State of California
The Resources Agency
Department of Water Resources

FINAL REPORT
FISH PASSAGE MODEL
SP-F15, TASK 4

Oroville Facilities Relicensing
FERC Project No. 2100

JANUARY 2004

ARNOLD SCHWARZENEGGER
Governor
State of California

MIKE CHRISMAN
Secretary for Resources
The Resources Agency

LINDA S. ADAMS
Interim Director
Department of Water Resources

State of California
The Resources Agency
Department of Water Resources

FINAL REPORT
FISH PASSAGE MODEL
SP-F15, TASK 4

Oroville Facilities Relicensing
FERC Project No. 2100

This report was prepared under the direction of

Terry J. Mills ..... Environmental Program Manager I, DWR

by

Paul Bratovich .....Principal/Fisheries Technical Lead, SWRI
Bill Smith .....Principal/Modeling Technical Lead, SWRI
David Olson..... Senior Environmental Scientist/Project Manager, SWRI

Assisted by

Adrian Pitts .....Environmental Scientist, SWRI
Erin Gibson .....Environmental Scientist, SWRI
John Cornell .....Environmental Scientist, SWRI
Ben Ransom .....Environmental Scientist, SWRI
Amanda O'Connell .....Environmental Planner, SWRI

REPORT SUMMARY

Ongoing operation of the Oroville Facilities and structures prohibit passage of anadromous and migratory fish in the Feather River above the Oroville Facilities. Anadromous salmonids migrating up the Feather River to spawn are currently blocked at the Fish Barrier Dam. Because they are unable to pass over, around or through the Oroville Facilities, potential upstream spawning habitat is inaccessible. The Fish Passage Model provides the tool to evaluate the feasibility of a potential fish passage program for the Oroville Project.

The objective of SP-F15 Task 4 is to develop and provide a fish passage assessment model to evaluate various combinations of alternative fish passage program elements and goals for the Oroville Dam relicensing project environmental documentation. The model is user interactive and allows evaluation and sensitivity analyses of multiple model elements and scenarios in a single model run. The model provides output totals for metrics on the performance ranges and expected outcomes for the model runs. These model output totals are documented in summary output reports and allow for easy comparison of model run alternatives.

Many of the elements included within a potential fish passage program are not definitively quantifiable, so the model uses “Best Case”, “Expected” and “Worst Case” values for each fish passage program variable. The user can provide input values for the “Expected” scenario. Model results are output in aggregations of all the “Best Case” values calculated as a group to characterize results under the most favorable conditions and assumptions. The “Worst Case” values are treated similarly to demonstrate the worst likely outcome of the selected passage program elements. The use of “Worst Case” does not incorporate eventualities for catastrophic events as almost all elements represented in the model are potentially subject to complete failure. The “Expected” values provide an example of how the program is expected to perform. The model results are interpreted by evaluating whether the range of outcomes, from best case to worst case, are “acceptable” or not. If the range of the outcomes from best case to worst case are considered to be acceptable, then the program could be feasible. If the range of outcomes from best to worst case are considered to be unacceptable, then the proposed fish passage program would not be feasible. If portions of the range of outcomes are determined to be both partially acceptable and unacceptable, then further refinement of the values used in the ranges is required to achieve definitive fish passage feasibility conclusions.

The model incorporates many variables to represent fish passage program conditions and interactions, and is designed to evaluate fish passage and should not be confused with “stream productivity models” that utilize intensive habitat characterization information to estimate the number of fish produced by a given area of stream. This model is limited by available habitat data and some critical assumptions. The upstream available spawning habitat quantification is based on SP-G1 survey data that provided estimates of available “riffle” type mesohabitat, but did not address the variability in the

amount of suitable habitat under various upstream tributary flows. Consequently, the actual amount of potentially suitable spawning habitat is likely less than the amounts utilized in the model, so the model estimates should provide optimistic assessments of potential fish passage production. Upstream water temperatures were assumed to be suitable for Chinook salmon under the assumption that the upstream facilities would provide appropriate water temperature conditions in the event that anadromous salmonids were present in the upstream tributaries. Potential biases in the values used in the model do not affect the ability to compare between passage program alternatives because of consistent application across all scenarios.

The model automatically generates a "Fish Passage Model Output Report" which includes metrics for model results evaluation by providing ratios of production performance for critical program elements. These performance ratios allow for comparisons with other passage programs and fishery production systems (e.g., hatcheries or alternative programs to accomplish the same goals), and serve as a basis for evaluating whether model outputs are providing realistically anticipated results. For example, the ratio of returning program adult fish-to-adult fish passed is a critical fish passage program performance metric. If the number of returning program adults is lower than the number of fish required for passage in the program, then the program is not sustainable for establishing or protecting a unique population or run.

The basis for evaluation of the model results depends on the objective of the fish passage program selected by the user. Potential fish passage program objectives could include: (1) access to additional habitat or increase total salmonid production in the Feather River; (2) protection or enhancement of run or species genetic integrity or distinctness; and (3) access to conditions more closely approximating historical habitat. The model provides relevant metrics in an output summary report and reference benchmark values for the evaluation of each of the potential fish passage program goals.

To evaluate the viability of a fish passage program with the objective to create access to additional spawning and rearing habitat, the "Total Cost Per Spawning Habitat Accessed" of the fish passage program should be compared to the alternative costs of creating comparable amounts of habitat or increased fish production in the Lower Feather River. Costs for these alternative programs to accomplish this same goal will be available as the cost evaluations of the proposed Resource Actions are completed by DWR.

If the objective is to develop, reestablish or protect the genetic integrity or distinctiveness of a run, then the cost of such a fish passage program should be compared to the costs, effectiveness and risks of a Lower Feather River program using fish weirs to accomplish the goal. The proposed Resource Action EWG-2 "*Fish Barrier Weir in the Lower Feather River*" is intended to achieve the same resource objective to protect or enhance the genetic integrity or distinctness of spring-run Chinook salmon.

If the objective is to provide fish access to conditions that more closely approximate historical conditions, there is no meaningful metric available from the model other than comparison of the fish passage program cost per fish to other passage programs to determine if the fish passage scenario provides comparable rates of returns. If this objective is pursued, then conditions in the upstream tributaries (e.g., water temperature regimes) should be evaluated against "historical conditions" to determine if a passage program would actually result in fish accessing habitat more closely resembling historical conditions.

The example model scenario included in this report was designed for the goal of "Protect or Enhance Spring-Run Chinook Genetic Integrity" with the lowest cost per fish. There are many possible combinations of fish passage program options selections, alternatives and assumptions that could also have these same goals. Although the evaluation of the example model scenario was determined to not be sustainable, this example is for illustrative purposes only and is not intended as a definitive conclusion on the viability of all potential fish passage programs or other scenarios with these same goals.

TABLE OF CONTENTS

REPORT SUMMARY RS-1
1.0 INTRODUCTION 1-1
1.1 Background Information 1-1
1.1.1 Statutory/Regulatory Requirements 1-1
1.1.2 Study Area 1-2
1.1.2.1 Description 1-2
1.1.2.2 History 1-2
1.1.3 Generalized Fish Passage Model Description 1-5
1.2 Description of Facilities 1-6
1.3 Current Operational Constraints 1-9
1.3.1 Downstream Operation 1-9
1.3.1.1 Instream Flow Requirements 1-9
1.3.1.2 Water Temperature Requirements 1-10
1.3.1.3 Water Diversions 1-10
1.3.1.4 Water Quality 1-11
1.3.2 Flood Management 1-11
2.0 NEED FOR STUDY 2-1
3.0 STUDY OBJECTIVES 3-1
3.1 Application Of Study Information 3-1
3.1.1 Department of Water Resources/Stakeholders 3-1
3.1.2 Other Studies 3-1
4.0 METHODOLOGY 4-1
4.1 Model Design Elements 4-1
4.2 Use of the Model 4-2
5.0 STUDY RESULTS 5-1
5.1 Model Limitations 5-1
5.2 Model Output Report 5-2
5.2.1 Total Capital Cost 5-2
5.2.2 Total Annual O&M Costs 5-2
5.2.3 Total Adults Passed 5-3
5.2.4 Cost Per Adult Passed 5-3
5.2.5 Total Juveniles Released 5-3
5.2.6 Cost Per Juvenile Released 5-4
5.2.7 Total Habitat Accessed 5-4
5.2.8 Cost Per Habitat Accessed 5-4
5.2.9 Total Returning Adults 5-4
5.2.10 Cost Per Returning Adult 5-4
5.3 Interpretation of Results 5-5
5.3.1 Adult Return-to-Adult Passed Ratio 5-5
5.3.2 Adults Passed-to-Juvenile Release Ratio 5-5
5.3.3 Juvenile Release-to-Adult Return Ratio 5-6
6.0 ANALYSES 6-1

6.1 Existing Conditions/Environmental Setting 6-1
6.2 Potential Fish Passage Effects 6-1
6.3 Major Influences ON Model Results 6-3
6.4 Interpretation and Evaluation of Model Results 6-5
6.4.1 Access Additional Habitat/Increase Total Fish Production 6-5
6.4.2 Protect Species or Run Genetic Integrity 6-5
6.4.3 Access to Areas More Closely Approximating Historical Conditions 6-5
6.5 Evaluation of Example Model Scenario 6-6
7.0 REFERENCES 7-1

LIST OF APPENDICES

Appendix A: Biological Relationships
Appendix B: Model Output

LIST OF FIGURES

Figure 1.1-1. Upstream Fish Passage Barriers. 1-3
Figure 1.1-2. Historical Anadromous Salmonid Spawning Extent with Current Fish Passage Barriers and Upstream Facilities. 1-4
Figure 1.2-1. Oroville Facilities FERC Project Boundary. 1-8
Figure 6.5-1 Proportional sources of mortality in example model scenario 6-7
Figure 6.5-2 Proportional contributors to the total annualized fish passage program costs in the example model scenario. 6-8

1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

Ongoing operation of the Oroville Facilities and related project structures prohibit passage of anadromous and migratory fish in the Feather River above the Oroville Facilities. Anadromous salmonids migrating up the Feather River to spawn are currently blocked at the Fish Barrier Dam. Because they are unable to pass over, around or through the Oroville Facilities, potential upstream spawning habitat is inaccessible. As a component of study plan (SP)-F15, *Evaluation of the Feasibility to Provide Passage for Targeted Species of Migratory and Anadromous Fish Past Oroville Facility Dams,* Task 4 of SP-F15 develops a fish passage model to assess the feasibility of various combinations of alternative elements and goals for a potential fish passage program. This tool is designed to evaluate fish passage feasibility in support of the relicensing environmental documentation and in the definition and program implementation phasing design of potential related protection, mitigation and enhancement (PM&E) measures.

1.1.1 Statutory/Regulatory Requirements

The feasibility evaluation provided by this study will complement the assessments of project-related effects on the passage of in-river fish to and from available fish habitat upstream of Lake Oroville, and within the lower Feather River (SP-F3.1 and SP-F10, respectively). These assessments and the present feasibility study will be important components in the evaluation of effects of the Oroville Facilities required to comply with NOAA Fisheries federal Endangered Species Act (ESA) consultation requirements, and with Section 18 of the Federal Power Act (FERC 2001).

