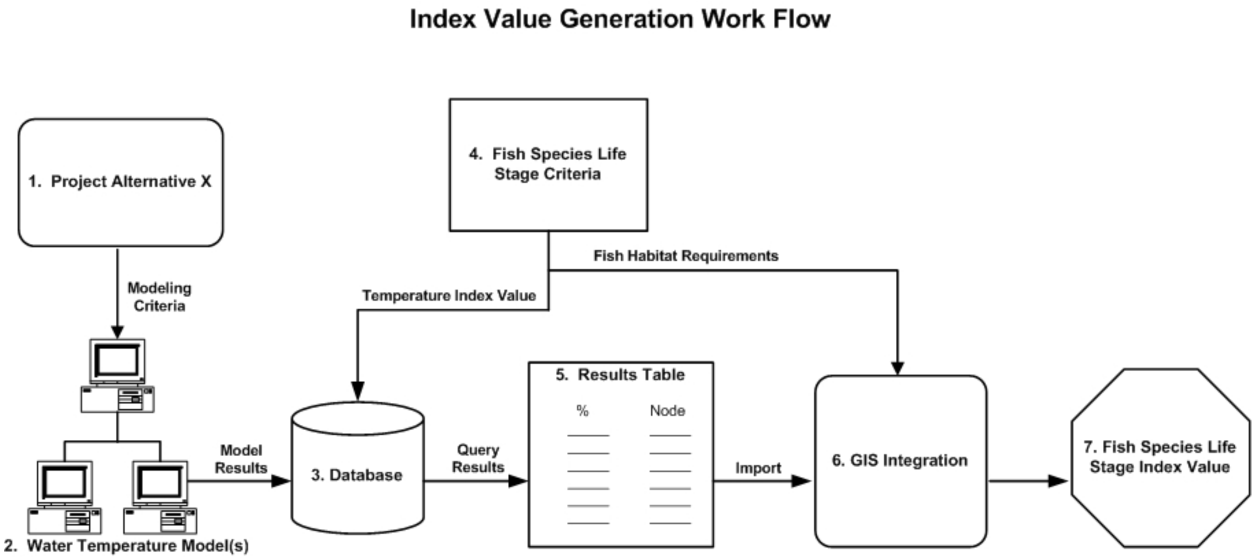

Figure G-AQUA2.2-3. Workflow process for calculating fish habitat index values.

In the third step illustrated in Figure G-AQUA2.2-1, the OHSIV for the Proposed Action, Alternative 2, and the existing condition were compared to the No-Action Alternative to determine proportional changes in overall habitat suitability index values among alternatives.

The graph of the distribution of the proportion of relative habitat suitability in Figure G-AQUA2.2-4 illustrates the nature of the distribution of the calculated overall habitat suitability index values. A similar graph of the distribution of the proportion of the relative fish habitat suitability is included for each water temperature index value calculated for each fish species and life stage evaluated. “Relative Fish Habitat Suitability Units” on the X axis of the graph indicates the quantity of potential fish habitat and “Proportion of Suitability” on the Y axis indicates the percentage of time within the time period for each species and life stage that water temperatures are below (for coldwater fish species) a water temperature index value. For warmwater and other fish species, water temperature index values are calculated based on the percentage of time that the water temperatures are between the minimum and maximum water temperature index values reported as suitable for the species and life stage.

Elements from the graph that depict the distribution of the proportions of relative fish habitat suitability are summarized in the example Table G-AQUA2.2-1. These elements compare differences in the amount and proportion of relative fish habitat suitability for each water temperature index value evaluated between the basis of comparison and each alternative. When changes in the proportions of the amount of potentially suitable habitat are identified in any of the comparisons, if the water temperature index values are based on conditions that are reportedly associated with specific biological effects,

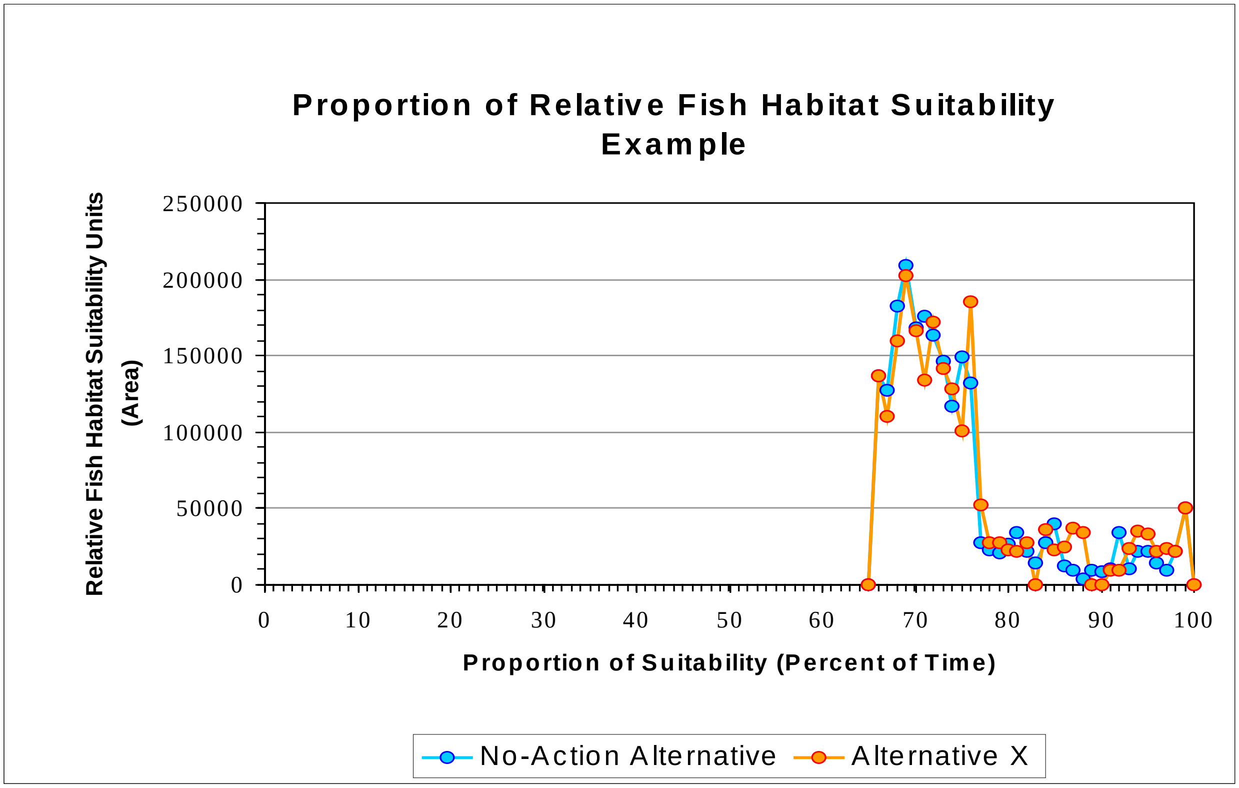

Figure G-AQUA2.2-4. Example distribution of the proportion of relative fish habitat suitability.

Table G-AQUA2.2-1. Example of overall habitat suitability index comparison between the No-Action Alternative and Alternative "X."

Water Temperature Index Value	**60°F**
No-Action Alternative	
Minimum Percentage of Time Value	68 percent
Maximum Percentage of Time Value	100 percent
Habitat Units at 100 Percent of Time	9,000
Percentage of Time at Maximum Habitat Units	72 percent
Total OHSIV	**944,853**
Alternative "X"	
Minimum Percentage of Time Value	92 percent
Maximum Percentage of Time Value	100 percent
Habitat Units at 100 Percent of Time	22,000
Percentage of Time at Maximum Habitat Units	97 percent
Total OHSIV	**953,016**
Percent Change	**0.86 percent**

then the nature of the biological effects also is reported with the analysis of the proportion of change.

The total overall habitat suitability index value presented in the example table as “Total OHSIV” describes the overall relative habitat suitability for the entire lower Feather River for each water temperature index value used for the evaluation of each fish species and life stage. The total OHSIV is calculated by multiplying the amount of habitat unit area by the proportion of time during which the water temperatures are considered suitable based on the water temperature index value definition for each data point on the graph, and is represented as the sum of all of the data point values. The resulting index value literally represents the amount of area and time of potentially suitable habitat for a fish species and life stage. Comparison of the Total OHSIV metric between alternatives indicates which alternative has the greatest amount of suitable habitat with water temperatures equal to or below each water temperature index value for coldwater fish species, and the greatest amount of suitable habitat with water temperatures between the water temperature index values for warmwater and other fish species.

The first analysis was to compare the percentage of change in the OHSIV between the basis of comparison and each alternative to determine the proportion of total habitat change resulting from the implementation of each alternative. The analysis of the percent change of OHSIV was performed using the following calculation:

$$\text{Total OHSIV Change (\%)} = \left(\frac{\text{Total OHSIV}_{ALTERNATIVE\text{"}X\text{"}}}{\text{Total OHSIV}_{NO-ACTION}} - 1 \right) \times 100$$

The results of the calculation of proportion of total habitat change are represented in the example Table G-AQUA2.2-1 as “Percent Change” on the bottom line of the table. Positive percentages indicate increases in the proportion of fish habitat available for a species and life stage for the existing condition, the Proposed Action, and Alternative 2 compared to the No-Action Alternative; conversely, negative percentages indicate a reduced proportion of relative fish habitat. This calculation provides a quantitative value for the magnitude of change in suitable fish habitat as a function of implementation of each alternative. OHSIV is the principal metric for comparing alternatives because it is the most global representation of all fish habitat potentially available for each fish species and life stage evaluated.

The example graph in Figure G-AQUA2.2-4 shows the lowest proportion of time during which the habitat units are suitable with the data values farthest to the left and are reported in the example Table G-AQUA2.2-1 as “Minimum Percentage of Time Value.” In this example, the lowest proportion of suitability for the No-Action Alternative is 68 percent, whereas for Alternative “X” it is 92 percent. The comparison between Alternative “X” and the No-Action Alternative was made by subtracting the No-Action Alternative value for the “Minimum Percentage of Time Value” from the “Minimum Percentage of Time Value” for Alternative “X” and reporting the difference between the values. In this example, the difference between the No-Action Alternative and Alternative “X” indicates that the worst water temperature suitability proportions are suitable for this water temperature index value for Alternative “X” for 24 percent more of the life stage period than under No-Action Alternative conditions.

The “Maximum Percentage of Time Value” metric presented in the example Table G-AQUA2.2-1 represents the percentage of time that water temperatures in the most suitable habitat unit are below each specified water temperature index value. This value is represented as the data point the farthest to the right on the example graph in Figure G-AQUA2.2-4 for Alternative “X.” Again, the difference in the values is reported in the table. In the example case, both Alternative “X” and the No-Action Alternative display data points at the 100 percent proportion of habitat suitability; therefore, there is no difference in values for this example comparison.

Another comparison between the alternatives that can be made using the example graph presented in Figure G-AQUA2.2-4 is a comparison of the amount of habitat that is suitable during 100 percent of presence period for the fish species and life stage. The number of relative fish habitat suitability units in the graph of the proportion of relative fish habitat suitability that occur at 100 percent of proportion of suitability is reported in the example Table G-AQUA2.2-1 as “Habitat Units at 100% of Time.” In this example, the No-Action Alternative would have 9,000 habitat units that are suitable during 100 percent of the presence period for the fish species and life stage, while Alternative “X” would have 22,000 habitat units that are suitable 100 percent of the time. This example indicates that there is 2.4 times more suitable habitat for 100 percent of the fish species’ life stage period under Alternative “X” than under the No-Action Alternative.

The percentage of time within the life stage period in which the highest quantity of fish habitat occurs for both Alternative “X” and the No-Action Alternative is reported in the example Table G-AQUA2.2-1 as “Percentage of Time at Maximum Habitat Units.” In the example graph (Figure G-AQUA2.2-4) these values are 72 percent and 97 percent, respectively, for the No-Action Alternative and Alternative “X.” This metric shows the peak of the population distribution of the proportion of relative fish habitat suitability; comparisons are reported as differences calculated similarly as the comparison of the “Minimum Percentage of Time Value.”

The evaluation of the resulting proportions of OHSIV discusses the types of effects that, according to available literature, may result in fish exposed to water temperatures associated with the selected water temperature index values. The discussion of potential biological effects associated with exposure to water temperatures at or above a water temperature index value contributes to the understanding of the nature and severity of the potential effects on fisheries resources associated with implementation of each alternative.

For each alternative evaluated, the three evaluation steps illustrated in Figure G-AQUA2.2-1 were repeated for each life stage for which each fish species of primary management concern was present in the lower Feather River, for each water temperature index value. The results of the evaluation of the proportion of relative habitat suitability for each life stage for a fish species were synthesized with the relevant qualitative analyses applicable to that fish species for an evaluation of the overall effects on a fish species.

Like the model outputs described in Section G-AQUA2.1, Hydrologic Model Summary, the GIS analysis should be viewed as having “reasonable detection limits” due to the limitations inherent in the GIS software, fineness of the available data, and model output node locations. For example, 101 model output nodes are not evenly distributed throughout the lower Feather River, creating unevenly sized habitat units to which the proportion of time within a water temperature range was assigned. Additionally, the GIS software utilized for the analysis utilized only whole integers for the proportion of time that each habitat unit was within a specific water temperature range, allowing rounding errors to occur. Thus, the proportion of time within all the possible water temperature ranges assigned to any given river segment between model output nodes did not always sum to 100 percent. Additionally, because model output nodes were not evenly distributed throughout the lower Feather River, and because each species had different habitat requirements, the compounded errors differed for each life stage analysis performed. In order to maintain consistency and to be as protective as possible, a detection limit of one percent was assigned to the GIS analysis. Due to the accumulation of errors associated with rounding the percentage of time within each water temperature range associated with each river segment, OHSIV values less than 1 percent were not detectable using the analysis methodology. Therefore, for purposes of alternatives analyses, values of less than 1 percent were considered equivalent.

G-AQUA2.3.1 Water Temperature Index Values

Water temperature index values are used as indicators of water temperatures that are potentially biologically suitable or at which biological effects could occur. The water temperature index values are based on a comprehensive review of available literature on the potential biological effects of water temperatures for each specific fish species and life stage evaluated. When literature describing specific effects of specific water temperatures on a salmonid species was available, it was used as the basis for water temperature index values, above which specific biological effect could potentially occur. When literature describing specific biological effects was not available, the highest and lowest water temperatures reportedly tolerated by the species were used as endpoints of a range of water temperatures considered suitable. Because water temperature index values were developed as indicators of potential biological effects, they were used as a basis for comparing the conditions associated with implementation of the No-Action Alternative, the Proposed Action, or Alternative 2 with the basis of comparison. Water temperature indices and analysis periods for each life stage of each species of primary management concern used in the evaluation of alternatives are presented in Table G-AQUA2.2-2.

Table G-AQUA2.2-2. Life stage timing for fish species and water temperature index values.

Species	Life Stage	Start Date	End Date	Water Temperature Index Values (°F)					
Spring-run Chinook salmon	Adult Immigration and Holding	Mar 1	Oct 31	60<	64<	68<			
Spring-run Chinook salmon	Adult Spawning and Embryo Incubation	Sep 1	Feb 15	56<	58<	60<	62<		
Spring-run Chinook salmon	Juvenile Rearing and Downstream Movement	Jan 1	Dec 31	60<	63<	65<	68<	70<	75<
Fall-run Chinook salmon	Adult Immigration and Holding	Jul 15	Dec 31	60<	64<	68<			
Fall-run Chinook salmon	Adult Spawning and Embryo Incubation	Sep 1	Feb 15	56<	58<	60<	62<		
Fall-run Chinook salmon	Juvenile Rearing and Downstream Movement	Nov 15	Jun 30	60<	63<	65<	68<	70<	75<
Steelhead	Adult Immigration and Holding	Sep 1	Apr 15	52<	56<	70<			
Steelhead	Adult Spawning and Embryo Incubation	Dec 1	May 31	52<	54<	57<	60<		
Steelhead	Fry & Fingerling Rearing and Downstream Movement	Jan 1	Dec 31	65<	68<	72<	75<		
Steelhead	Smolt Emigration	Jan 1	Jun 30	52<	55<				
American Shad	Adult Immigration and Spawning	Apr 1	Jun 30	>46	79<				
Black Bass (spp.)	Adult Spawning	Mar 1	Jun 30	>54	75<				
Green Sturgeon	Adult Immigration and Holding	Feb 1	Jul 31	>44	61<				
Green Sturgeon	Adult Spawning and Embryo Incubation	Mar 1	Jul 31	>46	68<				
Green Sturgeon	Juvenile Rearing	Jan 1	Dec 31	>50	66<				
Green Sturgeon	Juvenile Emigration	May 1	Sep 30	>50	66<				
Hardhead	Adult Spawning	Apr 1	Aug 31	>55	75<				
River Lamprey	Adult Spawning	Apr 1	Jun 30	>43	72<				
Sacramento Splittail	Adult Spawning, Embryo Incubation, and Initial rearing	Feb 1	May 31	>45	75<				
Striped Bass	Adult Spawning	April 1	Jun 30	>59	68<				

The availability of species-specific literature describing water temperature effects determined the availability and accuracy of water temperature index values. For example, little literature was available describing the effects of water temperatures on river lamprey, while an abundance of literature was available describing the effects of water temperatures on Chinook salmon. Thus, water temperature index values provided for various life stages of Chinook salmon are supported by more literature and are likely more accurate, and the biological effects of water temperatures associated with each water temperature index value are more well documented than those index values presented for river lamprey.

Additionally, because more documentation was available regarding thermal tolerances and potential effects of elevated water temperatures on anadromous salmonids than for other species analyzed, multiple water temperature index values were developed for all life stages of anadromous salmonids (except steelhead smolt emigration, for which only two water temperature index values were available). For example, 6 water temperature target values were identified for the juvenile rearing and downstream movement life stage for fall-run Chinook salmon, based on information presented in 22 literature sources (Banks et al. 1971; Brett et al. 1982; Burck 1980; Cech and Myrick 1999; Clarke and Shelbourn 1985; USEPA 2001; USEPA 2003; Independent Scientific Group 1996; Johnson and Brice 1953; Marine 1997; McCullough 1999; Myrick and Cech 2001; NOAA Fisheries 1993; NOAA Fisheries 1995; NOAA Fisheries 1997b; NOAA Fisheries 2000; NOAA Fisheries 2002a; Ordal and Pacha 1963; Rich 1987; Seymour 1956; USFWS 1999; Zedonis and Newcomb 1997). Two water temperature index values were developed for each life stage analyzed for the rest of the warmwater and other species evaluated.

The anadromous salmonid species and life stages for which water temperature target values were chosen included:

- Spring-run Chinook salmon (adult immigration and holding, adult spawning and embryo incubation, and juvenile rearing and downstream movement);
- Fall-run Chinook salmon (adult immigration and holding, adult spawning and embryo incubation, and juvenile rearing and downstream movement); and
- Steelhead (adult immigration and holding, adult spawning and embryo incubation, fry and fingerling rearing and downstream movement, and smolt emigration).

Because anadromous salmonids are coldwater species and water temperatures approaching their coldwater tolerances do not occur in the lower Feather River, no water temperature index values were developed to represent water temperatures that are too cold to be considered suitable habitat for anadromous salmonids. The lowest water temperature index value developed for each coldwater fish species and life stage is generally agreed upon in the available literature to have no adverse biological effects on the species. Each successive increase in water temperature index value has specific incremental detrimental effects that reportedly can occur in association with the exposure of a species and life stage to water temperatures at or above the subsequent index value. Additional discussion on salmonid thermal tolerances is provided in the study plan reports described in Appendix G-AQUA1, Affected Environment. Species and life stage–specific documentation regarding the basis for the water temperature index values is presented in Section G-AQUA2.4, Lower Feather River Fish Species of Primary Management Concern, of this appendix.

The warmwater and other fish species and life stages for which water temperature index values were developed included:

- American shad adult immigration and spawning;
- Black bass (largemouth bass, smallmouth bass, spotted bass, and redeye bass) adult spawning;
- Green sturgeon adult immigration and holding;
- Green sturgeon adult spawning and embryo incubation;
- Green sturgeon juvenile rearing;
- Green sturgeon juvenile emigration;
- Hardhead adult spawning;
- River lamprey adult spawning;
- Sacramento splittail adult spawning, embryo incubation, and initial rearing; and
- Striped bass adult spawning.

In the case of the warmwater and other fish species evaluated, the water temperature index values were selected based on the reported water temperature ranges or preferences of the species and life stages. Available literature generally reported either preferred, suitable, or optimal water temperatures without describing the biological effects of lowered or elevated water temperatures or simply provided ranges of water temperatures in which the species were observed. Therefore, these water temperature indices are not necessarily associated with specific biological effects on the species. To provide the most protective water temperature targets for the bases of the warmwater fisheries analyses, the water temperature target values for most warmwater and other fish species represent the lowest water temperature presented in the literature and the highest water temperature presented in the literature, regardless of the context in which the water temperatures were described. For example, of the warmwater and other fish species evaluated, literature describing the thermal ranges of spawning adult black bass was the most abundant because the life stage includes four species.

The lowest water temperature at which largemouth bass spawning begins was reported in available literature to be 53.6°F (12°C) (Miller and Storck 1984); the lowest water temperatures at which smallmouth bass, redeye bass, and spotted bass are reported to spawn are 54.5°F (12.5°C), 62.6°F (17°C), and 57°F (14°C), respectively (Graham and Orth 1986; Moyle 2002). The highest water temperatures at which largemouth bass, smallmouth bass, redeye bass, and spotted bass are reported to spawn are 75.2°F (24°C), 74.3°F (23.5°C), 69.8°F (21°C), and 73.4°F (23°C), respectively (Aasen and Henry 1981; Graham and Orth 1986; Moyle 2002; Wang 1986). Based on these available reports, after rounding reported values to the nearest degree Fahrenheit, the water temperature index values chosen for black bass spawning life stage analyses were 54°F (12.2°C) and 75°F (23.9°C). Because the index values for warmwater and other fish species are based on the range of water temperatures for suitability, the index value calculations are interpreted differently than the index values for the coldwater fish water temperatures. In the case of the warmwater fishes, the amount of time and area with water temperatures between the water temperature index values are the basis of comparison for the alternatives. For example, the percentage of time during which water temperatures are between 54°F (12.2°C) and 75°F (23.9°C) multiplied by the area containing all of the physical habitat components required by black bass was compared among alternatives.

G-AQUA2.3 QUALITATIVE FISH HABITAT COMPONENT EVALUATIONS

G-AQUA2.3.1 Chinook Salmon Spawning Segregation

Blocking upstream migration has eliminated the spatial separation between spawning by fall-run and spring-run Chinook salmon. Reportedly, spring-run Chinook salmon migrated to the upper Feather River and its tributaries from mid-March through the end of July (DFG 1998). Fall-run Chinook salmon reportedly migrated later and spawned in lower reaches of the Feather River than spring-run Chinook salmon (Yoshiyama et al. 2001). Restricted access to historic spawning grounds cause spring-run Chinook salmon to spawn in the same lowland reaches that fall-run Chinook salmon use as spawning habitat. The overlap in spawning site location, combined with a slight overlap in spawning timing (Moyle 2002) with temporally adjacent runs, may be responsible for inbreeding between spring-run and fall-run Chinook salmon in the lower Feather River (Hedgecock et al. 2001).

The Proposed Action and Alternative 2 include actions that would address effects on anadromous fishes caused by the blockage of upstream passage by the Oroville Facilities. In both scenarios, fish barrier weirs would be installed downstream of the Fish Barrier Dam to segregate spring-run and fall-run Chinook salmon. The reason for implementing this action is that spring-run Chinook salmon migrate upstream earlier in the year than fall-run Chinook salmon, which allows the runs to be segregated by allowing fish passage on a temporal basis. The effects of this action were evaluated on a qualitative basis using historic information on escapements, information collected during preparation of the SP-F10 Study Plan Report, and various agency reports on Chinook salmon run timing in the Feather River.

G-AQUA2.3.2 Macroinvertebrate Populations

Aquatic macroinvertebrates consist primarily of insects, snails, clams, shrimp, and zooplankton. The current status of macroinvertebrate populations in the project study area was described in the interim and final reports for SP-F1, Task 1, *Evaluation of Project Effects on Non-Fish Aquatic Resources*, and is summarized in Section G-AQUA1.1 of Appendix G-AQUA1. Construction of Oroville Dam changed the hydrologic cycle of the Feather River. These changes likely affected invertebrate life cycles and communities that evolved over time. Fluctuating reservoir levels, controlled flows, and less frequent scouring events have likely affected non-fish aquatic resources. Macroinvertebrates and plankton communities may be directly affected by future changes in project operations that affect the amount of surface water, flow rates, water temperatures, or water quality in the project area.

Aquatic macroinvertebrates and plankton are important components of the biological food web in any aquatic ecosystem. Many invertebrate species are important to the recycling of nutrients in aquatic systems. They also are an important food source for fish, and their community structure and diversity are important factors in determining general ecosystem conditions. Stream health is usually determined by the species diversity of the assemblage present or through groupings at higher taxonomic levels. Negative effects from environmental shifts or anthropogenic effects are shown by decreasing species diversity, organism size, or changes in taxa composition (Erman 1996).

As a basis for the assessment, projected physical and chemical changes associated with future project operations were compared with ecological requirements for macroinvertebrates and plankton populations within waters affected by the project. A qualitative assessment of potential effects was conducted that determined the general direction of such effects. Professional judgment was used to qualitatively assess effects, as supported by biological information.

G-AQUA2.3.3 Woody Debris Recruitment

The Oroville Facilities prevent the recruitment of large woody debris from the upstream reaches of the Feather River and its tributaries to the lower Feather River below Oroville Dam. Current sources of large woody debris in the lower Feather River are the riparian zone along the river, occasional inputs from orchards adjacent to the river, and other tributaries flowing into the lower Feather River. Moderated flow regimes in the lower Feather River also have reduced recruitment of large woody debris. In addition, current large woody debris recruitment is different in quality than under pre-dam conditions because the origin of the pre-dam wood would have been from mixed hardwood and coniferous forests not present in riparian zones downstream of Lake Oroville.