Anadromous salmonids present in the lower Feather River include spring-run Chinook salmon (*Oncorhynchus tshawytscha*), fall-run Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*). On September 16, 1999, naturally-spawned Central Valley spring-run Chinook salmon were listed as threatened under the federal ESA by NOAA Fisheries (NOAA 1999). The Central Valley spring-run Chinook salmon Evolutionarily Significant Unit (ESU) includes all naturally-spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, which includes naturally-spawned spring-run Chinook salmon in the lower Feather River (NOAA 1999). On March 19, 1998, naturally-spawned Central Valley steelhead were listed as threatened under the federal ESA by NOAA Fisheries (NOAA 1998). The Central Valley steelhead ESU includes all naturally-spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries, which includes naturally-spawned steelhead in the lower Feather River (NOAA 1998).

The results and recommendations from this study fulfill, in part, statutory and regulatory requirements mandated by the ESA as it pertains to Central Valley spring-run and fall-

run Chinook salmon. In addition to the ESA and California Species of Special Concern, Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (FERC 2001). The discussion is required to identify the potential impacts of the project on these resources.

1.1.2 Study Area

1.1.2.1 Description

The study area encompasses the Feather River upstream and downstream of the Fish Barrier Dam, including but not limited to FERC project waters comprised of Lake Oroville, its upstream tributaries, the Thermalito Complex, the Fish Barrier Pool and the Diversion Pool. This includes areas of the upper Feather River watershed within the fluctuation zone of Lake Oroville to the high water mark. The upstream tributaries of Lake Oroville consist of four major tributaries – the North Fork Feather River, the West Branch of the North Fork Feather River, the Middle Fork Feather River and the South Fork Feather River. The upstream extent of this study area extends to the first stream channel obstructions that completely block upstream migration of anadromous salmonids as defined in **Figure 1.1-1**. The upstream migration barriers on the tributaries have been preliminarily defined in the SP-F3.1 Task 1A Interim Report. It should be noted that the definitive complete fish passage barrier for the West Branch of the Feather River is still under investigation pending the SP-F3.1, Task 1A Final Report.

1.1.2.2 History

As part of the Oroville Facilities, the Fish Barrier Dam was constructed during the early 1960s. Located upstream of the Feather River Hatchery and approximately five miles below Oroville Dam, it is identified as the first impassible salmonid migration barrier on the Feather River (DWR and USBR 2000; Yoshiyama et al. 1998).

Historically, the upper Feather River watershed provided habitats for anadromous and resident salmonids. Spring-run Chinook salmon and steelhead were reported to ascend the very highest streams and headwaters of the Feather River watershed, while fall-run Chinook salmon occupied the lower foothill reaches (DWR and USBR 2000; Yoshiyama et al. 1998). Prior to the construction of Oroville Dam, the upstream extent of fish passage was limited by natural fish barriers and previously constructed hydroelectric projects.

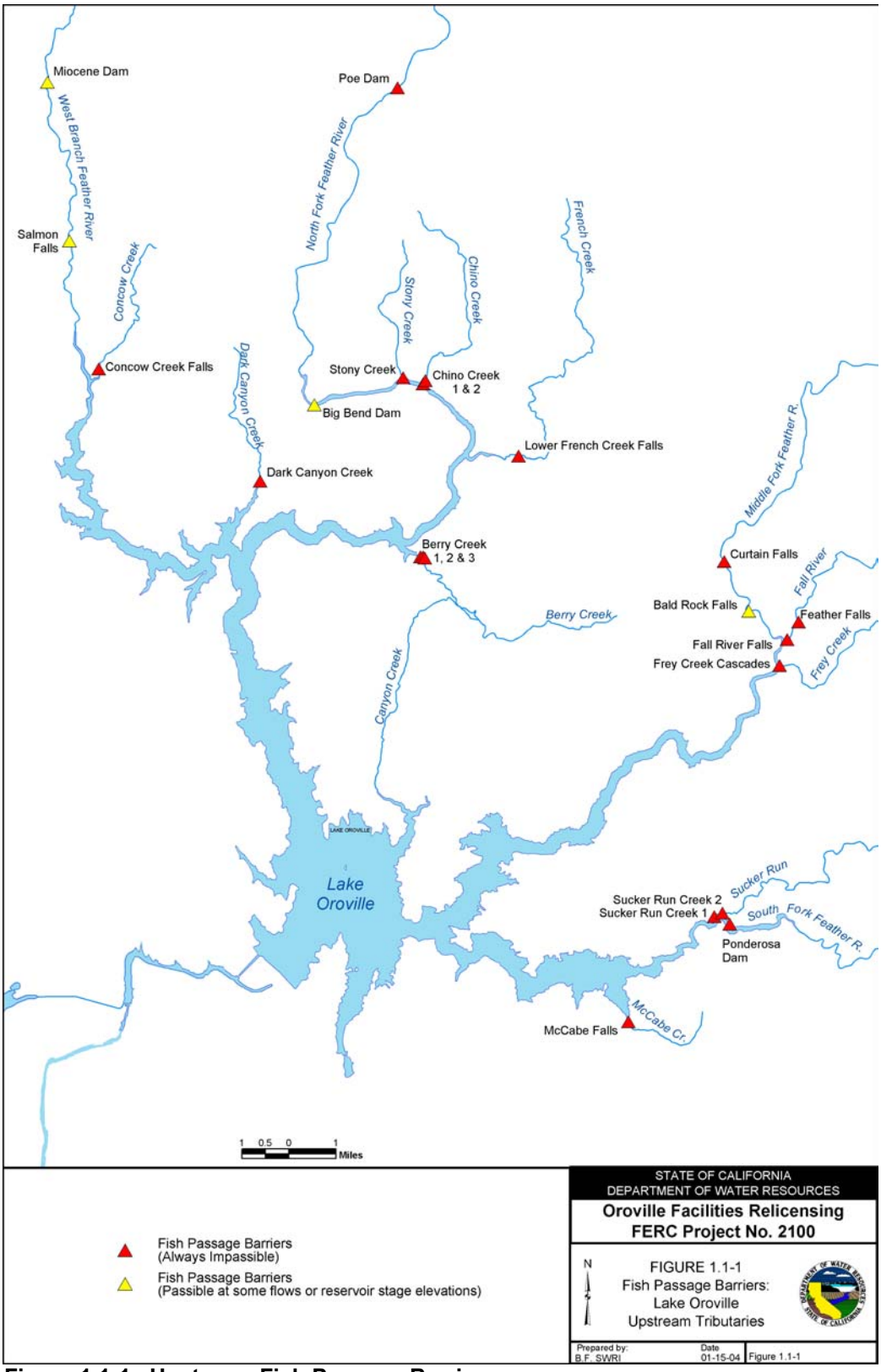

Figure 1.1-1. Upstream Fish Passage Barriers.

Figure 1.1-2 depicts the historical spawning distribution as defined in Yoshiama et al. 1998, and the current definition of the expected geographic scope of the cumulative analysis for fish passage.

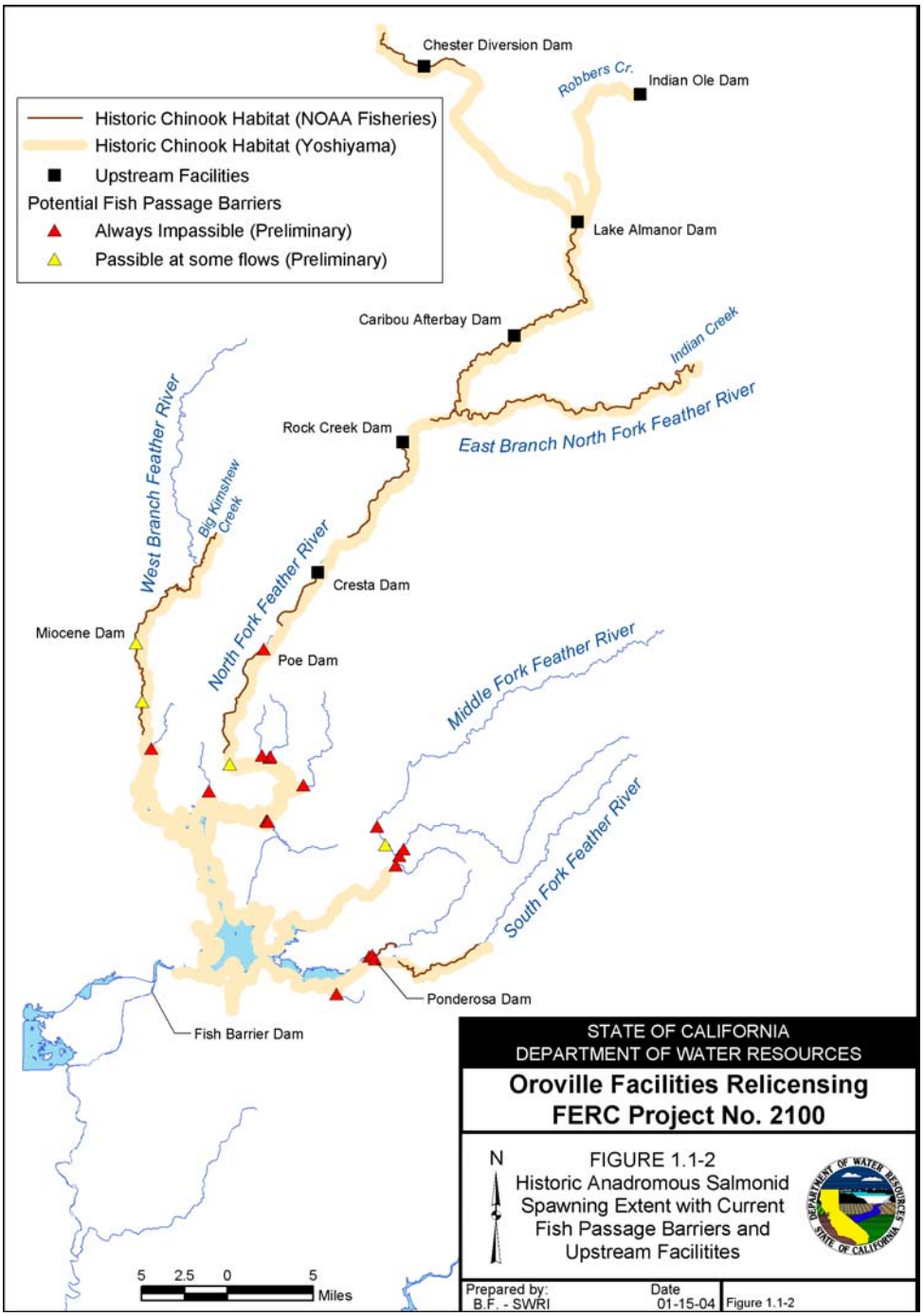

Figure 1.1-2. Historical Anadromous Salmonid Spawning Extent with Current Fish Passage Barriers and Upstream Facilities.

The geographic scope encompassing the entire geographic range of historical salmonid spawning extent in the Feather River Basin is anticipated to be considered separately in the cumulative effects evaluation.