Large woody debris is an important component of geomorphic processes and ecological functions in rivers and streams. Woody debris enhances the complexity of fish habitat and may redirect streamflow to create pools that serve as holding areas for anadromous salmonids. In addition, decaying large woody debris provides a source of nutrients for aquatic organisms. Generally, the influence of large woody debris on stream geomorphology and ecology varies with stream size (Lassettre and Harris 2001). On larger streams such as the Feather River the effects of large woody debris on geomorphic processes are limited, but it still performs important ecological functions. In these larger streams, large woody debris can provide shelter for salmonids, and when associated with secondary channels, it contributes to the quality and diversity of juvenile rearing habitat.

Large woody debris supplementation programs for the lower Feather River are included under the Proposed Action and Alternative 2. Effects of large woody debris supplementation were evaluated qualitatively for the Proposed Action and Alternative 2 using a literature review, and comparisons were made between the current quantity, distribution, and habitat function of large woody debris in the lower Feather River and fish habitat quality.

G-AQUA2.3.4 Gravel/Sediment Recruitment

Spawning habitat for anadromous salmonids below Oroville Dam has been affected by changes to the geomorphic processes caused by several factors, including hydraulic mining, land use practices, construction of flood management levees, regulated flow regimes, and operation of Oroville Dam. The dam blocks sediment recruitment from the upstream areas of the watershed. In the lower reaches of the river, levees and bank armoring prevent gravel recruitment. Periodic flows of sufficient magnitude to mobilize smaller sized gravel from spawning riffles result in armoring of the remaining substrate. DWR (1996) evaluated the quality of spawning gravels in the lower Feather River based on bulk gravel samples and Wolman surface samples obtained in the spring of 1996. The study concluded that the worst scoured areas had an armored surface layer too coarse for spawning salmonids. Additionally, much of the streambed substrate in the reach from the Fish Barrier Dam to the Thermalito Afterbay Outlet is composed of large gravel and cobble, which is too large for construction of spawning redds for Chinook salmon and steelhead. This reach of the lower Feather River is by far the most intensively used spawning habitat of the river for salmon and steelhead.

Chinook salmon, steelhead, and river lamprey use riffles and runs with a gravel substrate for spawning. Females of each species construct nests (redds) in the substrate by creating a shallow depression in the gravel. Eggs are then deposited in the depression while males release sperm over the eggs for fertilization. Next, eggs are covered with a layer of gravel where they incubate, and juveniles emerge from the gravel at a later date depending on egg incubation time required for the species. Because the incubating eggs require a constant supply of oxygenated water, gravel is the required substrate.

Gravel supplementation is a proposed action under both the Proposed Action and Alternative 2. Both the Proposed Action and Alternative 2 would implement rip and raking of selected armored stream bottoms, in addition to the placement of gravel at targeted sites in the river reach between the Fish Barrier Dam and the Thermalito Afterbay Outlet. Effects of the Gravel Supplementation and Improvement Program on the quality of fish habitat were evaluated qualitatively for both alternatives using a literature review and professional judgment.

The Proposed Action and Alternative 2 include actions to improve the quality and quantity of salmonid spawning gravel, as well as to potentially create new spawning habitat. The effects of superimposition on egg mortality and alevin survival were qualitatively evaluated for the Proposed Action and Alternative 2 based on changes in habitat quality, quantity, and distribution in relation to salmonid spawning habitat use characteristics.

G-AQUA2.3.5 Channel Complexity

For purposes of this analysis, channel complexity refers to the diversity of geomorphologic features in a particular river reach. Such features include undercut stream banks, meanders, point bars, side channels, backwaters, etc. Regulation of the lower Feather River by the Oroville Facilities has changed both streamflow and sediment discharge. More than 97 percent of the sediment is trapped in the reservoir, resulting in sediment starvation downstream. Attenuation of peak flows, decreased winter flows, increased summer flows, and changes to historic flow frequencies have led to a general decrease in channel complexity downstream of Oroville Dam.

Because several fish species of management concern and different life stages of these species occur in the lower Feather River, a diversity of habitat types is required. Increases in channel complexity lead to an increase in habitat diversity and habitat quality. Increases in channel complexity are proposed in several different actions under the Proposed Action and Alternative 2. These actions include gravel and large woody debris supplementation, as well as the restoration and creation of side channels to increase spawning and juvenile rearing habitat for steelhead and Chinook salmon. Effects of increasing channel complexity were evaluated qualitatively for the Proposed Action and Alternative 2 using a literature review and professional judgment.

G-AQUA2.3.6 Water Quality Criteria for Aquatic Life

Water quality, as it affects aquatic life in the project area, was evaluated in the Final SP-F3.2, Task 1, 4, 5 Report, *Comparison of Fish Distribution to Fish Habitat and Maps (by species)*, which is summarized in Section G-AQUA1.4.1 of Appendix G-AQUA1, Affected Environment. DO concentrations were evaluated separately in the report but are included in the discussion of water quality effects on aquatic life in this appendix. The National Ambient Water Quality Criteria (NAWQC) is the applicable regulatory standard that is calculated by USEPA. These criteria represent half the value of toxic substance concentration that would cause 50 percent mortality in 5 percent of a briefly exposed population (USEPA 2002). In addition to NAWQC criteria, on May 18, 2000, USEPA published 40 Code of Federal Regulations (CFR) 131, Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California, generally known as the California Toxics Rule (CTR). Section 5.4.2, Environmental Effects—Water Quality, provides additional information on these water quality standards.

USEPA reports that the 30-day mean water column DO concentration required for the protection of adult life stages of coldwater fish species is 6.5 mg/L (USEPA 2002). USEPA also reports criteria for a single-day minimum to be 4.0 mg/L and 7-day mean minimum to be 3.0 mg/L; however, both of these criteria are less protective than the 30-day mean value provided by USEPA as a minimum DO concentration suitable for coldwater aquatic life (USEPA 2002).

Although no protection, mitigation, and enhancement (PM&E) measures included in the No-Action Alternative, Proposed Action, or Alternative 2 directly target water quality in the project area as it pertains to aquatic species, construction activities within and adjacent to the Oroville Facilities and the lower Feather River could result in short-term effects on water quality. Water quality effects on aquatic life were evaluated qualitatively for the Proposed Action and Alternative 2 using a literature review and professional judgment. Water quality–related effects associated with instream construction activities are included in Section 5.4.2, Environmental Effects—Water Quality.

G-AQUA2.4 LOWER FEATHER RIVER FISH SPECIES OF PRIMARY MANAGEMENT CONCERN

Changes in Oroville Facilities operations could potentially alter seasonal drawdown rates in Lake Oroville and, thus, Feather River flows and water temperatures, which could change the relative availability of habitat for fish species present in the lower Feather River. The lower Feather River is used by a number of fish species of primary management concern, primarily as habitat during one or more of their life stages, but also as a migration corridor to upstream habitat in other river systems (e.g., the Yuba River). For these reasons, species-specific effect assessments were conducted for the following species of primary management concern:

- Fall-run Chinook salmon;
- Spring-run Chinook salmon;
- Steelhead/rainbow trout;
- American shad;
- Black bass (largemouth bass, smallmouth bass, redeye bass, and spotted bass);
- Green sturgeon;
- Hardhead;
- River lamprey;
- Sacramento splittail; and
- Striped bass.

Implementation of the No-Action Alternative, the Proposed Action, or Alternative 2 could potentially alter Feather River water temperatures. Changes in Feather River water temperatures are oriented primarily to meet coldwater fisheries water temperature requirements for salmonids, so the salmonid fish species of management concern are the primary focus of the evaluations of the alternatives with regard to water temperature. Moreover, thermal requirements of Chinook salmon and steelhead are generally similar; and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Biological Opinion on interim operations of the Central Valley Project (CVP) and State Water Project (SWP) on Federally listed threatened Central Valley spring-run Chinook salmon and Central Valley steelhead (NOAA Fisheries 2002a) has established quantitative water temperature criteria for the lower Feather River at the Feather River Fish Hatchery and for the Low Flow Channel (monitored near Robinson Riffle [below River Mile 62]) to protect spring-run Chinook salmon and steelhead; therefore, the assessment methodologies focus primarily on the Chinook salmon and steelhead life stages. The species and life stage–specific flow and water temperature assessment methodologies for the Feather River effect analyses are discussed in the following sections.

G-AQUA2.4.1 Spring- and Fall-run Chinook Salmon

Potential fisheries effects in the two reaches of the lower Feather River were evaluated separately because of the differences in the characteristics of the flow regimes, and because each reach provides different values to the different life stages of anadromous salmonids (adult immigration and holding, adult spawning and embryo incubation, and juvenile rearing and downstream movement). Detailed descriptions of fall-run Chinook salmon life stages and periods are provided in Section 5.5.1 and are summarized in Table G-AQUA2.2-2. Detailed descriptions of spring-run Chinook salmon life stages and periods are provided in Section 5.7.2.1.

G-AQUA2.4.1.1 Flow-related Effects

Because of the differences in the proposed changes in flow in the Low Flow Channel and High Flow Channel for the No-Action Alternative, the Proposed Action, and Alternative 2, the reaches were evaluated separately for flow-related effects on aquatic resources. Chapter 3.0, Proposed Action and Alternatives, provides additional information describing flows.

Site-specific flow-related effects on the spawning and egg incubation life stage of Chinook salmon and steelhead were determined by analyzing the results of Instream Flow Incremental Methodology (IFIM) studies. IFIM is a decision-support analytical tool designed to aid resources managers and stakeholders in determining the effects of different water management alternatives (Bovee et al. 1998), and currently is reported to be the most widely used and defensible technique worldwide for assessing instream flow requirements for fisheries purposes. IFIM includes a wide variety of analytical tools of varying complexity to address multiple aspects of riverine dynamics and ecology, including sophisticated computer models such as a physical habitat simulation

(PHABSIM) model. PHABSIM results were used to quantify changes in available habitat between alternatives.

In general, three main components are needed to obtain PHABSIM results. First, hydraulic data along with substrate and cover data characterizing the conditions in the river are required. The data are subsequently used to create hydraulic models (i.e., models that describe the movement and force of water), which evaluate and predict habitat variables (e.g., water depth, water velocity, substrate, and cover) throughout a selected study site at different flows. The hydraulic models, in turn, are combined with habitat suitability criteria (HSC) models that evaluate the relative incremental utility of habitat attributes to each life stage and species under consideration. HSC curves are derived from observations of hydraulic and physical habitat variables associated with each species and life stage being analyzed (Bovee et al. 1998). PHABSIM results are an index of the quantity and quality of the relative amount of fish habitat by species and life stage and typically are referred to as WUA RSI.

Because the results of the PHABSIM model calculations, expressed as WUA, were used in the quantification of flow changes among alternatives, a brief explanation of WUA is necessary. WUA is a relative indicator of suitability and, as such, is an index representing available habitat area. WUA does not represent actual physical area available for use by the species. Because WUA is an index of habitat suitability, it cannot be directly related to the number of individuals that could occupy the lower Feather River at modeled flows. WUA does, however, indicate the differences in relative habitat suitability among alternatives. Figures G-AQUA2.4-1 and G-AQUA2.4-2 show the Chinook salmon WUA index curves for the Low Flow Channel and High Flow Channel, respectively.

Analysis was completed of flow-related effects on fisheries and aquatic resources in the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet (the Low Flow Channel) and from the Thermalito Afterbay Outlet to Honcut Creek (the High Flow Channel). For each alternative, changes in WUA were compared to determine the relative amount of change in availability of spawning habitat for anadromous salmonids based on the proposed flow changes. To assess flow-related effects on spring- and fall-run Chinook salmon spawning life stages in the lower Feather River, PHABSIM results at flows associated with each alternative were compared to those associated with the basis of comparison.

Detailed descriptions of the methodology associated with the IFIM studies conducted on the lower Feather River, including descriptions of the PHABSIM model and HSC curves used for calculation of Chinook salmon spawning WUA, are available in the Final Report for SP-F16 (see Section G-AQUA1.10 of Appendix G-AQUA1, Affected Environment).