1.1.3 Generalized Fish Passage Model Description

The Fish Passage Model is constructed in Microsoft Excel on several worksheets. The first worksheet in the spreadsheet model is the "Title Page & Report Summary" and includes the report title page, list of preparers and the report summary. The second worksheet in the model is the "Model Documentation" (this report). The third worksheet in the spreadsheet model is the "Main Option Selection" sheet with a set of menu pick lists and toggles that allow the user to select the major elements to be included in the fish passage alternative to be evaluated. Functional relationships between the fish passage alternative elements have already been established, and the selection of some alternatives or options automatically activate related, dependent passage elements. The next worksheet, "Fishery User Input Values", shows the values of the passage elements selected from the "Main Option Selection" sheet as well as allows the user to modify the "expected" values used in the model calculations. "Best Case", "Expected" and "Worst Case" values are presented for "Fishery" (biological related elements), "Capital Cost" (one time design and construction costs with a specified useful lifespan) and "Annual O&M Cost" (annual operations and maintenance costs). Default model values are based on literature review and estimates provided. Metrics on the fish passage program performance are continuously updated on the header areas of both the "Fishery User Input Values" and the "Cost User Input Values" as the user supplies input values. This function allows the user to perform sensitivity analyses for various fish passage model elements within a single model run. "Information Buttons" are available for all model variables on both of these pages and contain information on the definitions, functional relationships and user instructions. Additional documentation of the terminology definitions, assumptions, literature citations for model value sources and rationalization for the default values used in the model are available in the worksheet "Biological Relationships."

The worksheet, "Fish Passage Model Computations" shows the values of the passage elements selected, as well as the mathematical functional relationship between passage elements. This sheet is not user modifiable. The model "Output Summary" provides documentation of user options selected and values provided, and reports the totals of all of the report metrics on fish passage performance. The output summary allows for quick comparison of the model assumptions used, and the performance of alternative scenarios.

The flexibility inherent to this decision-support tool allows for a very extensive range of fish passage alternatives to be evaluated. Depending upon the respective outcome under certain operational scenarios, the decision-support tool also can provide comparison of multiple passage alternatives occurring across a range of temporal and

spatial components. The model tests the feasibility of a fully implemented passage program, but also can be used to test the feasibility and sequencing for a phased implementation of a fish passage program. The model, as with any similar decision-support tool, is expected to evolve based on user input on refined values for model elements, as well as to incorporate new features and capabilities as required.

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management and power generation, to improve water quality in the Delta, to provide recreation and to enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on Figure 1.2-1. The Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (MAF) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam, four miles downstream of the Oroville Dam, creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the

114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate an average of 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000 acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000-acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

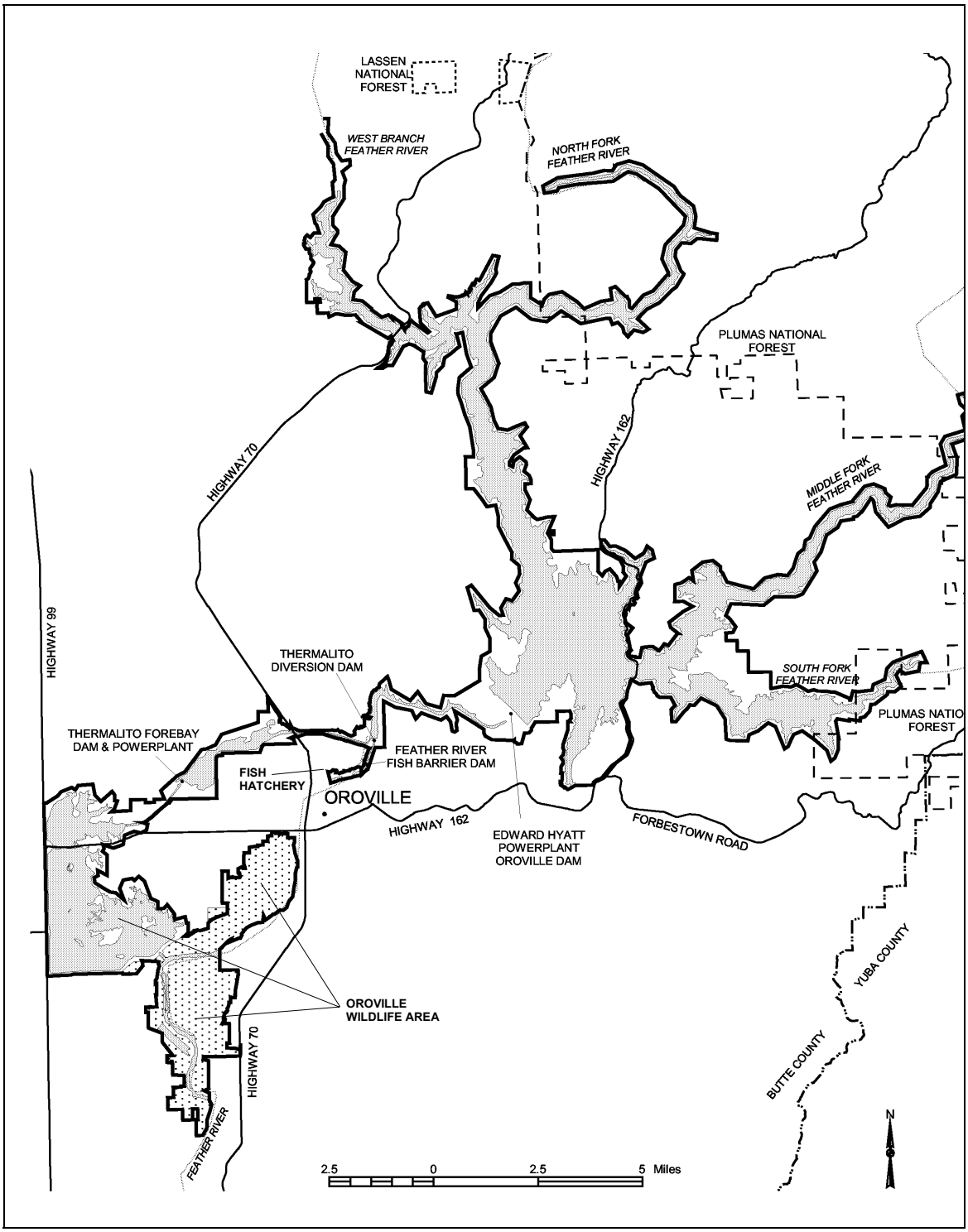

Figure 1.2-1. Oroville Facilities FERC Project Boundary.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected or requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG titled, "*Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife*," sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the

Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Water Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for the objectives extending from April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook salmon. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

NOAA Fisheries has also established an explicit criterion for steelhead and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook salmon and steelhead as a reasonable and prudent measure, DWR is required to maintain daily average water temperature of < 65° F at Feather River Mile 61.6 (Robinson Riffle in the low flow channel) from June 1 through September 30. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 af (July 2002) are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 MAF. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta,

water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 MAF to ensure adequate space in Lake Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

As a subtask of SP-F15, *Evaluation of the Feasibility to Provide Passage for Targeted Species of Migratory and Anadromous Fish Past Oroville Facility Dams,* Task 4 of SP-F15 develops a fish passage model to assess the feasibility of various combinations of alternative elements and goals for a potential fish passage program. This tool is designed to evaluate fish passage feasibility in support of the Relicensing environmental documentation, to facilitate the evaluations of alternatives in support of Relicensing negotiations, and in support of the development and definition of potential related PM&E's.

Providing passage into Lake Oroville's upstream tributaries may diminish certain project-related migration limitations caused by current barriers (e.g., Fish Barrier Dam) and return fish to potentially suitable spawning, rearing and holding habitats. Providing passage to (and from) the upstream tributaries is a consideration which potentially may complement or provide an alternative to those benefits currently provided ongoing Feather River hatchery operations, and may serve as another means of endangered species recovery.

3.0 STUDY OBJECTIVES

3.1 APPLICATION OF STUDY INFORMATION

SP-F15 Task 4 is designed to assess the feasibility of providing fish passage over, around or through the Oroville Facilities. Fish passage program alternatives evaluated with the tool developed for this task will serve as a foundation for future evaluations and consideration of potential Resource Actions.

The model also is designed to help define and differentiate fish passage program goals. Potential fish passage program goals identified include: (1) access to additional habitat or increase total salmonid production in the Feather River; (2) protect or enhance run or species genetic integrity or distinctness; and (3) provide access to conditions more closely approximating historical habitat. The working definitions and the specific basis for evaluation of success for each potential goal is explained in section 6.0 Analyses.

The Fish Passage Model is a tool, not a report. The model is capable of evaluating numerous potential alternatives and scenarios. The characteristics of the types of results and factors contributing to the results of the model are explained in this report.

The results of this Fish Passage Model are not anticipated to be incorporated into any other study plan report, but are anticipated to be incorporated into the Relicensing application documentation. Many other study plan results provide the basis for the values and variables used in the development of the model.

3.1.1 Department of Water Resources/Stakeholders

The information from Task 4 of SP-F15 will be used by DWR and the Environmental Work Group (EWG) to evaluate potential alternative scenarios of a fish passage program. Additionally, data collected in this task serve as a foundation for future evaluations and development of potential Resource Actions.

3.1.2 Other Studies

SP-F15 Task 1, *Describe the Life History and Habitat Requirements of Feather River Anadromous Salmonids and Other Migratory Species*, provides information to the model for the basis of several model elements including:

- Adult upstream migration requirements (timing, and prevalent water temperature and flow conditions);
- Adult holding habitat (habitat availability, water temperature, holding pool or stream characteristics);

- Spawning (habitat availability and suitability, abundance and distribution, timing, and factors affecting timing and success such as substrate conditions and water temperatures);

- Early development (factors affecting embryo incubation survival through emergence);

- Juvenile rearing (habitat availability and utilization, distribution and abundance, water temperature, substrate characteristics, refuges, shade, cover, food availability);

- Juvenile outmigration and movements (timing, prevalent flow, water temperature and other abiotic conditions); and

- Adult outmigration for steelhead and sturgeon (timing, prevalent flow, water temperature and other abiotic conditions).

SP-F15 Task 2, *Inventory of Potentially Available Habitat for Juvenile and Adult Fish Upstream of Lake Oroville*, provides information to the model for the basis for the most critical elements of habitat quantity per tributary and includes:

- Mesohabitat maps provided by SP-G1. Due to physical access limitations, the survey was completed by interpolating mapped Mesohabitat unit proportions to unsurveyed river reaches.

- Substrate characterization, transect data, channel morphology, assessment of woody debris, and cover cross-sectional monitoring data including water depth, velocity and turbidity obtained from SP-G1. However, as earlier reported by SP-G1, this data was not available for all of the areas in the upstream tributaries.

- Inundation flow boundaries at various flow levels interpolated from SP-G1 channel transects. However, as earlier reported by SP-G1, this data was not available for all of the areas in the upstream tributaries.

- Water temperature data from SP-W6. Although data was available, for the purposes of the fish passage model it was assumed that the current water temperature regimes would be altered in the event of the presence of anadromous salmonids from a fish passage program. As a result, the water temperature component of the fish habitat quantification was omitted from the Fish Passage Model.

Due to these data availability constraints on upstream habitat quality and quantity, the model utilizes the amount of “riffle” Mesohabitat from SP-G1 to represent “spawning habitat” in the upstream reaches. Salmonid spawning habitat requires suitable water depth, velocity, and substrate, in addition to other requirements. Because these habitat

variables were not available in the unsurveyed river reaches, “riffle” Mesohabitat quantity was used to quantify potential salmonid spawning habitat for the model default values. This quantification of potential salmonid habitat results in an “optimistic” assessment of the quantity of spawning habitat. Water depth, water velocity, cross section profiles and cover are required to quantify the amount of juvenile rearing habitat, but these data sets were not available for the upstream juvenile rearing habitat quantification.