Analysis of available spawning area using PHABSIM model results does not provide information regarding the potential for stage reductions during the embryo incubation portion of the adult spawning and embryo incubation life stage. However, because flows under the alternatives would remain constant in the Low Flow Channel, and fluctuate within the minimum flow and maximum flow agreed upon by DFG and DWR in

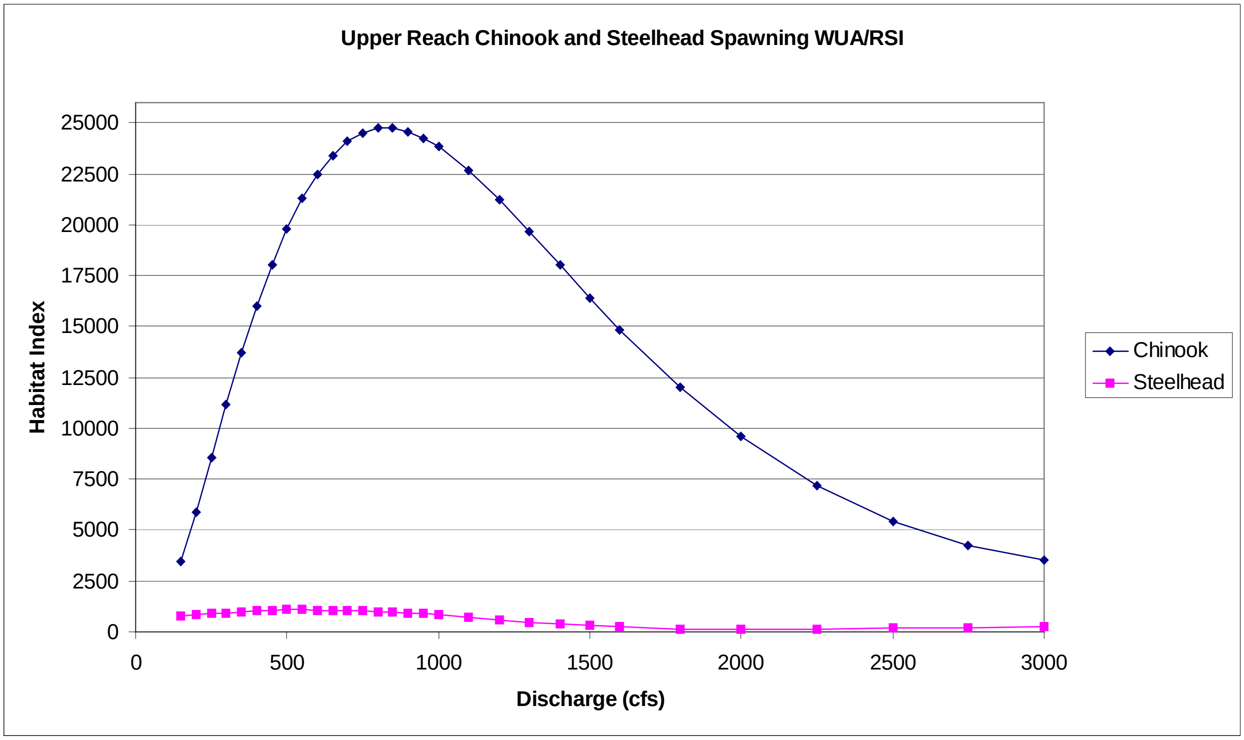

Figure G-AQUA2.4-1. WUA/relative suitability index for Chinook salmon and steelhead spawning in the Low Flow Channel of the lower Feather River.

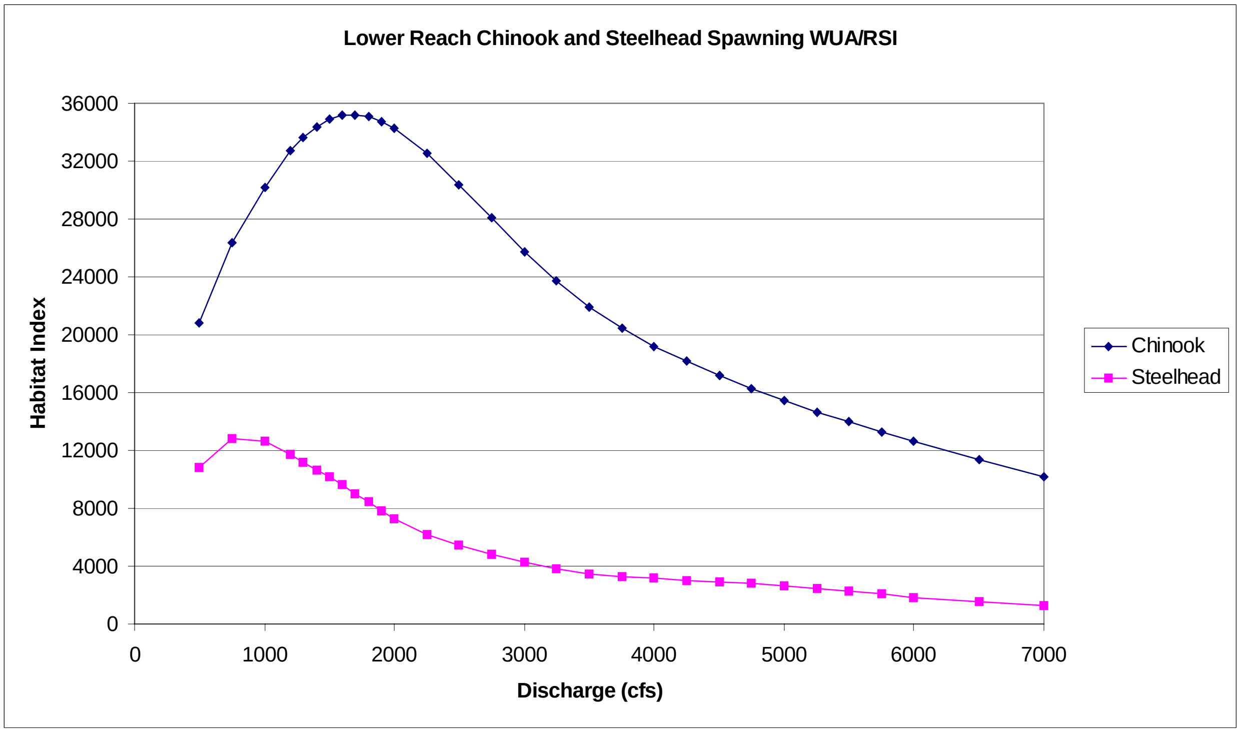

Figure G-AQUA2.4-2. WUA/relative suitability index for Chinook salmon and steelhead spawning in the High Flow Channel of the lower Feather River.

the High Flow Channel, further quantitative analysis of flow fluctuations in the Low Flow Channel or High Flow Channel is unnecessary.

Flow changes and flow fluctuations associated with the alternatives were evaluated qualitatively for potential effects on Chinook salmon adult immigration (see Section G-AQUA1.8.1 of Appendix G-AQUA1, Affected Environment), and Chinook salmon juvenile rearing and downstream movement (see Section G-AQUA1.8.4 of Appendix G-AQUA1). The analysis focused on determining the relative changes to fish habitat with respect to water depth, water velocity, and the amount of inundated habitat area compared to the known fish distribution and relative abundance.

G-AQUA2.4.1.2 Water Temperature–related Effects

A three-phased assessment was performed to evaluate potential water temperature–related effects for spring-run Chinook salmon adult immigration and holding, fall-run Chinook salmon adult immigration, Chinook salmon adult spawning and embryo incubation, and Chinook salmon juvenile rearing and downstream movement. The balance of this section documents the basis of the selection of the water temperature index values and defines the biological effects that are reported to be associated with exposure at or above the water temperature index values used in the analysis.

Water temperature index values were developed for spring- and fall-run Chinook salmon life stages from an extensive review of the available literature to be used as guidelines for assessing potential effects of each alternative. The specific index values developed for each Chinook salmon life stage (the index values are the same for spring- and fall-run Chinook salmon) are discussed below. The derivation and description of each water temperature index value and life stage also is included in the following discussion.

Adult Immigration and Holding (Spring-run, March through August; Fall-run, September through November)

Description of Life Stage

After spending 3–4 years in the ocean, Chinook salmon begin their return to fresh water to spawn (Moyle 2002). Chinook salmon show considerable temporal variation in the timing of their spawning migrations; this life history variation is evident in the classification of Chinook salmon by run type (i.e., fall-run, late fall–run, winter-run, and spring-run). In the Central Valley, adult spring-run Chinook salmon generally migrate upstream from March to September, and fall-run migrate upstream from June to December (Fisher 1994). The holding period extends from the time that adult Chinook salmon enter their natal stream until the onset of spawning site selection. On the Feather River, the entire adult immigration and holding period lasts from March through October for spring-run Chinook salmon and from mid-July through December for fall-run (Eaves 1982; Moyle 2002; NOAA Fisheries 1999; Sommer et al. 2001).

The adult immigration and adult holding life stages are evaluated together, because it is difficult to determine the thermal regime to which Chinook salmon have been exposed in the river before spawning. Additionally, to sufficiently protect pre-spawning fish, water temperatures that provide high adult survival and high egg viability must be available throughout the entire pre-spawning freshwater period. Although studies examining the effects of thermal stress on immigrating Chinook salmon are lacking, it has been demonstrated that thermal stress during the upstream spawning migration of sockeye salmon negatively affected the secretion of hormones controlling sexual maturation, causing numerous reproductive impairment problems (Macdonald et al. in McCullough et al. 2001).

Index Value Selection Rationale

Water temperatures of 60°F, 64°F, and 68°F were used as index values to assess the potential effects of each alternative relative to the basis of comparison. Table G-AQUA2.4-1 provides some of the sources used to select each water temperature index value. For each month of the adult immigration and holding period, modeled water temperatures under each alternative were compared to those modeled under the basis of comparison to evaluate potential water temperature–related effects on immigration and holding of adult Chinook salmon.

Table G-AQUA2.4-1. Water temperature index values and supporting literature for Chinook salmon adult immigration and holding.

Index Value	Supporting Literature
60°F	• The maximum water temperature for adults holding, while eggs are maturing, is approximately 59°F to 60°F (NOAA Fisheries 1997b). • Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NOAA Fisheries 1997b). • The upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NOAA Fisheries 2000). • Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F (ODEQ 1995). • Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995).
64°F	• The acceptable range for adults migrating upstream is from 57°F to 67°F (NOAA Fisheries 1997b). • Disease risk becomes high at water temperatures above 64.4°F (USEPA 2003). • Latent embryonic mortalities and abnormalities associated with exposure of pre-spawning adults to particular water temperatures occur at 63.5°F to 66.2°F (Berman 1990).
68°F	• The acceptable range for adults migrating upstream is 57°F to 67ºF (NOAA Fisheries 1997b). • For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). • Spring-run Chinook salmon embryos from adults held at 63.5ºF to 66.2°F had greater numbers of pre-hatch mortalities and developmental abnormalities than embryos from adults held at 57.2°F to 59.9°F (Berman 1990). • Water temperatures of 68°F resulted in nearly 100 percent mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963).

Water temperature index values for adult immigration and holding were established for all Chinook salmon run types collectively. This was done to show an evenly spaced water temperature range that provides conditions reportedly ranging from optimal to lethal for adult Chinook salmon during upstream immigration and holding. Although 56°F is referenced in the literature frequently as the upper water temperature limit required for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, many of the references to 56°F are based on Hinze (1959), which is a study examining the effects of water temperature on incubating Chinook salmon eggs. Boles et al. (1988), Marine (1992), and NOAA Fisheries (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for Chinook salmon immigration. Because 56°F is not strongly supported by foundational literature, it was not selected as an index value.

The lowest water temperature index value selected was 60°F, because in the NOAA Fisheries Biological Opinion for the proposed operation of the CVP and SWP, 59°F to 60°F is reported as "The upper limit of the optimal temperature range for adults holding while eggs are maturing" (NOAA Fisheries 2000). NOAA Fisheries (1997b) states, "Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F" and the "acceptable range for adults migrating upstream range from 57°F to 67°F. The Oregon Department of Environmental Quality (ODEQ 1995) reports that "…many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F."

64°F was chosen as an index value because Berman (1990) suggested that effects of thermal stress to pre-spawning adults are evident at water temperatures near 64°F, and also because 64°F represents a midpoint value between the water temperature index values of 60°F and 68°F. Berman (1990) conducted a laboratory study to determine whether water temperatures experienced by adult Chinook salmon before spawning influenced reproductive success, and found evidence suggesting that latent embryonic abnormalities associated with exposure of pre-spawning adults to particular water temperatures occur at 63.5°F to 66.2°F.

68°F was selected as an index value because available foundational and regulatory literature suggests that thermal stress at water temperatures greater than or equal to 68°F is pronounced, and severe adverse effects on immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1992; NOAA Fisheries 1997b).

Because significant effects on immigrating and holding adult Chinook salmon reportedly occur at water temperatures greater than or equal to 68°F, it was not necessary to select index values higher than 68°F.

Adult Spawning and Embryo Incubation (September through mid-February)

Description of Life Stage

In the Sacramento River basin, spring-run Chinook salmon spawn from late August to October and fall-run spawn from late September to December (Fisher 1994). In the Feather River, adult spawning and embryo incubation occurs from September through mid-February. The duration of embryo incubation is dependent on water temperature and can be variable (NOAA Fisheries 2002a). In Butte and Big Chico Creeks, emergence of spring-run Chinook salmon generally occurs from November through January (NOAA Fisheries 2002a). In Mill and Deer Creeks, colder water temperatures delay emergence to January through March (DFG 1998). In the lower American River, fall-run Chinook salmon emergence generally begins in March (SWRI 2004).

The adult spawning and embryo (i.e., eggs and alevins) incubation life stage includes redd construction and egg deposition, and embryo incubation through emergence. Potential effects on the adult spawning and embryo incubation life stages are evaluated together using one set of water temperature index values. It is difficult to separate the effects of water temperature between life stages that are closely linked temporally; studies elucidating how water temperature affects embryonic survival and development based on varying water temperature treatments on holding adults often report results similar to those of water temperature experiments conducted on fertilized eggs (Marine 1992; McCullough 1999; Seymour 1956; SWRI 2004).

Index Value Selection Rationale

Water temperatures of 56°F, 58°F, 60°F, and 62°F were used as index values to assess the potential effects of each of the alternatives relative to the basis of comparison. Table G-AQUA2.4-2 provides some of the sources used to select each water temperature index value. For each month of the adult spawning and embryo incubation period for spring- and fall-run Chinook salmon, each alternative was compared to the basis of comparison to evaluate potential water temperature–related effects.