SP-F15 Task 3, *Evaluation of Methods and Devices Used in the Capture, Sorting, Holding, Transport and Release of Fish*, provides information on the efficiency and mortality rates associated with various fish passage devices and alternative methods, including:

- Routing considerations for adult fish approaching dams with fish ladders;
- Routing considerations for juvenile fish approaching dams with juvenile bypass systems;
- Species response to attraction flows, water turbulence and temperature;
- Species reaction to guidance devices (e.g., screens, surface flow deflectors);
- Estimates of residence and passing times;
- Probability of fall-back;
- Survival associated with passing through by-pass systems, spills and turbines;
- Survival associated with trap-and-trucking; and
- Survival associated with trap-and-barging.

SP-F3.1 Task 1A, *Identify Upstream Migration Barriers,* provides the basis for the geographic definition of the scope of the SP-F15 Task 4 Fish Passage Model. The geographic scope and dependent habitat quantification are based on the Interim Report pending the availability of the F3.1 Task 1A Final Report. The final report will be produced after receipt of the final fish passage assessment information on “sediment plugs” from SP-G1.

SP-F8, *Transfer of Energy and Nutrients by Anadromous Fish Migrations,* provides SP-F15 with information regarding historical escapement and estimates of potential maximum escapement, of Chinook salmon given the existing habitat of the tributaries upstream of Lake Oroville. This information serves as a basis for comparison of the various methods used to estimate the potential salmonid spawning habitat capacity of the upstream tributaries.

SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat, Information on the Feather River Below the Fish Barrier Dam*, provides SP-F15 with anadromous salmonid specific life history and habitat requirements for each of the three target species (fall-run Chinook salmon, spring-run Chinook salmon, and steelhead). This information includes collection and compilation of information on the habitat suitability characteristics of Chinook salmon and steelhead. The following topics are included in the description:

- Adult upstream migration (timing, and prevalent water temperature and flow conditions);
- Adult holding habitat (habitat availability, water temperature, holding pool or stream characteristics);
- Spawning (habitat availability and suitability, abundance and distribution, timing, and factors affecting timing and success such as substrate conditions and water temperatures);
- Early development (factors affecting embryo incubation survival through emergence);
- Juvenile rearing (habitat availability and utilization, distribution and abundance, water temperature, substrate characteristics, refuges, shade, cover, food availability, predation, stranding); and
- Juvenile outmigration and movements (timing, prevalent flow, water temperature and other abiotic conditions).

SP-F21, *Project Effects on Predation of Feather River Juvenile Anadromous Salmonids,* provides SP-F15 information regarding predation rates and factors for juvenile salmonids. The physical environment created by passage intakes and bypass structures associated with predation will be incorporated into the Fish Passage Model as the basis and rationale for some of the predation-related model variable values.

4.0 METHODOLOGY

4.1 MODEL DESIGN ELEMENTS

The Fish Passage Model is designed to support the evaluation of multiple potential fish passage program goals including: (1) access to additional habitat or increase total salmonid production in the Feather River; (2) protect or enhance run or species genetic integrity or distinctness; and (3) provide access to conditions more closely approximating historical habitat. The model provides relevant metrics in an output summary report, and reference benchmark values, for the evaluation of each of the potential fish passage program goals.

In addition to potentially different passage program goals, there are expected to be differences in user resource valuation and priority perspectives. The design of the model strives to minimize subjectivity in the model by utilizing published literature values wherever possible, and by utilizing ranges of values to represent uncertainties in the quantification of fish passage elements. Although some resource benefits are intrinsically unquantifiable (e.g., the value of exposing fish to conditions that more closely approximate historical habitat conditions), the model focuses on providing quantitative metrics of potential fish passage programs for comparison to benchmark values from other fish passage programs, hatchery production or other river systems to evaluate if the potential performance or costs per unit of fish passage production are comparable to other programs or locations.

The model is designed to support a large number and complexity of alternatives that encompass the range of potential options and alternatives for a fish passage program. Some potential alternatives were eliminated from the model during initial feasibility evaluation (e.g., railroad transport was determined infeasible in comparison to trucking transport), in order minimize the complexity and maximize the usability of the model. Fish passage program alternatives eliminated from consideration are documented in the SP-F15 Task 3 report.

The model also is designed to compensate for model input value data limitations and assumptions. Many of the variables utilized in the model are not definitively quantifiable. These limitations are due to lack of available supporting literature specificity, accuracy, applicability to Oroville conditions, or interannual variability in the conditions and resulting values. In some cases, even if Feather River specific information were to be available, the implementation of a fish passage program could change the conditions to the extent that the information may no longer be applicable (e.g., juvenile salmonid predation rates in the upstream tributaries). To compensate for the potential variability in the values to be used in the model, the model uses “Best Case”, Expected” and “Worst Case” model values. The definition of the use of “Best Case” in the model is characterization of results under the most favorable conditions and assumptions. The model definition of “Worst Case” is potential program results

under the least favorable conditions and assumptions, although this definition does not assume values that reflect potential catastrophic events. The use of “Expected” values represents the most likely anticipated outcome. Default values are provided for each variable and value range, the biological basis for which are provided in **Appendix A, Biological Relationships**. The user is allowed to substitute values for the “Expected” model calculations. This feature allows the user to compensate for differences based on their experience, perspective and resource values and priorities. As the "Expected" values are modified by the user, the model output metrics are dynamically updated so the user can test multiple variations of expected values for their own sensitivity analyses on the relative proportional weights of the model variables on the outcome of the model scenario. The strategy of applying all of the worst case and best case assumptions to calculate the model output totals is to create a range of model results that reflect the range in potential outcomes of an actual fish passage program. It is likely that neither the best or worst case scenarios would occur, but the actual fish passage program result would fall somewhere in between those scenarios.

The range of use of this decision-support tool for different objectives and by different groups of users requires the model to accommodate user interaction, as well as provide for distributed access to the model. The model accomplishes these functional goals by embedding user support and model documentation. User support is integrated into the model in the form of:

- Explanations in user menu items
- Information buttons documenting terminology definitions
- Functional relationships and user instructions for most user input value elements
- Model documentation for default value definitions, assumptions, associated literature references
- Rationale for the basis of the values provided in the model

The model produces a summary report of the fish passage program options selected and values provided by the user. This model run documentation also includes the user name, date, model version number and a series of metrics on the proposed fish passage program performance. The user is provided access to view the model calculations. This feature allows the user to see how each calculation that contributes to the overall fish passage program evaluation is performed, so that there is a greater understanding of the model functions and relationships as well as improved user confidence in the model results.

4.2 USE OF THE MODEL

The model can be used to sequentially evaluate the feasibility of a fish passage program and, in the event of an identified feasible passage program, it can be used to

define the elements for a logical passage program implementation sequence. The model initially evaluates the fish passage program performance that would be expected to occur at the full implementation of the fish passage program. The purpose of starting with the evaluation of a fully implemented program is that if the full program is not feasible, then there is no sequence of development and implementation that would be feasible either.

When evaluating the fully implemented proposed fish passage program, first the biological feasibility of the program is evaluated based on fish passage program performance and biological sustainability. If this phase of the program is feasible, then the cost phase of the fish passage program should be performed so that costs per unit of fish passage performance can be calculated for comparison to other passage programs or alternative Resource Actions designed to accomplish the same goals. In the event that a fully implemented program is both biologically feasible and costs are judged to be within acceptable ranges, then an implementation development sequence can be developed utilizing the principle components of the modeled scenario elements.

Fish passage program implementation sequencing is generally limited by the number of available fish for passage, and by capital cost requirements. The model accommodates the evaluation of the sequencing of the program implementation by allowing the user to specify the number of fish to be passed (based on availability or other limiting factor) and the number of active tributaries in the program (a major capital cost factor). As the habitat capacity of the first active tributary reaches maximum fish capacity, additional tributaries can be activated. The performance of the implementation sequence can be simulated by the user by starting with the year one passage program assumptions or constraints, and using the model output of those variables as the inputs for the year two implementation evaluation, continuing in this sequential evaluation until full implementation is reached. This implementation sequence determines the capital and O&M costs required by year for the program, as well as determines how long it will take for the program to achieve full implementation.

The user is encouraged to use the user input values to do “gaming” and sensitivity analyses of the response of the changes in the model output totals to different user values provided. The dynamic update of the model output totals, as each variable is changed, allows the user to measure the proportional weight each variable has in the total outcome of the model results. The proportional value of each model variable to the outcome of the model results is self-evident in the proportions of values used. The functional relationships of the variables are documented in the “information button” associated with each fish passage model variable. The dominant model variables for each passage phase are discussed in detail in section 6.3 Major Influences to Model Results.

As the user, through these sensitivity analyses, establishes what levels of performance are required in order to consider a fish passage program feasible, it may become

evident that certain variables must be managed within specific performance ranges in order to achieve the desired outcome (i.e., upstream juvenile survival rates must exceed a specified percentage for the program to be successful). These observations of required performance levels of specific passage program variables may identify the need for companion programs (e.g., juvenile predation management in the upstream tributaries), or companion monitoring programs (e.g., upstream juvenile predation rate monitoring) in order to measure the success of the program.

The model can be customized by the user selections to reflect several different potential goals, or combinations of goals, and any possible combination of various fish passage program alternatives. The model, as with all similar decision-support tools, is expected to evolve based on user feedback for suggested improved values for model variables and requests for additional specific functionalities or alternatives.

5.0 STUDY RESULTS

5.1 MODEL LIMITATIONS

Models are conceptual representations of variables and values based on a limited definition of reality. Models never account for all of the possible variables involved in estimating a condition or outcome. Model results are intended to represent the functional relationships and responses of resources to changes in conditions, inputs or assumptions. Model results are not usually expected to represent absolute values, but rather approximations of results that are most often used to compare the results between model runs with different input values or assumptions. Models are necessarily limited in their representation of reality by the level of complexity of the system being modeled and the quality and certainty of the input data values.

The Fish Passage Model uses hundreds of values as the basis for the calculations of the fish passage program performance and costs. Many of the values used in the model are based on available literature sources. Of these values, some are definitive while others are nearest approximations based on what is available from other sources that may or may not represent conditions within the Oroville system. Uncertainties in model values result from interannual variability (flows, temps, decadal ocean cycle), and from conditions that would likely change upon the implementation of the fish passage program (e.g., disease and predator composition, distribution and abundance. A few of the values used in the model are based on professional judgment, experience and estimation. The basis for the biological values used in the model are documented in Appendix A, Biological Relationships, and worksheets within the model, and cost values are documented in “Cost Values Justification” worksheets in the model documentation.

One of the most significant limitations to the accuracy of the fish passage model results is the estimate of the amount of salmonid spawning habitat in the upstream tributaries, which is used in the model to calculate the number of fish the potential fish passage program can accommodate. Salmonid spawning habitat consists of suitable water depth, velocity, and substrate in addition to other requirements. However, these data characterizations of salmonid spawning habitat were not available for the upstream tributaries, so the SP-G1 Mesohabitat mapping of “riffle” habitat was used as a surrogate value. This quantification of potential salmonid habitat results in an “optimistic” assessment of the quantity of spawning habitat. The quality of this estimation of the quantity of salmonid spawning habitat does directly affect the estimation of the capacity of the number of adult fish the passage program alternatives can accommodate, but this limitation does not substantially affect the resulting production ratio of fish, which is itself an important measure of fish passage biological feasibility. Many fish passage program costs are relatively insensitive to the number of fish, and those cost variables that are responsive to the number of fish will only be proportionately affected to the level of accuracy of the estimate of the number of fish in the program (e.g., an estimate of 20% more fish than actual would result in those cost

factors being 20% too high). The result of this potential bias in the estimated fish capacity is that the cost per fish passed and other cost per unit program metrics will be lower than they would otherwise be estimated.