Water temperature index values were selected from a comprehensive literature review. This was done to show an evenly spaced water temperature range that provides conditions reportedly ranging from optimal to lethal for Chinook salmon eggs during spawning site selection, spawning, and incubation. Relative to the large body of literature pertaining to water temperature effects on Chinook salmon embryos, there are few laboratory experiments that specifically examine Chinook salmon embryo survival under different constant or fluctuating water temperature treatments, and only one of these experiments is recent (Combs and Burrows 1957; Hinze 1959; Johnson and Brice 1953; Seymour 1956; USFWS 1999). In large part, supporting evidence for index value selections was derived from the aforementioned laboratory studies and from regulatory documents (NOAA Fisheries 1993; NOAA Fisheries 1997b; NOAA Fisheries 2002a). Field studies reporting river water temperatures during spawning also were considered (Dauble and Watson 1997; Groves and Chandler 1999).

Table G-AQUA2.4-2. Water temperature index values and supporting literature for Chinook salmon spawning and embryo incubation.

Index Value	Supporting Literature
56°F	• Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (USBR 2003 unpublished work). • Optimum water temperatures for egg development are between 43°F and 56°F (NOAA Fisheries 1993). • 56.0°F is the upper value of the water temperature range (i.e., 41.0°F to 56.0°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995). • 56.0°F is the upper value of the range (i.e., 42.0°F to 56.0°F) reported as the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NOAA Fisheries 1997b). • Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). • 56.0°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NOAA Fisheries 2002a). • Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999).
58°F	• 58.0°F is the upper value of the range reported as preferred water temperatures (i.e., 53.0°F to 58.0°F) for eggs and fry (NOAA Fisheries 2002a). • Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). • The natural rate of mortality for alevins occurs at 58°F or less (USBR 2003 unpublished work).
60°F	• 100 percent mortality occurs during the yolk-sac stage when embryos are incubated at 60°F (Seymour 1956). • An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been established for protection of late incubating larvae and newly emerged fry (NOAA Fisheries 1993). • Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). • Consistently higher egg losses resulted at water temperatures above 60.0°F than at lower temperatures (Johnson and Brice 1953)
62°F	• 100 percent mortality of fertilized Chinook salmon eggs after 12 days at 62°F (USBR 2003 unpublished work). • Incubation temperatures of 62°F to 64°F appear to be the physiological limit for embryo development, resulting in 80–100 percent mortality before emergence (USFWS 1999). • There is 100 percent loss of eggs incubated at water temperatures above 62°F (Hinze 1959). • 100 percent mortality occurs during the yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956).

The water temperature index values selected to evaluate the Chinook salmon spawning and embryo incubation life stages are 56°F, 58°F, 60°F, and 62°F. Some literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NOAA Fisheries (1993) reported that optimum water temperatures for egg development are between 43°F and 56°F. The U.S. Bureau of Reclamation (USBR)

(2003 unpublished work) reports that water temperatures less than 56°F result in a natural rate of mortality for fertilized Chinook salmon eggs. USFWS (1995) reported a water temperature range of 41.0°F to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. A range of 42.0°F to 56.0°F was suggested as the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NOAA Fisheries 1997b).

Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NOAA Fisheries (2002a) reported 56.0°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River.

High survival rates of Chinook salmon embryos have also been suggested to occur at incubation temperatures at or near 58.0°F. For example, USBR (2003 unpublished work) reported that the natural rate of mortality for alevins occurs at 58°F or less; Combs and Burrows (1957) concluded that constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs; and NOAA Fisheries (2002a) suggested that a range of 53.0°F to 58.0°F is the preferred water temperature range for Chinook salmon eggs and fry.

Johnson and Brice (1953) found that there were consistently higher rates of Chinook salmon egg losses at water temperatures above 60.0°F than at lower temperatures. To protect late-incubating Chinook salmon embryos and newly emerged fry, NOAA Fisheries (1993) has established a water temperature criterion of less than or equal to 60.0°F for the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. However, Seymour (1956) provided evidence that there is 100 percent mortality of late-incubating Chinook salmon embryos when they are held at a constant water temperature greater than or equal to 60.0°F.

Available literature largely agrees that there will be 100 percent mortality of Chinook salmon embryos incubated at water temperatures greater than or equal to 62.0°F (Hinze 1959; Seymour 1956; USBR 2003 unpublished work; USFWS 1999). Therefore, it was not necessary to select index values above 62°F. Similarly, mortality of spawning adult Chinook salmon before egg deposition (Berman 1990; Marine 1992) reportedly occurs at water temperatures above those at which embryo mortality results (i.e., 62°F) (Hinze 1959; Seymour 1956; USBR 2003 unpublished work; USFWS 1999); therefore, an index value above 62°F was not required. Pre-spawning mortality of adult Chinook salmon associated with exposure to high water temperatures is addressed in the adult immigration and holding life stage.

Juvenile Rearing and Downstream Movement (Spring-run, November through June; Fall-run, February through June)

Description of Life Stage

The juvenile life stage is composed of fry, fingerlings, and smolts; the parr stage is included in the fingerling category. Chinook salmon are fry from the time that the juvenile leaves the gravel of the spawning redd to swim up into the water column as a free-swimming fish until skeletal development is complete, at which point it reaches the fingerling stage (Bovee et al. 1998). Chinook salmon fry make the transition to the fingerling stage at approximately 45 millimeters (mm) to 60 mm (NOAA Fisheries 1997b; NOAA Fisheries 2003b). Fingerling Chinook salmon become smolts when physiological changes occur that allow juveniles to survive the transition from fresh water to salt water during seaward migration. In addition to physiological changes, morphological changes also take place during smoltification (Hoar 1988). Salmonid smolts can be distinguished from pre-smolts by their silvery appearance and relatively slim, streamlined bodies (Hoar 1988).

In the Sacramento River basin, the length of time that juvenile Chinook salmon rear in natal streams varies according to run type. Juveniles displaying spring-run (stream type) life history characteristics emerge from the spawning substrate from November to March and rear for 3–15 months (Fisher 1994), while juveniles displaying fall-run (ocean type) life history characteristics emerge from the spawning substrate from December to March and rear for 1–7 months (Fisher 1994). Recent studies from the American and Feather Rivers indicate that most juvenile Chinook salmon move downstream as fry shortly after they emerge from the spawning gravel (DWR 2002; Snider and Titus 2000). In the Sacramento River, juvenile Chinook salmon move downstream during all months, as both fry and smolts (Moyle 2002).

Water temperature is a major limiting factor for juvenile Chinook salmon because it strongly affects survival and growth. Water temperatures that are too high can be lethal or cause sublethal effects such as reduced appetite and growth, increased incidence of disease, increased metabolic costs, and decreased ability to avoid predators. Available scientific literature indicates that a similar range of water temperatures provides positive growth and high survival for Chinook salmon fry, fingerlings, and smolts. Chinook salmon juveniles reportedly rear and move downstream year-round as fry, fingerlings, or smolts, and available scientific literature indicates that a range of water temperatures that is important for fry also is important for fingerlings and smolts; therefore, effects on each phase of the juvenile life stage can be evaluated using a single set of water temperature index values.

Index Value Selection Rationale

Water temperatures of 60°F, 63°F, 65°F, 68°F, 70°F, and 75°F were used as evaluation guidelines to assess the potential affects of each alternative, relative to the basis of comparison. Table G-AQUA2.4-3 provides some of the sources used to select each water temperature index value. For each month of the juvenile rearing and downstream movement periods of spring- and fall-run Chinook salmon, each alternative was compared to the basis of comparison to evaluate potential water temperature–related effects.

Water temperature index values were selected from a comprehensive literature review. This was done to show an evenly spaced water temperature range that provides conditions reportedly ranging from optimal to lethal for juvenile rearing and downstream movement by Chinook salmon. Water temperature index values were determined

Table G-AQUA2.4-3. Water temperature index values and supporting literature for Chinook salmon juvenile rearing and downstream movement.

Index Value	Supporting Literature
60°F	• The optimum water temperature for Chinook salmon fry growth is between 55.0°F and 60°F (Seymour 1956). • The water temperature range that produced optimum growth in juvenile Chinook salmon was between 54.0°F and 60.0°F (Rich 1987). • A water temperature criterion of less than or equal to 60.0°F is required for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NOAA Fisheries 1993). • The upper optimal water temperature limit for Sacramento River fall-run Chinook salmon fry and fingerlings is 60.8°F (Marine 1997). • An upper water temperature limit of 60.0°F is preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NOAA Fisheries 2000; NOAA Fisheries 2002a). • To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NOAA Fisheries 1997b). • A water temperature of 60°F appears closest to the optimum for growth of fingerlings (Banks et al. 1971). • Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60 percent of that required to satiate them (Brett et al. 1982)
63°F	• Acceleration and inhibition of development of Sacramento River Chinook salmon smolts reportedly may occur at water temperatures above 62.6°F (Marine 1997). • Laboratory evidence suggests that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). • Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985).

**Table G-AQUA2.4-3. Water temperature index values and supporting literature for
Chinook salmon juvenile rearing and downstream movement.**

Index Value	Supporting Literature
65°F	• Water temperatures between 45°F and 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NOAA Fisheries 2002a). • The recommended summer maximum water temperature for migration and non-core rearing is 64.4°F (USEPA 2003). • Water temperatures greater than 64.0°F are considered not "properly functioning" by NOAA Fisheries in Amendment 14 to the Pacific Coast Salmon Plan (NOAA Fisheries 1995). • Fatal infection rates caused by *Cytophaga columnaris* are high at temperatures greater than or equal to 64.0°F (Fryer and Pilcher 1974 in USEPA 2001). • Disease mortalities diminish at water temperatures below 65.0°F (Ordal and Pacha 1963). • Fingerling Chinook salmon reared in water temperatures greater than 65.0°F contracted *C. columnaris* and exhibited high mortality (Johnson and Brice 1953). • Water temperatures greater than 64.9°F are identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). • Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett et al. 1982). • Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999).
65°F (continued)	• The optimal range for Chinook salmon survival and growth is from 53.0°F to 64.0°F (USFWS 1995). • Survival rates of Central Valley juvenile Chinook salmon decline at water temperatures greater than 64.4°F (Myrick and Cech 2001). • There is an increased incidence of disease, reduced appetite, and reduced growth rates at water temperatures of 66.2°F ± 1.4°F (Rich 1987).
68°F	• Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68.0°F suffer reductions in appetite and growth (Marine 1997). • There may be significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, when chronic elevated water temperatures exceed 68°F (Marine 1997). • Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F and 68°F; the colder water temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). • Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck 1980). • Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (Lindsay et al. 1986 in (McCullough 1999),

Table G-AQUA2.4-3. Water temperature index values and supporting literature for Chinook salmon juvenile rearing and downstream movement.

Index Value	Supporting Literature
70°F	• No growth at all would occur in Nechako River juvenile Chinook salmon at 70.5°F (Brett et al. 1982). • Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck 1980). • Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (Lindsay et al. 1986 in (McCullough 1999). • Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates was found at 69.8°F ± 1.8°F (Rich 1987).
75°F	• For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2°F was determined to be 100 percent lethal due to hyperactivity and disease (Rich 1987). • The lethal water temperature threshold for fall-run juvenile Chinook salmon was between 74.3°F and 76.1°F (NAS 1972 in McCullough 1999).

largely by emphasizing the results of laboratory experiments that examined how water temperature affects Central Valley Chinook salmon and by considering regulatory documents, such as Biological Opinions from NOAA Fisheries. Studies on fish from outside the Central Valley were used to supplement findings from local studies.

The lowest water temperature index value selected was 60°F; this temperature was chosen because regulatory documents and several source studies, including ones recently conducted on Central Valley Chinook salmon fry, fingerlings, and smolts, report 60°F as an optimal water temperature for growth (Banks et al. 1971; Brett et al. 1982; Marine 1997; NOAA Fisheries 1997b; NOAA Fisheries 2000; NOAA Fisheries 2001a; NOAA Fisheries 2002b; Rich 1987). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but these were not selected as index values because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990a; Taylor 1990b). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997). 62.6°F was rounded and used to support an index value of 63ºF.

65°F was selected as an index value because it represents an intermediate value between 64.0°F and 66.2°F, at which both adverse and beneficial effects on juvenile salmonids have been reported. For example, at temperatures approaching and exceeding 65°F, sublethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (USEPA 2003; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987). Conversely, numerous studies report that water temperatures between 64.0°F and 66.2°F provide conditions reportedly ranging from suitable to optimal for juvenile Chinook salmon growth (Brett et al. 1982; Cech and Myrick 1999; Myrick and Cech 2001; NOAA Fisheries 2002a; USFWS 1995).

68°F was selected as an index value because at water temperatures above 68°F, further sublethal effects, such as reductions in appetite and growth of juveniles as well as prohibition of smoltification, become severe (Marine 1997; Rich 1987; Zedonis and Newcomb 1997).

Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at water temperatures close to 70.0°F and growth was reported to be completely prohibited at 70.5°F (Brett et al. 1982; Marine 1997).

75°F was chosen as the highest water temperature index value because high levels of direct mortality of juvenile Chinook salmon reportedly result at this water temperature (Rich 1987). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was chosen because it was derived from experiments using Central Valley Chinook salmon and because it is a more rigorous index value that represents a more protective upper lethal water temperature level. Furthermore, the lethal level determined by Rich (1987) was derived using slow rates of water temperature change and thus is ecologically relevant. Additional support for an index value of 75°F is provided from a study conducted by Baker et al. (1995), in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests 95 percent confidence that the upper incipient lethal water temperature for Chinook salmon smolts is 71.5°F to 75.4°F.