The Fish Passage Model also is based on some other critical assumptions that limit its functionality, accuracy of results and representativeness of reality. Water depth, water velocity, cross section profiles and cover are required to quantify the amount of juvenile rearing habitat, but these data sets were not available for the upstream tributaries. As a result, the amount of juvenile rearing habitat available was not used as a limiting factor to juvenile fish production or in-river rearing survival estimates in the model. Upstream water temperature information was available from SP-W6, but the model assumes that current water temperatures most likely would not reflect future water temperature conditions because, in the event of a fish passage program and the presence of anadromous salmonids in the upstream tributaries, the upstream facilities would provide suitable water temperatures for anadromous salmonids. As a result of this assumption of suitable water temperatures being provided in the event of the implementation of a fish passage program, water temperature impacts to fish production were not incorporated into the model. The model also assumes that the locations for the facilities in the upstream tributaries are at existing access points and has not tried to incorporate the costs associated with creating new potential access points. The model also does not attempt to include the time value of money for capital cost investments, because those adjustments can be made outside of the model after the implementation period and capital expense expenditure sequencing is determined.

5.2 MODEL OUTPUT REPORT

The Fish Passage Model automatically generates a “Fish Passage Model Output Report” (see **Appendix B**). The output report documents the user name, date, scenario name, model version number, user options selected and values supplied and model output report totals. Model output report totals include:

5.2.1 Total Capital Cost

“Total Capital Cost” is the sum of all of the capital cost alternatives and options selected for each of the “Best Case”, “Expected” and “Worst Case” values respectively. The cost ranges of these results can be compared to other passage programs.

5.2.2 Total Annual O&M Costs

“Total Annual O&M Costs” is the sum of all of the annual O&M cost alternatives and options selected for each of the “Best Case”, “Expected” and “Worst Case” values respectively. The cost ranges of these results can be compared to other passage programs.

5.2.3 Total Adults Passed

"Total Adults Passed" is the sum of "Targeted Adults" of the adult "Fish Release Locations" selected on the "Fish Passage Option Selection" worksheet.

The total number of adult salmonids in the fish passage program is limited by the definition of the amount of available spawning habitat. As discussed in section 5.1, the amount of spawning habitat utilized in the model is based on generalized habitat data from SP-G1.

5.2.4 Cost Per Adult Passed

"Cost Per Adult Passed" is calculated by dividing the sum of the "Annual O&M Cost" plus the amortized "Capital Cost", based on the capital cost, divided by the "Useful Lifespan", by the "Total Adults Passed" in the respective "Best Case", "Expected" and "Worst Case" values. The cost ranges of these results can be compared to other fish passage programs.

In the *Alternatives Report for Fish Passage at Cougar Lake,* the U.S. Corps of Engineers estimated an escapement goal range of between 300 and 4,000 spawners with a capital cost estimate of $18.1 million and annual operating cost estimate of $320,000 per year. These costs include both a fish screen in the upstream tributaries and a "gulper", which is similar to the configurations and options available for the Oroville Fish Passage Program Model. If an average life span of capital assets is assumed at 20 years then the average amortized fish passage program would be approximately $1,225,000 (without time value of money adjustments). This would produce a cost per fish passed ranging from a "Worst Case" of $4,083 to a "Best Case" of $306.

5.2.5 Total Juveniles Released

"Total Juveniles Released" is the product of the "Total Adult Spawners" multiplied by the "Adult Productivity" factors of "Prespawn Mortality Survival Rate", "Egg Production Per Female" and "Egg Deposition-Emergence Survival Rate" for each of the "Best Case", "Expected" and "Worst Case" values, respectively. The number of juvenile produced estimate is then multiplied by the "In-River Survival Rate" and "In-Reservoir Predation Survival Rate", "Juvenile Collection Efficiency", "Juvenile Sorting Efficiency", "Tagging Survival Rate" (if selected as an option),"Fish Holding Survival Rate", "Fish Transport Survival Rate" and "Fish Release Location" for each of the "Best Case", "Expected" and "Worst Case" values, respectively.

5.2.6 Cost Per Juvenile Released

"Cost Per Juvenile Released" is calculated by dividing the sum of the "Annual O&M Cost" plus the amortized "Capital Cost", based on the capital cost divided by the "Useful Lifespan", by the "Total Juveniles Released" of the respective "Best Case", "Expected" and "Worst Case" values. The cost ranges of these results can be compared to other fish passage programs, alternative programs for increased juvenile fish production, or fish hatchery production systems.

5.2.7 Total Habitat Accessed

"Total Spawning Habitat Accessed" is the sum of "Spawning Habitat" of both existing and created spawning habitat for each of the active fish passage program tributaries of the adult "Fish Release Locations" selected on the "Fish Passage Option Selection" worksheet.

5.2.8 Cost Per Habitat Accessed

"Cost Per Spawning Habitat Accessed" is calculated by dividing sum of the "Annual O&M Cost" plus the amortized "Capital Cost", based on the capital cost divided by the "Useful Lifespan", by the "total Spawning Habitat Accessed", of the respective "Best Case", "Expected" and "Worst Case" values. The total cost per unit of habitat accessed can be compared to the alternative costs of creating similar quantities of spawning habitat in the Lower Feather River or for off site salmonid spawning habitat mitigation programs.

5.2.9 Total Returning Adults

"Total Fish Passage Program Returning Adults" is the product of several variables including "Total Juveniles Released", "Ocean Cycle Survival Rate", "Immigration Survival Rate", "Homing Rate" and "Adult Collection Efficiency" for each of the "Best Case", "Expected" and "Worst Case" values.

5.2.10 Cost Per Returning Adult

"Cost Per Returning Program Adult" is calculated by dividing the sum of the "Annual O&M Cost" plus the amortized "Capital Cost", based on the capital cost divided by the "Useful Lifespan", by the "Total Returning Program Adults" of the respective "Best Case", "Expected" and "Worst Case" values. The cost ranges of these results can be compared to other fish passage programs.

5.3 INTERPRETATION OF RESULTS

Many variables and uncertainties are included in the evaluation of the potential viability of a fish passage program. The intent of using "Best Case", "Expected" and "Worst Case" value ranges for "Capital Cost", "Annual O&M Cost" and "Net Efficiency" is intended to reflect these uncertainties. As long as the range of the results from best to worst indicate a definitive answer (either all acceptable or all unacceptable) then the current level of refinement of the value ranges for the selected fish passage alternatives is sufficient to evaluate the fish passage program viability. If portions of the ranges of the model results between "Best Case" and "Worst Case" are acceptable as well as unacceptable, then additional refinement of the ranges of the values of the model variables would be required to reach a definitive fish passage program assessment. The terms "acceptable" and "unacceptable" are user subjective terms subject to differences in program goals, as well as valuation of the unquantifiable intrinsic values of the resources.

The "Fish Passage Model Output Report" also includes metrics for model results evaluation by providing ratios of production performance for fish passage on critical program elements. These performance ratios allow for comparison of a program's efficiency and performance to other passage programs and fishery production systems (e.g., hatcheries or alternative programs to accomplish the same goals), and serve as a basis for evaluating whether model outputs are providing realistically anticipated results.

5.3.1 Adult Return-to-Adult Passed Ratio

"Adult Return-to-Adult Passed Ratio" is the result of dividing the "Total Returning Adults" by the "Total Adults Passed" for each of the "Best Case", "Expected" and "Worst Case" values respectively. The ratio of returning program adult fish-to-adult fish passed is a critical fish passage program performance metric. If the number of returning program adults is lower than the number of fish required for passage in the program, then the program is not sustainable for establishing or protecting a unique genetic population. Return rates of less than one also indicate that the program is not contributing successfully to an increase in overall salmonid production.

5.3.2 Adults Passed-to-Juvenile Release Ratio

The ratio of adults passed to juvenile fish released is an important fish passage program performance metric because benchmark values of these production ratios are available for reference and comparison to evaluate the performance of the program. The variables in this phase of the passage program are those elements that the passage program has the most potential influence over, so the relative performance of these elements is useful for program evaluation and potential identification of program modifications required for a successful fish passage program.

Reported adult-to-juvenile production rates serve as a useful basis for comparison to the model output report to evaluate if the model is providing potentially realistic results. Many factors affect this production ratio, and not all factors are present or necessarily comparable between different river systems. Hatcheries measure adult-to-juvenile production rates and the information is potentially useful as a component of the basis for evaluating this production ratio, but many of the factors that affect this production ratio are different or absent from the artificial and controlled conditions within a hatchery production system, compared to the conditions and factors in a fish passage program. The following publications illustrate the wide range of potential adult-to-juvenile production rates.

The 2002-2003 Annual Report of the Feather River Hatchery reports the number of adults received, as well as the total number of juveniles released, which can be used to calculate the juveniles released-to-adults passed ratio. A total of 4,189 fish were received between September 3, 2002 and September 15, 2002. Fish entering within this timeframe are identified as spring run Chinook salmon by FRH staff. Of the fish entering the hatchery, 401 females were spawned, and there was an average egg production of 5,662 per female. The entire spring run production was planted, for a total of 1,443,071 smolts. The ratio of juveniles released to adult females spawned is therefore calculated to be 3,599:1, or 3,599 juveniles per adult female spawned (Kastner 2003). In 1998, at the Feather River Hatchery, the ratio of juveniles released to females spawned is calculated to be 1,582:1, or 1,582 juveniles released for every female adult that was spawned (Quinones 1999).

A study by Petrosky et al. (2001) used Snake River Chinook salmon to estimate the productivity of salmonids in the Columbia River Basin. The study reported the average Snake River freshwater spawning and rearing (FSR) life stage productivity. A relationship of juveniles per adult was found, and it was concluded that Chinook salmon in the Snake River produced, from 1962-1997, an average of 86 smolts per spawner (Petrosky et al. 2001).

5.3.3 Juvenile Release-to-Adult Return Ratio

The ratio of juvenile fish released-to-returning passage program adult fish is an important fish passage program performance metric, because benchmark values of these production ratios are available for reference and comparison to evaluate the performance of the program. This production ratio is sometimes referred to as smolt-to-adult return. Some of the major variables in this phase of the passage program are those elements that the passage program has little potential influence over (e.g., ocean cycle survival), so the relative contribution of these elements to the success or failure of the program is useful to evaluate whether the program has the ability to influence or control program performance to the extent required for a successful sustainable program.

Reported smolt-to-adult return rates are a useful basis for comparison to the model output report to evaluate whether the model is providing potentially realistic results. The following publications illustrate the wide range of potential smolt-to adult return rates.

Cramer and Chapman (2002) examined catch and spawning escapements at Central Valley Hatcheries over the period of 1967-1996. They found that at the Feather River Hatchery, survival between the 1978 and 1996 brood years varied from approximately 1% to 9%. These estimates are based on releases made between April through June each year. It also was found that survival rate was affected by both release year and release location, although size at release was found not to affect the survival rate (Cramer and Chapman 2002).

Bilton (1984) reported return rates for 1976, 1977, and 1978 experimental releases of Chinook salmon tagged in the Big Qualicum River, Vancouver, B.C. The mean age of returning fish was 3.13 years. Returns were lowest in 1977, with only a 0.24% return rate, including catch plus escapement. In 1976, returns were more than 5 times as high as in 1977, with a rate of 1.28%. The highest return rate was observed in 1978 at 6.75%. Bilton (1984) also observed an apparent positive relationship between the average weight of juveniles at release and the percent of returns (both catch and escapement as measures of returns).

Thedinga (1998) studied Chinook salmon juvenile-to-adult returns on the Situk River, Alaska for the 1989 brood year. A juvenile-to-adult return rate of 2.9% was estimated for tagged Chinook salmon, and a return rate of 2.3% was established for all fish (Thedinga et al. 1998). In the Columbia River, Giorgi et al. (2001) reported smolt-to-adult return (SAR) estimates for Chinook salmon transported and tagged upstream of Lower Granite Dam. They found that the estimates ranged from 0.07% in 1993 to a high of 2.37% for the 1999 out-migration. Some annual SAR estimates from the migrations in 1997-1999 for transported fish are now approaching two percent, which are relatively high compared to historical estimates.

In the Pacific Fisheries Research Conservation Council's Third Annual Report, the Council reports returns to Robertson Creek Hatchery from juvenile Chinook salmon released into Barclay Sound from 1974 to 1999. The results, plotted graphically, show a wide range, from a low of 0.03% to a high of approximately 16.0%, only seen in 1975. Variation in ocean survival is strongly co-related to the year of release, which is also dependent upon the year's El Nino events (Pacific Fisheries Resource Conservation Council 2001). Long-range smolt-to-adult return rates have been calculated using historical Snake River data. Marmorek (1998) *in* Nez Pierce Tribe (2001) found that from 1977 to 1994, the Snake River Chinook smolt-to-adult return rates ranged from 0.2% to 2.6%. The median value was calculated as one percent (Nez Pierce Tribe 2001).

6.0 ANALYSES

6.1 EXISTING CONDITIONS/ENVIRONMENTAL SETTING

As a task of SP-F15, *Evaluation of the Feasibility to Provide Passage for Targeted Species of Migratory and Anadromous Fish Past Oroville Facility Dams*, Task 4 develops a fish passage model to access the feasibility of various combinations of alternative elements and goals for a potential fish passage program. This tool is designed to evaluate fish passage feasibility in support of the Relicensing environmental documentation, to facilitate the evaluations of alternatives in support of Relicensing negotiations and in the definition and program implementation phasing design of potential related PM&E's. The Fish Passage Model fulfills a portion of the FERC application requirements by providing a basis for evaluating potential fish passage alternatives.

Ongoing operation of the Oroville Facilities and project related structures prohibit passage of anadromous and migratory fish in the Feather River above the Oroville Facilities. Anadromous salmonids migrating up the Feather River to spawn are currently blocked at the Fish Barrier Dam. Because they are unable to pass over, around or through the Oroville Facilities, potential upstream spawning habitat is inaccessible. The Fish Passage Model provides the tool to evaluate the feasibility of a potential fish passage program for the Oroville Project.

6.2 POTENTIAL FISH PASSAGE EFFECTS

The Fish Passage Model provides the basis for evaluation of potential fish passage programs. The model represents the functional relationships of fish passage variables and alternatives, and incorporates the best available values to represent the potential range of fish passage program outcomes. Although the model is designed to compensate for variations in potential conditions or critical values used in the model, the model cannot anticipate all potential changes to conditions as the result of the implementation of a potential fish passage program. The model does not attempt to anticipate catastrophic events, nor can it guarantee the accuracy of the model results to represent the results that would be achieved from an actual fish passage program implementation. There are many potential general fish passage considerations that affect the potential feasibility of a fish passage program and the resulting potential adverse affects on other resources. These fish passage program considerations are documented in detail in the SP-F15 Task 3 Report. Only those general passage considerations that affect the potential performance and viability of a fish passage program, Oroville project operations that affect the passage program, or resources that may be affected by a potential fish passage program are listed below.

- Future upstream tributary flows regimes are controlled by upstream projects. These flows are not within the control of the Oroville project, but could profoundly

affect fish accessibility and habitat availability for the fish passage program. Due to available data limitations, the model does not incorporate variations in the quantity of available habitat to upstream tributary flow variations, nor does it compensate for fish production losses of redd dewatering or juvenile stranding attributable to upstream flow fluctuations.

- Upstream water temperatures are controlled by upstream projects. The fish habitat suitability due to water temperatures is not incorporated into the model as it is assumed that appropriate water temperatures will be mandated to the upstream facilities in the event of the presence of anadromous salmonids from a fish passage program. It is uncertain if the upstream facilities can accomplish potential suitable anadromous salmonid water temperature goals, and the resulting water temperatures could be a profound factor in the potential success or viability of a fish passage program.

- If a fish passage program releases adult fish into the Oroville reservoir, the stage elevation of the reservoir during salmonid adult immigration can potentially effect upstream accessibility by exposing sediment plugs and other natural fish passage barriers. Oroville reservoir stage elevations during juvenile emigration may affect the suitable locations for operation of the juvenile fish collection devices which may effect the juvenile fish exposure to in-river and in-reservoir predation. could potentially

- Presence of anadromous fish from a fish passage program may create disease pressures or incidences in the upstream tributaries, reservoir complex, Feather River Hatchery and downstream Feather River reaches, and are not integrated into the Fish Passage Model assessments. Additional fish passage disease related operational effects could include increased fish kills in the Feather River Hatchery, need for water treatment for the Feather River Hatchery and impacts to the performance, manageability and viability of the reservoir complex coldwater fishery stocking program. The cost for water treatment for the Feather River Hatchery is included as a cost option in the fish passage model.

- Introduction of ESA listed species into new geographic areas from a fish passage program may precipitate fishing regulation rule changes and recreational fishing, as well as ESA compliance requirements that presently do not exist in upstream areas.

- Potential genetic introgression of steelhead with resident (non-native strains stocked) rainbow trout. In the event of a steelhead fish passage program, there may be genetic introgression impacts both to the resident rainbow trout stocks and anadromous steelhead. The Middle Fork Feather River has been designated Wild and Heritage Trout water by the California Department of Fish and Game (DFG 2003). Other tributaries of the Feather River upstream from the dam also are popular recreational trout fisheries suggesting significant numbers

of rainbow and brown trout. Leary et al. (1995) suggest a one percent threshold of introgression is acceptable while higher percentages present a risk of altering the biological characteristics of the native fish assemblage. With significant numbers of naturally reproducing rainbow trout in the upper watershed, a one percent threshold would almost certainly be exceeded (Leary et al. 1995).

- Predation and competition for food and habitat between resident upstream tributary fish populations and fish passage program fish will occur in the event of a fish passage program. The presence of anadromous salmonid adults and juveniles will likely affect the species composition, number and distribution of resident fish in the upstream tributaries.

- Resident rainbow trout populations may also be affected by a potential fish passage program if resident juvenile rainbow trout are mistakenly passed down river with the other captured fish passage program juvenile salmonids.

- A potential fish passage program would provide some level of upstream fish nutrient and energy transfer. SP-F8 examined the effects of nutrient and organic matter transfers to the upstream tributaries. Several studies have been completed documenting increased stream productivity following the planting of salmon carcasses in streams or comparing stream productivity among streams with salmon spawning vs. nearby streams without salmon (Bilby et al. 1998; Finney et al. 2000; Johnston et al. 1997; Minkawa et al. 2002; Minkawa and R.I.Gara 1999; Naiman et al. 2002; Schuldt and A.E.Hershey 1995; Wipfli et al. 1998)). Although it is generally expected that the nutrient and energy transfer to the upstream tributaries would be a positive influence on stream productivity, it remains unknown what the limits of beneficial nutrient contributions or potential nutrient loading limits would be.

- Removal of some fish from the lower Feather River for a potential fish passage program may reduce redd superimposition and resulting egg mortality in the lower Feather River.

6.3 MAJOR INFLUENCES ON MODEL RESULTS

The Fish Passage Model functions in a series of equations that represent a sequence of events that occur over the entire life cycle of a fish. The biological element equations of the model can be thought of as a series of transactions where losses to the system (to the number of fish) occur. Some phases of the life-cycle of the fish are under the direct control or influence of the design and options selected for the fish passage program, while some life cycle phases (e.g., ocean cycle survival), are completely outside of the fish passage program's ability to control.

The fish passage program has the ability to control or influence the fish life-cycles that occur within the Feather River and project area. Within the model, these life phases

include: adult capture, sorting, holding, transport and release; prespawn mortality, spawning, egg deposition to emergence; juvenile rearing and juvenile capture, sorting, tagging (optional), holding, transport and release. The portions of the fish life-cycle that are out of the control and only have limited potential influence from the fish passage program include ocean cycle survival, adult immigration mortality and straying rates. Ocean cycle survival could potentially be somewhat influenced by fish size and condition factor at release from the fish passage program. Straying rates can be more directly influenced by the fish passage program selection of juvenile fish release location, which is incorporated into the Fish Passage Model.

Changing the input values to the model by only a few percent in several of the calculations will not typically change the nature of the model result due to the cumulative nature of the calculations. In order to change the general character of the outcome of the model, typically different passage options must be selected, or fundamental changes in assumptions and resulting values of key model variables must be made. Using the default values provided in the model, the pie chart in Figure 6.3-1 shows the relative proportions of factors affecting the model results.

- Prespawn mortality survival rates
- Egg deposition to emergence survival rates
- In-river mortality survival rates (particularly spring-run Chinook due to their extended rearing behavior)
- In-reservoir predation survival rates
- Juvenile emigration survival rates (in-river release location only)
- Ocean cycle survival rate
- Homing rate (compliment value to straying rate) (for San Pablo Bay release location only)

The more significant factors affecting the model results for the capital cost calculations include:

- Adult fish collection option – “New Fish Ladder”
- Number of active tributaries selected in the program
- Hatchery water treatment option

The more significant factors affecting the model results for the annual O&M cost calculations include:

- Number of fish selected to be passed
- Number of active tributaries selected in the program
- Tagging option selected
- Juvenile release location option – “Feather River Barge”

6.4 INTERPRETATION AND EVALUATION OF MODEL RESULTS

The basis for evaluation of the model results depends on the objective of the fish passage program selected by the user. Potential fish passage program objectives could include: (1) access to additional habitat or increase total salmonid production in the Feather River; (2) protection or enhancement of run or species genetic integrity or distinctness; and (3) access to conditions more closely approximating historical habitat. The model provides relevant metrics in an output summary report and reference benchmark values for the evaluation of each of the potential fish passage program goals.

6.4.1 Access Additional Habitat/Increase Total Fish Production

To evaluate the viability of a fish passage program with the objective to create access to additional spawning and rearing habitat, the "Total Cost Per Spawning Habitat Accessed" of the fish passage program should be compared to the alternative costs of creating comparable amounts of habitat or increased fish production in the Lower Feather River. Costs for these alternative programs to accomplish this same goal will be available as the cost evaluations of the proposed Resource Actions are completed by DWR.

6.4.2 Protect Species or Run Genetic Integrity

If the objective is to develop, reestablish or protect the genetic integrity or distinctiveness of a run, then "Pit Tagging" should be selected as a component of the fish passage program alternative. For this objective to be viable and sustainable, the "Fish Passage Program Production Ratio" should be greater than 1. The cost of a fish passage program with the objective to protect or restore the genetic integrity of a species or run should be compared to the costs, effectiveness and risks of a Lower Feather River program using fish weirs to accomplish the goal. The proposed Resource Action EWG-2 "*Fish Barrier Weir in the Lower Feather River*" is intended to achieve the same resource objective to protect or enhance the genetic integrity or distinctness of spring-run Chinook salmon. Preliminary cost evaluations included in a DWR Narrative Report on this proposed RA estimate a cost of $100,000 to $200,000 for the program depending on whether there are one or two weirs utilized.