G-AQUA2.4.1.3 Predation-related Effects

The high concentration of spawning salmonids in the reach of the Feather River between the Fish Barrier Dam and the Thermalito Afterbay Outlet results in a high concentration of juvenile salmonids (Seesholtz et al. 2003). Additionally, Seesholtz et al. (2003) reported that most outmigration of juvenile Chinook salmon occurs between January and March. Based on historic accounts of juvenile salmonid emigration, the current peak in the emigration period is somewhat earlier than under pre-dam conditions (Painter et al. 1977; Warner 1955). Seesholtz et al. (2003) speculate that the early emigration may be caused by competition for resources resulting from unnaturally high populations of juvenile salmonids.

Water temperature and flow changes included as components of the alternatives affect predator fish species distribution, relative abundance, feeding behavior, and consumption rates. Water temperature changes, flow changes, and actions anticipated to improve the quantity, quality, and distribution of rearing habitat for juvenile salmonids (i.e., large woody debris placement and side-channel habitat improvement and creation) also affect rearing behavior and duration, growth rates, predator avoidance cover, and emigration timing and behavior of juvenile Chinook salmon. The alternatives were evaluated qualitatively to determine the nature and general magnitude of potential predation-related effects on juvenile rearing and downstream movement by Chinook salmon. Section G-AQUA1.11.3 of Appendix G-AQUA1 contains a summary report and additional information on project effects on salmonid predation.

G-AQUA2.4.1.4 Fisheries Management–related Effects

There would be no changes in fish stocking or reservoir fisheries habitat enhancement programs under the alternatives; therefore, these programs are not included in the evaluation of alternatives. Adaptive hatchery management practices are included in the Proposed Action and Alternative 2, and include proposals for experimental releases of different sized juvenile fish at different times and locations, predator avoidance and cover utilization conditioning, changes to brood stock selection, disease management and screening, and other hatchery management changes. These changes in hatchery management were evaluated qualitatively for their potential effects on predation, juvenile rearing and emigration survival rates, adult immigration straying rates, genetic introgression, and the incidences of fish diseases. Section G-AQUA1.5.1 of Appendix G-AQUA1 contains additional information related to salmonid management–related effects.

Fishing Regulations

Increases in recreation access, including increases in visitation and fisheries-related use of recreational resources, are anticipated under all of the alternatives. Chapter 3.0, Proposed Action and Alternatives, contains descriptions of recreation-related changes included in each of the alternatives, and Section 5.10 contains evaluations of recreation-related effects. Effects of increased recreational fishing and poaching on angling-related mortality and the contribution to adult pre-spawning mortality rates were evaluated qualitatively to determine the effects on fisheries resources, and specifically, on Chinook salmon.

Fish barrier weirs for Chinook salmon are included in the Proposed Action and Alternative 2, which are described in detail in Chapter 3.0, Proposed Action and Alternatives. These actions would result in changes in fishing regulations. Therefore, placement of barrier weirs was evaluated qualitatively to determine their effects on fishing take limits and poaching. Effects on recreational activities resulting from changes in fishing regulations associated with these actions are included in Section 5.10.

G-AQUA2.4.2 Steelhead/Rainbow Trout

Similar to the Chinook salmon analyses, the steelhead effects analysis is based upon individual life stages, because each life stage has specific flow and water temperature requirements. The steelhead life stages included in this analysis are:

- Adult immigration and holding (September through April 15);
- Adult spawning and embryo incubation (December through May);
- Fry and fingerling rearing and downstream movement (year-round); and
- Smolt emigration (January through June).

More detailed descriptions of steelhead life stages and periods are provided in Section 5.7.2.1, Affected Environment—Fish Species.

G-AQUA2.4.2.1 Flow-related Effects

Quantitative analyses of the alternatives were conducted for steelhead adult spawning and embryo incubation using the available PHABSIM WUA index of the relationship of flow to availability of steelhead spawning habitat for the Low Flow Channel and High Flow Channel in the lower Feather River. Section G-AQUA2.4.1 of this appendix provides additional detail describing the PHABSIM analysis conducted; Figures G-AQUA2.4-1 and G-AQUA2.4-2 show the steelhead WUA index curves for the Low Flow Channel and High Flow Channel, respectively.

Analysis of available spawning area using PHABSIM model results does not provide information regarding the potential for stage reductions during the embryo incubation portion of the adult spawning and embryo incubation life stage. Flows under the alternatives would remain constant in the Low Flow Channel, however, and would fluctuate within the minimum flow and maximum flow agreed upon by DFG and DWR in the High Flow Channel; therefore, further quantitative analysis of flow fluctuations in the Low Flow Channel or High Flow Channel is unnecessary.

Flow changes and flow fluctuations associated with the alternatives were evaluated qualitatively for potential effects on steelhead/rainbow trout adult immigration and holding, steelhead/rainbow trout fry and fingerling rearing and downstream movement, and steelhead smolt emigration. The objective of this analysis was to determine the relative changes to the fish habitat with respect to water depth, water velocity, and the amount of inundated habitat area compared to the known fish distribution and relative abundance.

G-AQUA2.4.2.2 Water Temperature–related Effects

A three-phased water temperature assessment was performed to evaluate potential water temperature–related effects on adult immigration and holding by steelhead/rainbow trout, adult spawning and embryo incubation by steelhead/rainbow trout, rearing and downstream movement by steelhead/rainbow trout fry and fingerlings, and emigration by steelhead smolts. For a detailed description of the water temperature–related effects analysis process, see Section G-AQUA2.2.3 of this appendix. The balance of this subsection documents the basis of selection of the water temperature index values and defines the biological effects that are reported to be associated with exposure at or above the water temperature index values used in the analysis.

Water temperature index values were developed for steelhead/rainbow trout life stages from an extensive review of available literature to be used as guidelines for assessing potential effects associated with each alternative. The specific index values developed for each steelhead/rainbow trout life stage are discussed below. The derivation and description of each water temperature index value and each life stage also is included in the following discussion.

Adult Immigration and Holding (September through April 15)

Description of Life Stage

Most Central Valley steelhead spend 1–2 years in the ocean before entering fresh water in August, with a peak in late September to October. Steelhead then hold in fresh water until spawning. Movement of adult steelhead from freshwater holding areas to spawning grounds generally can occur any time from December to March, with peak activities occurring in January and February (Moyle 2002). In the Feather River, the adult immigration and holding time period lasts from September through mid-April, with peak migration extending from October through November (pers. comm., Cavallo 2004; McEwan 2001; Moyle 2002; S. P. Cramer & Associates 1995).

The adult immigration and adult holding life stages are evaluated together in this subsection because it is difficult to determine the thermal regime to which steelhead have been exposed before spawning. Additionally, to be sufficiently protective of pre-spawning fish, water temperatures that provide high adult survival and high in-vivo egg survival must be available throughout the entire pre-spawning freshwater period. Although there is a paucity of studies examining the effects of thermal stress on immigrating steelhead, it has been demonstrated that thermal stress during the upstream spawning migration of sockeye salmon negatively affected the secretion of hormones controlling sexual maturation, causing numerous reproductive impairments (Macdonald et al. in McCullough et al. 2001).

Index Value Selection Rationale

Water temperatures of 52°F, 56°F, and 70°F were used as evaluation guidelines to assess the potential effects of each alternative relative to the basis of comparison. For each month of the adult immigration and holding period, each alternative was compared to the basis of comparison to evaluate potential water temperature–related effects on steelhead adult immigration and holding. Water temperatures can control 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, and none of these studies have been recent (Billard and Breton 1977, Billard and Gillet 1981, and Strickland 1967 in McCullough et al. 2001; Bruin and Waldsdorf 1975). The available studies suggest that there are adverse effects on immigrating and holding steelhead at water temperatures exceeding the mid

50°F range, and that immigration would be delayed if water temperatures approach approximately 70°F (see Table G-AQUA2.4-4).

Table G-AQUA2.4-4. Water temperature index values and supporting literature for steelhead adult immigration and holding.

Index Value	Supporting Literature
52°F	• The preferred temperature range for adult steelhead immigration is 46.0°F to 52.0°F (NOAA Fisheries 2000; NOAA Fisheries 2002a; State Water Resources Control Board 2003). • The optimum temperature range for adult steelhead immigration is 46.0°F to 52.1°F (USBR 1997). • The recommended temperature range for adult steelhead immigration is 46.0°F to 52.0°F (USBR 2003).
56°F	• To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). • Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2–6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). • Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough et al. 2001).
70°F	• Migration barriers have frequently been reported for Pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough et al. 2001). • Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (Strickland 1967 in McCullough et al. 2001). • A water temperature of 68°F was found to drop egg fertility in vivo to 5 percent after 4.5 days (Billard and Breton 1977 in McCullough et al. 2001).

Water temperatures of 52°F, 56°F, and 70°F were chosen because they incorporate a range of conditions—from conditions that are reported to have no adverse affects to conditions that are highly adverse—and because the available literature provided the strongest support for these values. Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of water temperature index values could not be achieved. 52°F was selected as a water temperature index value because it has been referred to as a “recommended” (USBR 2003), “preferred” (NOAA Fisheries 2002a), and “optimum” (USBR 1997) water temperature for steelhead adult immigration. 56°F was selected because 56°F represents a water temperature above which adverse effects on migratory and holding steelhead begin to arise (Leitritz and Lewis 1980; McCullough et al. 2001; Smith et al. 1983). 70°F was selected as the highest water temperature index value because the literature suggests that water temperatures near and above 70.0°F present a thermal barrier to adult steelhead migrating upstream (McCullough et al. 2001); Strickland 1967 in McCullough et al. 2001).

Adult Spawning and Embryo Incubation (December through May)

Description of Life Stage

Steelhead spawning includes the time period from redd construction until spawning is completed with the deposition and fertilization of eggs. The embryo incubation period extends from egg deposition through alevin emergence from the substrate. In the

Central Valley, steelhead spawning reportedly occurs from October through June (McEwan 2001) and embryo (i.e., eggs and alevins) incubation generally lasts 2–3 months after deposition (McEwan 2001; Moyle 2002; Myrick and Cech 2001). In the Feather River, steelhead spawning and embryo incubation extends from December through May, with peak spawning occurring in January and February (Busby et al. 1996; pers. comm., Cavallo 2004; California Bay-Delta Authority Website; Moyle 2002). As with Chinook salmon, the steelhead embryo life stage is the most sensitive to water temperature. Because the initial embryo incubation water temperatures are a function of spawning water temperatures, one set of water temperature index values was established to evaluate spawning adults and incubating embryos.

Index Value Selection Rationale

Water temperatures of 52°F, 54°F, 57°F, and 60°F were used as evaluation guidelines to assess the potential effects of each alternative relative to the basis of comparison. For each month of the adult spawning and embryo incubation period, each alternative was compared to the basis of comparison to evaluate potential water temperature–related effects on adult spawning and egg incubation. Few studies have been published regarding the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of water temperature index values for steelhead spawning and embryo incubation (McEwan 2001; Moyle 2002). From the available literature, water temperatures in the low 50°F range appear to support high embryo survival rates, with substantial mortality of steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above (see Table G-AQUA2.4-5).

Table G-AQUA2.4-5. Water temperature index values and supporting literature for steelhead spawning and embryo incubation.

Index Value	Supporting Literature
52°F	• Rainbow trout from Mattighofen (Austria) had higher egg survival rates at 52.0°F than at 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). • Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NOAA Fisheries 2000; NOAA Fisheries 2001a; NOAA Fisheries 2002a). • The optimum water temperature range for steelhead spawning in the Central Valley is 46.0°F to 52.0°F (USFWS 1995). • The optimum water temperature range is 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (USBR 1997). • The upper limit of preferred water temperature for steelhead spawning and egg incubation is 52.0°F (State Water Resources Control Board 2003).

Table G-AQUA2.4-5. Water temperature index values and supporting literature for steelhead spawning and embryo incubation.

Index Value	Supporting Literature
54°F	• Big Qualicum River steelhead eggs had 96.6 percent survival to hatch at 53.6°F (Rombough 1988). • The highest survival rate from fertilization to hatch for *Oncorhynchus mykiss* was for those incubated at 53.6°F (Kamler and Kato 1983). • Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F rather than at 60.8°F (Redding and Schreck 1979). • The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (USEPA 2001). • From fertilization to hatch, rainbow trout eggs and larvae had 47.3 percent mortality (Timoshina 1972). • Survival of rainbow trout eggs declined at water temperatures between 52.0°F and 59.4°F (Humpesch 1985). • The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough et al. 2001).
57°F	• From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). • A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kato 1980 in Kamler and Kato 1983).
60°F	• From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). • From fertilization to 50 percent hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56 percent survival when incubated at 59.0°F (Kwain 1975).

Water temperatures of 52°F, 54°F, 57°F, and 60°F were selected for two reasons. First, the available literature provided the strongest support for water temperature index values at or near these levels, and second, the index values reflect an evenly distributed range reported as optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests that water temperatures less than or equal to 50°F are optimal for steelhead spawning and embryo survival (Myrick and Cech 2001; Timoshina 1972); however, a larger body of literature suggests that optimal conditions occur at water temperatures less than or equal to 52°F (Humpesch 1985; NOAA Fisheries 2000; NOAA Fisheries 2001a; NOAA Fisheries 2002a; State Water Resources Control Board 2003; USBR 1997; USFWS 1995). Therefore, 52°F was selected as the lowest water temperature index value.

54°F was selected as the next index value because, although most of the studies conducted at or near 54.0°F report high survival rates and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress begin to appear at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions and conditions that cause negative effects on steelhead spawning and embryo incubation.

57°F was selected as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57.0°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50 percent hatch under incubation temperatures ranging from 33.8°F to 60.8°F, and demonstrated a twofold increase in mortality for embryos incubated at 57.2°F compared to embryos incubated at 53.6°F.

The 60°F index value was selected because further increases in embryonic abnormalities occurred at water temperatures near 60°F. For example, a laboratory study using gametes from Big Qualicum River, Vancouver Island, reported that steelhead mortality increased to 15 percent at a constant temperature of 59.0°F compared to less than 4 percent mortality at constant water temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59.0°F were considerably smaller and appeared less well developed than those incubated at the lower water temperature treatments. From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987).

Fry and Fingerling Rearing and Downstream Movement (Year-round)

Description of Life Stage

The juvenile life stage is composed of fry and fingerlings. Steelhead are fry from the time that the juvenile leaves the gravel of the spawning redd to swim up into the water column as a free-swimming fish until skeletal development is complete, at which point it reaches the fingerling stage (Bovee et al. 1998). Steelhead fry make the transition to the fingerling stage at approximately 45 to 60 mm (Bovee et al. 1998; Moyle 2002; NOAA Fisheries 1997a). After Central Valley steelhead emerge from the gravel, juveniles remain in fresh water for 1–3 years before smolting and migrating to salt water (Myrick and Cech 2001). Shapovalov and Taft (1954) suggest that most Waddell Creek, California, steelhead rear in fresh water for 2 years.

Index Value Selection Rationale

Water temperatures of 65°F, 68°F, 72°F, and 75°F were used as index values to assess the potential effects of each alternative relative to the basis of comparison. For each month of the rearing and downstream movement period for steelhead fry and fingerlings, each alternative was compared to the basis of comparison to evaluate potential water temperature–related effects on fry and fingerling rearing and downstream movement.

As with other salmonids, growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making steelhead more vulnerable to changes in the natural water temperature regime. Central Valley juvenile steelhead have high growth rates at water temperatures in the mid 60°F range, but require lower water temperatures to successfully undergo transformation to the smolt stage (see Tables G-AQUA2.4-6 and G-AQUA2.4-7). Water temperature index values of 65°F, 68°F, 72°F, and 75°F were selected to represent an evenly distributed range of water temperatures that reportedly provide optimal to lethal conditions for steelhead fry and fingerling rearing and downstream movement.

65°F was selected as the lowest water temperature index value because NOAA Fisheries (2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the reportedly preferred water temperature range (i.e., 62.6°F to 68.0°F) and the range that supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999).

Table G-AQUA2.4-6. Water temperature index values and supporting literature for steelhead fry and fingerling rearing and downstream movement.

Index Value	Supporting Literature
65°F	• An upper limit of 65°F is preferred for growth and development of Sacramento River and American River juvenile steelhead (NOAA Fisheries 2002a). • Nimbus strain juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). • The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry et al. 1977). • Nimbus strain juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). • Rainbow trout fingerlings selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971).
68°F	• Nimbus strain juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). • The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry et al. 1977). • The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya et al. 1977).
72°F	• Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen et al. 1994). • The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya et al. 1977). • Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole et al. 2001 in USEPA 2002).
75°F	• The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (USEPA 2002). • Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NOAA Fisheries 2001b). • Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole et al. 2001 in USEPA 2002).

Table G-AQUA2.4-7. Water temperature index values and supporting literature for steelhead smolt emigration.

Index Value	Supporting Literature
52°F	• Steelhead successfully undergo the smolt transformation at water temperatures in the 43.7°F to 52.3°F range (Myrick and Cech 2001). • Steelhead undergo the smolt transformation when reared in water temperatures below 52.3°F, but not at higher water temperatures (Adams et al. 1975). • The optimum water temperature range for successful smoltification in young steelhead is 44.0°F to 52.3°F (Rich 1987).
55°F	• ATPase activity was decreased and migration reduced for steelhead at water temperatures greater than or equal to 55.4°F (Zaugg and Wagner 1973). • Water temperatures should be below 55.4°F at least 60 days before the release of hatchery steelhead to prevent premature smolting and desmoltification (Wedemeyer et al. 1980). • In winter steelhead, a water temperature of 54.1°F is nearly the upper limit for smolting (McCullough et al. 2001). • Water temperatures less than or equal to 54.5°F are suitable for emigrating juvenile steelhead (USEPA 2003).

Cherry et al. (1977) and Kaya et al. (1977) both reported an upper preferred water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead reported by Cech and Myrick (1999). Because a body of evidence supporting 68.0°F as the upper preferred limit for juvenile *Oncorhynchus mykiss* existed, 68°F was selected as a water temperature index value.

72°F was selected as a water temperature index value because symptoms of thermal stress in juvenile steelhead have been reported to occur at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen et al. 1994). Also, 72°F was selected as an index value because 71.6°F has been reported as an upper avoidance water temperature (Kaya et al. 1977) and an upper thermal tolerance water temperature (Ebersole et al. 2001 in USEPA 2002) for juvenile rainbow trout.

Smolt Emigration (January through June)

Description of Life Stage

Fingerling steelhead become smolts when physiological changes occur that allow the juvenile to survive the transition from fresh water to salt water during seaward migration. In addition to physiological changes, morphological changes also take place during smoltification (Hoar 1988). Salmonid smolts can be distinguished from pre-smolts by their silvery appearance and relatively slim, streamlined bodies (Hoar 1988). Steelhead smolts migrate out to sea between 1 and 3 years of age, between 10 and 25 centimeters (cm) fork length (FL) (Moyle 2002). In the Feather River, steelhead smolt emigration occurs from January through June (pers. comm., Cavallo 2004; McEwan 2001; Newcomb and Coon 2001; Snider and Titus 2000; USFWS 1995).

Index Value Selection Rationale

Water temperatures of 52°F and 55°F were used as index values to assess the potential effects of each alternative relative to the basis of comparison. For each month of the steelhead smolt emigration period, each alternative was compared to the basis of comparison to evaluate potential water temperature–related effects on smolt emigration. Laboratory data suggest that smoltification, and therefore successful emigration of juvenile steelhead, is directly controlled by water temperature (Adams et al. 1973; Adams et al. 1975).

Water temperature index values of 52°F and 55°F were selected to evaluate the steelhead smolt emigration life stage because most literature on the effects of water temperature on steelhead smolting suggest that water temperatures less than 52°F (Adams et al. 1975; Myrick and Cech 2001; Rich 1987) or less than 55°F (USEPA 2003; McCullough et al. 2001; Wedemeyer et al. 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. Adams et al. (1975) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F, or 68.0°F) on the increase of gill microsomal Na^+-, K^+-stimulated ATPase activity associated with parr-smolt transformation in steelhead; this study found a twofold increase in Na^+-, K^+-ATPase at 43.7°F and 50.0°F, but no increase at 59.0°F or 68.0°F. In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams et al. 1973). The results of Adams et al. (1973) were reviewed by Myrick and Cech (2001) and Rich (1987); in both cases the authors recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead; this study found that ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by USEPA to provide temperature water quality standards for the protection of native salmon and trout in the Northwest, water temperatures less than or equal to 54.5°F were recommended for emigrating juvenile steelhead (USEPA 2003).

G-AQUA2.4.2.3 Predation-related Effects

As discussed above for Chinook salmon, the high concentration of spawning salmonids in the reach of the Feather River between the Fish Barrier Dam and the Thermalito Afterbay Outlet results in a high concentration of juvenile salmonids (Seesholtz et al. 2003). In addition, water temperature and flow changes included as components of the alternatives affect predator fish species distribution, relative abundance, feeding behavior, and consumption rates. Water temperature, flow changes, and actions anticipated to improve the quantity, quality, and distribution of rearing habitat for juvenile salmonids (large woody debris placement and side-channel habitat improvement and creation) also affect steelhead fry and fingerling rearing behavior and distribution, growth rates, predator avoidance cover, and smolt emigration timing and behavior. The alternatives were evaluated qualitatively to determine the nature and general magnitude of potential predation-related effects on rearing and downstream movement by steelhead fry and fingerlings. Section G-AQUA1.11.3 of Appendix G-AQUA1 contains additional information related to salmonid predation.

G-AQUA2.4.2.4 Fisheries Management–related Effects

There would be no changes in fish stocking or reservoir fisheries habitat enhancement programs under the alternatives; therefore, these programs are not included in the evaluation of alternatives. Adaptive hatchery management practices are included in the Proposed Action and Alternative 2 and include proposals for experimental releases of different sized juvenile fish at different times and locations, predator avoidance and cover utilization conditioning, changes to brood stock selection, disease management and screening, and other hatchery management changes. These changes in hatchery management were evaluated qualitatively for their potential effects on predation, juvenile rearing and emigration survival rates, adult immigration straying rates, genetic introgression, and the incidences of fish diseases. Section G-AQUA1.5.1 of Appendix G-AQUA1 contains additional information related to the effects of salmonid management on Feather River fishes.

Fishing Regulations

Increases in recreation access, including increases in visitation and fisheries-related use of recreational resources, are anticipated under all of the alternatives. Chapter 3.0, Proposed Action and Alternatives, contains descriptions of recreation-related changes included in each of the alternatives; Section 5.10 contains evaluations of recreation-related effects. Effects of increased recreational fishing and poaching on angling-related mortality and the contribution to adult pre-spawning mortality rates were evaluated qualitatively to determine effects on fisheries resources, and specifically, on steelhead.

Fish barrier weirs for Chinook salmon are included in the Proposed Action and Alternative 2, which are described in detail in Chapter 3.0, Proposed Action and Alternatives. These actions would result in changes in fishing regulations. Therefore, placement of barrier weirs was evaluated qualitatively to determine their effects on fishing take limits and poaching. Effects on recreational activities resulting from changes in fishing regulations associated with these actions are included in Section 5.10.

G-AQUA2.4.3 American Shad

G-AQUA2.4.3.1 Flow-related Effects

Flow changes and flow fluctuations associated with the alternatives were evaluated qualitatively to determine the potential effects on adult immigration and spawning by American shad based on the relative changes to the fish habitat with regard to water depth, water velocity, and fish passage impediments compared to the known fish distribution and relative abundance. The American shad spawning migration period in the Feather River occurs from April through June. Sections G-AQUA1.4.2 and

G-AQUA1.4.3 of Appendix G-AQUA1 provide additional information on American shad immigration and potential flow-related passage impediments in the lower Feather River.

G-AQUA2.4.3.2 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. The reported suitable water temperature range for adult immigration and spawning by American shad is 46°F to 79°F, and this life stage occurs from April through June in the lower Feather River (DFG 1986; Leggett and Whitney 1972; Moyle 2002; Painter et al. 1979; USFWS 1995; Walburg and Nichols 1967; Wang 1986).

Because of the limitations of available literature in reporting effects of specific water temperatures on adult immigration and spawning by American shad, the water temperature index values selected represent the range of water temperatures reported as "preferred," "optimal," or "suitable," or water temperatures in which the species has been observed. The water temperature analysis for American shad habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable American shad habitat during the life stage period evaluated. Section 5.5.1.3, Fish Species Overview, and Section G-AQUA1.4.2 of Appendix G-AQUA1 provide additional information on American shad life history, and habitat and water temperature requirements.

G-AQUA2.4.4 Black Bass

G-AQUA2.4.4.1 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. The reported suitable water temperature range for black bass adult spawning is 54°F to 75°F, and this life stage occurs from March through June in the lower Feather River (Aasen and Henry 1981; Davis and Lock 1997; Graham and Orth 1986; Lee 1999; Lukas and Orth 1995; McKechnie 1966; Miller and Storck 1984; Moyle 2002; Sammons et al. 1999; pers. comm., See 2003; Wang 1986).

The water temperature analysis for black bass habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable black bass habitat during the life stage period evaluated. The black bass analysis includes several fish species with similar water temperature requirements, including largemouth bass, smallmouth bass, redeye bass, and spotted bass. Because of the limitations of available literature in reporting effects of specific water temperatures on black bass adult spawning, the water temperature index values selected represent the range of water temperatures reported as "preferred," "optimal," or "suitable," or water temperatures in which the species has been observed. Section 5.5.1.3, Fish Species Overview, and Sections G-AQUA1.4.2, G-AQUA1.3.2, and G-AQUA1.3.4 of Appendix G-AQUA1 contain additional information on black bass life history, and habitat and water temperature requirements.

G-AQUA2.4.5 Green Sturgeon

The green sturgeon effect analysis is based upon individual life stages because each life stage has specific flow and water temperature requirements. The green sturgeon life stages included in this analysis are:

- Adult immigration and holding (February through July);
- Adult spawning and embryo incubation (March through July);
- Juvenile rearing (year-round); and
- Juvenile emigration (May through September).

More detailed descriptions of green sturgeon life stage water temperature requirements and periods are provided in Section 5.5.1.3, Fish Species Overview, and Section G-AQUA1.4.2 of Appendix G-AQUA1.