6.4.3 Access to Areas More Closely Approximating Historical Conditions

If the objective is to provide fish access to conditions that more closely approximate historical conditions, there is no meaningful metric available from the model other than comparison of the fish passage program cost per fish to other passage programs to determine if the fish passage scenario provides comparable rates of returns. If this objective is pursued, then current conditions in the upstream tributaries (water temperature regimes) should be evaluated against "historical conditions" to determine if

a passage program would actually result in fish accessing habitat more closely resembling historical conditions.

6.5 EVALUATION OF EXAMPLE MODEL SCENARIO

The example model scenario included in this report was designed for the goal of "Protect or Enhance Spring-Run Chinook Genetic Integrity" with the lowest cost per fish. There are many possible combinations of fish passage program options selections, alternatives and assumptions that could also have these same goals. This example is for illustrative purposes only and is not intended as a definitive conclusion on the viability of all potential fish passage programs or other scenarios with these same goals.

The main options selected for this scenario include:

- Spring-run – targeted species/run to benefit
- Existing Fish Ladder – selected for its low capital cost and assumes compatible operations with the hatchery
- West Branch, North Fork and Middle Fork – selected all tributaries with habitat to maximize the total number of fish passed to lower the cost per fish passed
- Targeted Adults – targeted near maximum capacity without superimposition (so goal of protect genetic integrity was not conflicted)
- CWT Tagging – selected for low cost and ability to monitor passage program success, PIT tagging would have been more expensive, but would be more in line with the goal of protecting genetic integrity
- Gulper and Screen and Gulper Only – juvenile collection devices were chosen
- In-River – juvenile release location was selected for its low cost
- Hatchery Water Treatment – was not selected to minimize total program costs

The results of the example model run indicate that the fish passage program options selected did produce a low $ per adult fish passed at an "Expected" cost of $118.08 per fish. The total annualized program cost would be $3,365,190 ("Total Amortized Capital Cost" plus "Total Annual O&M Cost"). The "Expected" and "Worst Case" scenarios are not sustainable due to the low number of returning program adults compared to the number passed in the program. To be sustainable the "Adult Return to Adult Passed Ratio" should be near or above a value of 1.0.

The low number of returning adults and the resulting un-sustainable fish passage program is due to the cumulative sources of fish mortality in the model. The proportional contributors to the cumulative fish mortality in the example model scenario are profiled in Figure 6.5-1 below.

Example Scenario Output Totals:		
Best Case	**Expected**	**Worst Case**
Total Amortized Capital Cost ($)		
$544,067	$1,020,619	$1,818,517
Total Annual O&M Cost ($)		
$3,457,383	$2,344,571	$3,873,577
Total Habitat Accessed (sf)		
662276	662276	662276
Cost/Habitat Accessed ($)		
$6.04	$5.08	$8.59
Total Juveniles Released		
2231903	138006	952
Cost/Juvenile Released ($)		
$1.79	$24.38	$5,978.04
Total Adults Passed		
28500	28500	28500
Cost/Adult Passed ($)		
$140.40	$118.08	$199.72
Total Returning Adults		
130142	4761	16
Cost/Returning Adult ($)		
$30.75	$706.79	$356,472.49
Example Scenario Results Evaluation:		
Best Case	**Expected**	**Worst Case**
Sustainable		
Yes	No	No
Adult Return to Adult Passed Ratio		
4.57	0.17	0.00
Juvenile Release to Adult Passed Ratio		
78.31	4.84	0.03
Adult Return to Juvenile Release Ratio		
0.06	0.03	0.02

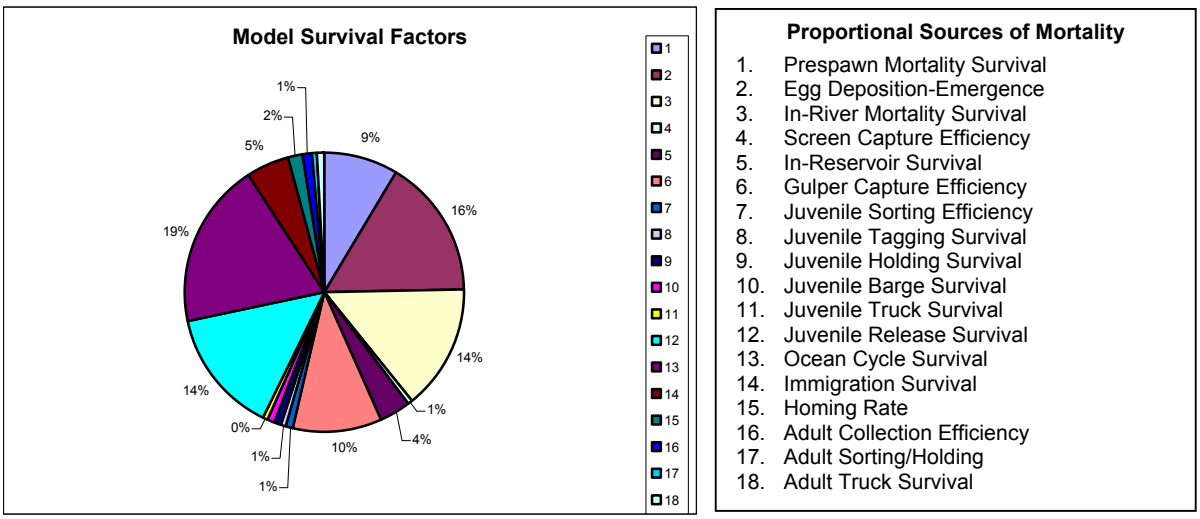

Figure 6.5-1 Proportional sources of mortality in example model scenario

In the figure above, “Prespawn Mortality Survival” is category 1 on the legend and is on the graph at the 12:00 – 1:00 clock position with 9%. The order of representation from the legend to the graph is with #1 at the 12:00 clock position and then proceeding sequentially through the list clock-wise on the graph.

Of the top 7 factors (19% - 5%) contributing to the cumulative mortality of the fish and dominating the outcome of the model results, only one of these factors is in the direct control of the fish passage program (#6 – Gulper Capture Efficiency at 10%).

The proportional contributors to the total annualized fish passage program costs in the example model scenario are profiled in Figure 6.5-2 below.

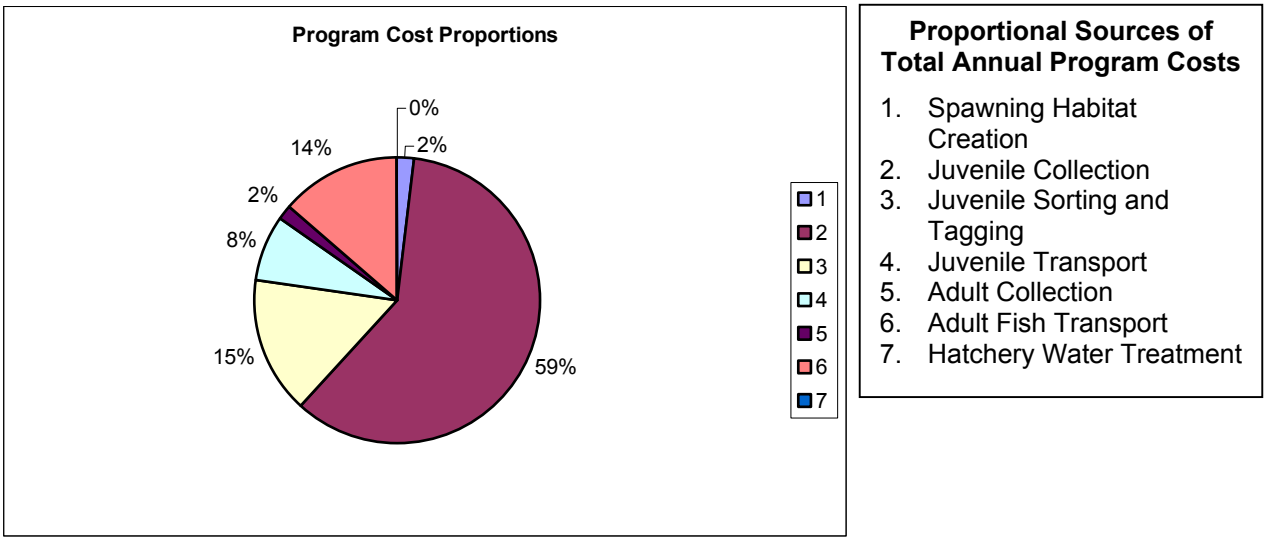

Figure 6.5-2 Proportional contributors to the total annualized fish passage program costs in the example model scenario

#1 – Spawning Habitat Creation is at the 12:00 clock position at 2% on the graph. Spawning habitat creation was included in the model options selected for the example scenario to demonstrate this option. Although habitat creation is probably not the best strategy to achieve a goal of lowest cost per fish, at 2% it did not significantly affect the overall costs. #2 – Juvenile Collection dominates the cost proportions at 59%. This is due to the capital and O&M costs for the gulpers. #3 – Juvenile Sorting and Tagging is the second highest contributor to overall cost at 15%. This is mainly due to the cost of the tagging even though only CWT tags were selected and not the much more expensive, but more appropriate for the stated fish passage program goal, PIT tag option. If PIT tags were to have been selected, the cost would have eclipsed the Juvenile Collection as the single largest contributor to overall fish passage program costs. The hatchery water treatment option was not selected, so its proportional cost contribution is 0%.

7.0 REFERENCES

Bilby, R.E., B.R. Fransen, P.A. Bisson, and J.K. Walter. 1998. Response of Juvenile Salmon (*Oncorhynchus kisutch*) and Steelhead (*Oncorhynchus mykiss*) to the Addition of Salmon Carcasses to Two Streams in Southwestern Washington, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 39:426-447:

Cramer, S.P. and C. Chapman. 2002. Estimation of Total Catch and Spawning Escapement From Fall Chinook Salmon Produced at Central Valley Hatcheries, 1967-1996. Progress Report. Gresham, Oregon: S.P. Cramer and Associates, Inc.

DFG. Accessed on October 8, 2003. Wild and Heritage Trout, Wild Trout and Catch-and-Release Waters- Middle Fork Feather River. Available at http://www.dfg.ca.gov/fishing/html

DWR and USBR. 2000. Biological Assessment- Effects of the Central Valley Project and State Water Project on Steelhead and Spring-Run Chinook Salmon.

FERC. 2001. Conservation of Power and Water Resources. 18 CFR 4.51. April 1, 2001.

Finney, B.P., I. Gregory-Eaves, J. Sweetnam, M.S.V. Douglas, and J.P. Smol. 2000. Impacts of Climatic Change and Fishing on Pacific Salmon Abundance Over the Past 300 Years. Science 290:795-799.

Johnston, N.T., J.S. MacDonald, K.J. Hall, and P.J. Tschaplinski. 1997. A Preliminary Study of the Role of Sockeye Salmon (*Oncorhynchus nerka*) Carcasses As Carbon and Nitrogen Sources for Benthic Insects and Fishers in the "Early Stuart" Stock Spawning Streams, 1050 Km From the Ocean.

Kastner, A. 2003. Feather River Hatchery- Draft Annual Report 2002-2003. Wildlife and Inland Fisheries Division Administrative Report. California Department of Fish and Game.