G-AQUA2.4.5.1 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. Green sturgeon water temperature index values were developed from an extensive review of the available literature to be used as guidelines for assessing potential effects of each alternative. The specific index values developed for each green sturgeon life stage are discussed below. Because of the limitations of available literature in reporting effects of specific water temperatures on green sturgeon, the water temperature index values selected represent the range of water temperatures reported as “preferred,” “optimal,” or “suitable,” or were the water temperatures in which the species has been observed. The water temperature analysis for green sturgeon habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable green sturgeon habitat during the life stage period evaluated.

Adult Immigration and Holding (February through July)

Water temperatures ranging from 44°F to 61°F are reported as “preferred,” “optimal,” “suitable,” or “observed” for adult immigration and holding by green sturgeon (Beamesderfer and Webb 2002; DFG 2001; DFG Website; Emmett et al. 1991; Environmental Protection Information Center et al. 2001; Erickson et al. 2002; USFWS 1995). The range of reported water temperatures was used as an evaluation guideline to assess the potential effects of each alternative on adult immigration and holding by green sturgeon relative to the basis of comparison.

Adult Spawning and Embryo Incubation (March through July)

Water temperatures ranging from 46°F to 68°F are reported as “preferred,” “optimal,” “suitable,” or “observed” for adult spawning and embryo incubation by green sturgeon (Artyukhin and Andronov 1990; Beamesderfer and Webb 2002; Cech Jr. et al. 2000;

DFG 2001; DFG Website; Environmental Protection Information Center et al. 2001; Erickson et al. 2002; Moyle et al. 1995; USFWS 1995). The range of reported water temperatures was used as an evaluation guideline to assess the potential effects of each alternative on adult spawning and embryo incubation by green sturgeon relative to the basis of comparison.

Juvenile Rearing (Year-round)

Water temperatures ranging from 50°F to 66°F are reported as “preferred,” “optimal,” “suitable,” or “observed” for green sturgeon juvenile rearing (Cech Jr. et al. 2000; Conservation Management Institute, Virginia Tech Website; Environmental Protection Information Center et al. 2001; Farr et al. 2001; Moyle 2002; NOAA Fisheries 2003a). The range of reported water temperatures was used as an evaluation guideline to assess the potential effects of each alternative on green sturgeon juvenile rearing relative to the basis of comparison.

Juvenile Emigration (May through September)

Water temperatures ranging from 50°F to 66°F are reported as “preferred,” “optimal,” “suitable,” or “observed” for green sturgeon juvenile emigration (Adams et al. 2002; Beamesderfer and Webb 2002; Cech Jr. et al. 2000; Conservation Management Institute, Virginia Tech Website; Environmental Protection Information Center et al. 2001; Erickson et al. 2002; Farr et al. 2001; Moyle 2002; NOAA Fisheries 2003a). The range of reported water temperatures was used as an evaluation guideline to assess the potential effects of each alternative on green sturgeon juvenile emigration relative to the basis of comparison.

G-AQUA2.4.6 Hardhead

G-AQUA2.4.6.1 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. The reported suitable water temperature range for hardhead adult spawning is 55°F to 75°F, and this life stage occurs from April through August in the lower Feather River (Cech Jr. et al. 1990; Moyle 2002; Wang 1986). The water temperature analysis for hardhead habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable hardhead habitat during the life stage period evaluated.

Because of the limitations of available literature in reporting effects of specific water temperatures on hardhead adult spawning, the water temperature index values selected represent the range of water temperatures reported as “preferred,” “optimal,” or “suitable,” or are the water temperatures in which the species has been observed. Section 5.5.1.3, Fish Species Overview, and Section G-AQUA1.4.2 of Appendix G-AQUA1 provide additional information on hardhead life history, and habitat and water temperature requirements.

G-AQUA2.4.7 River Lamprey

G-AQUA2.4.7.1 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. The water temperature range defined as suitable for adult spawning and embryo incubation by river lamprey is 43°F to 72°F, and this life stage reportedly occurs from April through June in the lower Feather River (Beamish 1980; Kostow 2002; Meeuwig et al. 2003; Meeuwig et al. 2002; Moyle 2002; Stone et al. 2001; Wang 1986). Because little literature was available regarding the life stage timing of and water temperature tolerance range for adult spawning and embryo incubation, literature describing Pacific lamprey (*Lampetra tridentata)* also was used as a substitute given the reported similarities between the two species. The water temperature analysis for river lamprey habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable river lamprey habitat during the life stage period evaluated.

Because of the limitations of available literature in reporting effects of specific water temperatures on adult spawning by river lamprey, the water temperature index values selected represent the range of water temperatures reported as "preferred," "optimal," or "suitable," or are the water temperatures in which the species has been observed. Section 5.5.1.3, Fish Species Overview, and Section G-AQUA1.4.2 of Appendix G-AQUA1 provide additional information on river lamprey life history, and habitat and water temperature requirements.

G-AQUA2.4.8 Sacramento Splittail

G-AQUA2.4.8.1 Flow-related Effects

Site-specific flow-related effects on the availability of habitat for the adult spawning, embryo incubation, and initial rearing life stages of the Sacramento splittail were evaluated using a relative habitat availability index (see Section G-AQUA1.4.3 of Appendix G-AQUA1 for additional information). Splittail adult spawning, embryo incubation, and initial rearing occur in the lower portions of the lower Feather River from February through May. The relative amount of available habitat for adult spawning, embryo incubation, and initial rearing by splittail was identified by locating habitat units that met the substrate requirements for the life stage (grass, shrub, and forb) from the SP-T4 vegetation classification mapping. Elevation data on selected potentially suitable habitat units were collected by DWR surveyors. The elevation ranges of the potential habitat units were compared to the nearest available U.S. Geological Survey (USGS) survey transect containing stage-discharge relationships established by SP-E1.6, Feather River Flow-Stage Model Development, to determine the flow ranges that would inundate each habitat unit to the reported suitable depth range of 3–6 feet deep. The amount of habitat with suitable substrate and inundation depth available at each flow was summed to create an index of the relative amount of spawning and initial rearing habitat for splittail available in the lower Feather River at any given flow. This index is shown in Figure G-AQUA2.4-3.

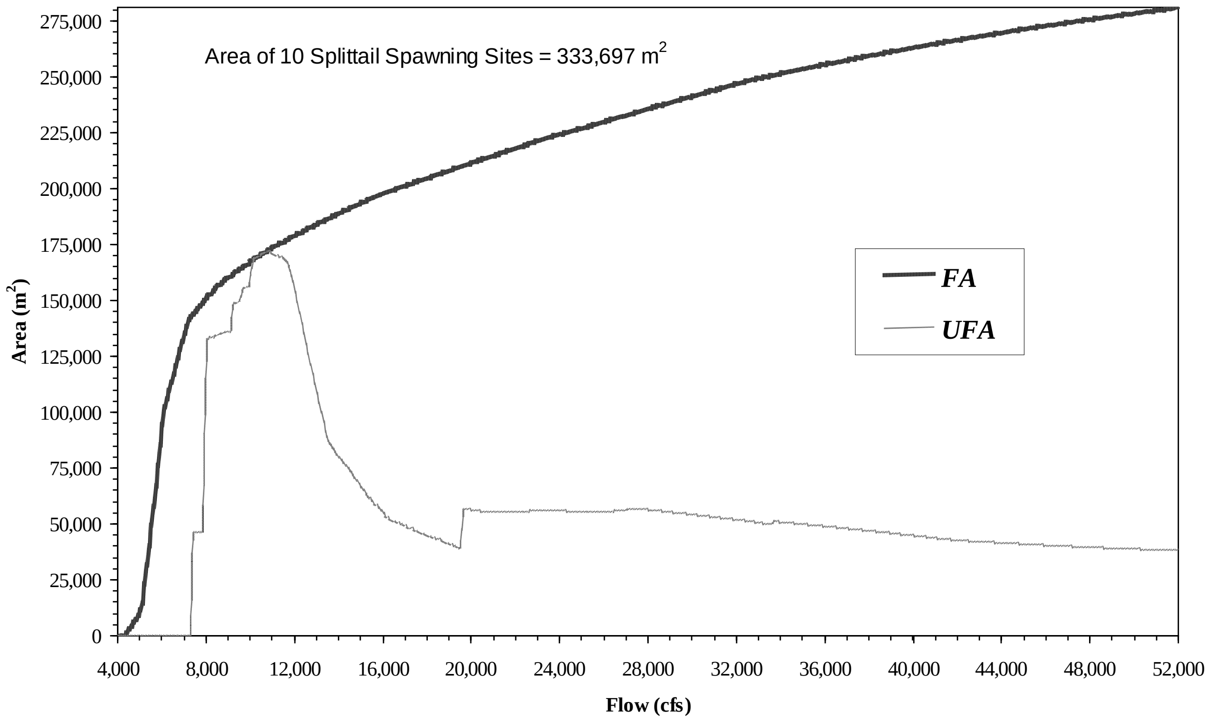

Figure G-AQUA2.4-3. Flow, or flooded area (FA), vs. useable flooded area (UFA) for adult spawning, egg incubation, and initial rearing by Sacramento splittail in the High Flow Channel.

The modeling results, which show lower Feather River flows under the alternatives during the February-through-May splittail adult spawning, embryo incubation, and initial rearing period over the 72-year period of record, were evaluated to determine the differences in the total resulting amount of available habitat. The total resulting amount of habitat available was calculated by multiplying the amount of useable flooded area (UFA) by the flows that occur during the February-through-May life stage period. The amounts of total available habitat were compared proportionately between the alternatives and the basis of comparison to determine the type and relative magnitude of habitat availability change that would occur with implementation of the alternatives. Section 5.5.1.3, Fish Species Overview, and Sections G-AQUA1.4.2 and G-AQUA1.4.3 of Appendix G-AQUA1 provide additional information on Sacramento splittail life history and habitat requirements.

G-AQUA2.4.8.2 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. The reported suitable water temperature range for adult spawning, egg incubation, and initial rearing by Sacramento splittail is 45°F to 75°F, and this life stage occurs from February through May in the lower Feather River. Young and Cech Jr. (1996) investigated thermal tolerances for juvenile splittail and reported a tolerance range of 7°C to 32°C (44.6°F to 89.6°F). Caywood (1974) reported splittail spawning in water temperatures from 9°C to 20°C

(48.2°F to 68.0°F). Sommer et al. (2002) reported splittail spawning in water temperatures from 11°C to 24°C (51.8°F to 75.2°F). The water temperature analysis for splittail habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable splittail habitat during the life stage period evaluated.

Because of the limitations of available literature in reporting the effects of specific water temperatures on splittail adult spawning, embryo incubation, and initial rearing, the water temperature index values selected represent the range of water temperatures reported as “preferred,” “optimal,” or “suitable,” or were water temperatures in which the species has been observed. Section 5.5.1.3, Fish Species Overview, and Sections G-AQUA1.4.2 and G-AQUA1.4.3 of Appendix G-AQUA1 provide additional information on Sacramento splittail life history habitat and water temperature requirements.

G-AQUA2.4.9 Striped Bass

G-AQUA2.4.9.1 Flow-related Effects

Flow changes and flow fluctuations associated with the alternatives were evaluated qualitatively for the potential effects on striped bass adult spawning for the relative changes to the fish habitat with regard to water depth, water velocity, and fish passage impediments compared to the known fish distribution and relative abundance. The striped bass adult spawning period in the lower Feather River occurs from April through June. Section 5.5.1.3, Fish Species Overview, and Section G-AQUA1.4.2 of Appendix G-AQUA1 provide additional information on striped bass adult spawning, egg incubation, and initial rearing and life history habitat requirements.

G-AQUA2.4.9.2 Water Temperature–related Effects

Water temperature–related effects were evaluated using the three-step process described in Section G-AQUA2.2.3 of this appendix. The reported suitable water temperature range for striped bass adult spawning is 59°F to 68°F, and this life stage occurs from April through June in the lower Feather River (Bell 1991; Hassler 1988; Hill et al. 1989; Moyle 2002). The water temperature analysis for striped bass adult spawning habitat compares the number of days of daily mean water temperatures that fall within the water temperature range reported as suitable striped bass adult spawning habitat during the life stage period evaluated.

Because of the limitations of available literature in reporting effects of specific water temperatures on striped bass adult spawning, the water temperature index values selected represent the range of water temperatures reported as “preferred,” “optimal,” or “suitable,” or were the water temperatures in which the species has been observed. Section 5.5.1.3, Fish Species Overview, and Section G-AQUA1.4.2 of Appendix G-AQUA1 provide additional information on striped bass life history habitat and water temperature requirements.

G-AQUA2.5 DETERMINATION OF EFFECTS

The evaluation process for determining potential effects resulting from implementation of the alternatives was based on the integration of the effects identified for each species and life stage selected for evaluation. The results of the evaluation of each life stage and qualitative analyses for a species were aggregated and evaluated to determine the overall effect of an alternative on a species. Positive and negative effects on the species and life stages were evaluated using professional experience and judgment to weigh the relative magnitude, biological effects, and importance of a life stage in contributing to the overall success and condition of the species. The overall effect of an alternative on a species was the basis for the evaluation of the alternatives. Sections 5.5.2 and 5.7.3.1 provide a summary of the overall effects of the alternatives on each species of primary management concern.

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