Leary, R.F., F.W. Allendorf, and G.K. Sage. 1995. Hybridization and Introgression Between Introduced and Native Fish. American Fisheries Society Symposium 91-101.

Minkawa, N. and R.I.Gara. 1999. Ecological Effects of a Chum Salmon (*Onchorhynchus keta*) Spawning Run in a Small Stream of the Pacific Northwest. Journal of the North American Benthological Society 21:651-659.

Minkawa, N., R.I. Gara, and J.M. Honea. 2002. Increase Growth Rate and Community Biomass of Stream Insects Associated With Salmon Carcasses. Journal of the North American Benthological Society 21:651-659.

Naiman, R. J., R.E. Bilby, D.E. Schindler, and J.M. Helfield. 2002. Pacific Salmon, Nutrients, and the Dynamics of Freshwater and Riparian Ecosystems. Ecosystems 5:399-417.

NOAA. 1998. Final Rule: Notice of Determination. Endangered and Threatened Species: Threatened Status for Two ESUs of Steelhead in Washington, Oregon, and California. Federal Register 63(53):13347-13371. March 19, 1998.

NOAA. 1999. Final Rule: Notice of Determination. Endangered and Threatened Species: Threatened Status for Two Chinook Salmon Evolutionarily Significant Units (ESUs) in California. Federal Register 64(179):50394-50415. September 16, 1999.

Pacific Fisheries Resource Conservation Council. 2001. Pacific Fisheries Resource Conservation Council: Third Annual Report.

Petrosky, C.E., H.A. Schaller, and P. Budy. 2001. Productivity and Survival Rate Trends in the Freshwater Spawning and Rearing Stage of Snake River Chinook Salmon (Oncorhynchus Tshawytscha). Canadian Journal of Fisheries and Aquatic Science 58:1196-1207.

Quinones, A. R. 1999. Feather River Hatchery- Draft Annual Report 1998-1999. Wildlife and Inland Fisheries Division Administrative Report. California Department of Fish and Game.

Schuldt, J.A. and A.E. Hershey. 1995. Effect of Salmon Carcass Decomposition on Lake Superior Tributary Streams. Journal of the North American Benthological Society 14:259-268:

Thedinga, J.F., S.W. Johnson, and K.V. Koski. 1998. Age and Marine Survival of Ocean-Type Chinook Salmon *Oncorhynchus tshawytscha* From the Situk River, Alaska. Alaska Fishery Research Bulletin 5:143-148.

Wipfli, M. S., J. Hudson, and J. Caouette. 1998. Influence of Salmon Carcasses on Stream Productivity: Response of Biofilm and Benthic Macroinvertebrates in Southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 55:1503-1511.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California. North American Journal of Fisheries Management 18:487-521.

Appendix A

Biological Relationships

1.0 INTRODUCTION

Currently, the Fish Passage Model functions by using a series of equations that represents a sequence of events occurring during the Chinook salmon life cycle. The biological element equations on the Fishery User Input Values page of the model could be considered to be a series of transactions where loss of a proportion of the population occurs. The input values were derived from those reported in the literature, and were termed "Biological Relationships."

The Biological Relationships, below, provide the definition of each biological element input value on the Fishery User Input Values page of the model and technical terms associated with each input value, assumptions made about each biological element input value, and the relationship of each input value to the literature. Each Biological Relationship provides reported values, or ranges of values that were used to determine the best case, expected, and worst case value in each of the biological element input values.

2.0 SPAWNING

2.1 PRE-SPAWN SURVIVAL RATE

Definition of Terms

- Pre-spawn Survival Rate is the complement of pre-spawn mortality rate, which is defined as the percentage of female adult Chinook salmon transported to the tributaries upstream from Lake Oroville that die prior to spawning. That is, the Pre-spawn Survival Rate is the percentage of female adult Chinook salmon transported to the tributaries upstream from Lake Oroville that survive to spawn.

- Pre-spawn mortality is defined as the proportion of females transported and released into the upstream tributaries that die prior to spawning and includes, but is not limited to, in-river mortality caused by transport, or any other immigration or handling, related stress (latent mortality), water temperature-dependent mortality, disease-induced mortality, predation of adults prior to spawning, angler induced mortality, and competition between spawning adults sufficient to preclude some fish from spawning.

Assumptions

- Spring- and fall-run Chinook salmon pre-spawn survival rates are similar.

- Water temperatures recommended by regulatory agencies, including NOAA Fisheries and DFG, protective of Chinook salmon during adult upstream immigration and holding, spawning and incubation, and juvenile rearing and emigration will be provided in the Feather River tributaries to Lake Oroville.

- During spring-run Chinook salmon adult holding in the Feather River tributaries to Lake Oroville, angling restrictions would be implemented to minimize pre-spawn mortality rates.

Biological Justification

Pre-spawn mortality rates are usually low, but can vary across regions and through time. Shepard (1975) *in* (Healey 1991)) reported a 19.1 percent pre-spawn mortality estimate for Bear River Chinook salmon, and that 30 of 230 female Chinook salmon (13%) observed in the Babine River died unspawned. In 1965, approximately 25 percent of Chinook salmon in a spawning channel at Priest Rapids, Washington died prior to spawning, reportedly due to a protozoan infection of the gills (Pauley (1965) *in* (Healey 1991). In 1988, DFG reported that pre-spawn mortality of Trinity River Chinook salmon ranged from a high of 75 percent at the beginning of the spawning season, to a low of 23 percent in the final weeks of the spawning season (Zuspan et al. 1991). The

overall female Chinook salmon pre-spawn mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River reportedly ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001).

Pre-spawn mortality estimates were calculated by linear regression analysis of carcass survey data collected from the 2000 through 2002 Chinook salmon spawning seasons in the lower Feather River below the Fish Barrier Dam. Study Plan Report SP-F10 Task 2B summarizes the survey protocol and statistical analyses performed to derive pre-spawn mortality estimates. In 2000, average pre-spawn mortality for the entire spawning season was estimated to be 33.0% in the LFC and 38.8% in the HFC. In 2001, average pre-spawn mortality for the entire spawning season was estimated to be 50.8% in the LFC and 39.1% in the HFC. In 2002, average pre-spawn mortality for the entire spawning season was estimated to be 46.5% in the LFC and 29.2% in the HFC. From 2000 through 2002, the pre-spawn mortality estimate in the LFC and HFC averaged 43.4 and 35.7 percent, respectively. The average pre-spawn mortality rate combining all study years and both reaches was 39.6 percent (DWR 2004).

For the purposes of model development, the expected pre-spawn mortality in the Feather River tributaries to Lake Oroville is expected to be 43% based on the average of pre-spawn mortality estimates from the LFC from 2000 through 2002. The range of pre-spawn mortality is expected to be between 33% and 51% based on the lowest and highest pre-spawn mortality estimates in the LFC for individual years between 2000 and 2002. It is possible, however, that angling restrictions during spring-run Chinook salmon holding in the upper Feather River could potentially result in lower than expected pre-spawn mortality rates.

The best, expected, and worst case pre-spawn survival rates selected for the upper Feather River tributaries to Lake Oroville are the complements of the lowest, average, and highest pre-spawn mortality rates, respectively, that were estimated for the LFC of the lower Feather River from data collected for the 2000 through 2002 Chinook salmon spawning seasons. Because pre-spawn mortality survival rate is the complement of pre-spawn mortality rate, the best case Pre-spawn Survival Rate in the upper Feather River tributaries is 67% (100%-33%=67%), the expected Pre-spawn Survival Rate is 57% (100%-43%=57%), and the worst case Pre-spawn Survival Rate in the upper Feather River tributaries is 49% (100%-51%=49%). Pre-spawn Survival Rates were based on pre-spawn mortality estimates for the LFC because fish in the LFC comprise the same population being considered for passage. If genetic differences between populations of Chinook salmon equate to differential susceptibility to pre-spawn mortality, then LFC Chinook salmon pre-spawn mortality rates are most representative of potential upper Feather River pre-spawn mortality rates. Additionally, the LFC represents the portion of the lower Feather River with the lowest water temperatures during the Chinook salmon spawning season. Also, the LFC represents the last natural riverine condition the adult Chinook salmon would experience prior to transportation upstream. Therefore, based on the assumption that water temperatures protective of

Chinook salmon spawning will be provided in the tributary reaches likely to be considered as Chinook salmon spawning reaches, the LFC is most likely representative of the Feather River tributaries upstream of Lake Oroville.

Based on the pre-spawn mortality literature reviewed, calculation of pre-spawn survival rate yields a best case Pre-spawn Survival rate of 67%, an expected pre-spawn survival rate of 57%, and a worst case pre-spawn survival rate of 49%.

2.2 REDD SIZE

Definition of Terms

- Redd Size is defined as the area of substrate disturbed, and thus utilized, by a spawning female adult Chinook salmon.

Assumptions

- Redd size is not related to fish size.
- Redd size does not differ between spring-run Chinook salmon and fall-run Chinook salmon.
- Adult female Chinook salmon construct only one redd per spawning event.
- Adult female Chinook salmon spawn only once.

Biological Justification

Specific river mean redd size is typically quantified through field measurement or by aerial photograph interpretation. When these options are not available, literature reviews are conducted to estimate the mean and range of redd sizes of the same salmonid species and race in other river systems for use as a surrogate. The mean dimensions of Chinook salmon redds vary geographically and between runs (Healey 1991). Differences in the reported mean size of Chinook salmon redds also may be a function of measurement methodology (Healey 1991). For example, field measurements might lead to smaller redd areas than measurements obtained from aerial photographs due to difficulties in the field identification of the tail spill and head of newly constructed redds, particularly if the redds are irregularly shaped (Snider and Vyverberg 1995).

Using field measurement techniques, Burner (1951) reported a grand mean size for fall-run Chinook salmon redds of 53.5 ft^2 and a range from approximately 42 ft^2 to 70 ft^2 for three tributaries of the Columbia River. Using similar techniques, Chapman et al. (1986) reported a grand mean size for fall-run Chinook salmon redds of 184.1 ft^2 and a

range from approximately 22.6 ft^2 to 482 ft^2 in the Hanford reach of the Columbia River and, using field measurement techniques, (Chapman et al. 1986). Field measurements and aerial photography were used to delineate mean redd size of fall-run Chinook salmon in the American River (Snider and Vyverberg 1995). The grand mean size of redds calculated from field measurements and aerial photographic interpretation was reported as 33 ft^2 and 190.5 ft^2 respectively. Healey (1991) calculated redd areas from dimensions provided by Vronskiy (1972) from the Kamchatka River. Redd areas were obtained by multiplying the maximum and minimum measurements of redd lengths and widths. Based on the measurements taken by Vronskiy (1972), Healey (1991) reported redd areas ranging from 43 ft^2 to 161 ft^2. Nielson and Banford (1983) *in* Healey (1991) reported redd sizes ranging from 5.4 ft^2 to 296 ft^2 with an average redd size of 102 ft^2 using maximum length and width calculation techniques. Moyle (2002) reported that redd areas for Chinook salmon ranged from approximately 22 ft^2 to 108 ft^2. During studies conducted to determine the factors affecting Chinook salmon spawning in the Feather River, Sommer et al. (2001) calculated superimposition rates utilizing a redd area provided by Bell (1986). Sommer et al. (2001) reported that 55 ft^2 was, "*the average surface area for an average size fall-run Chinook salmon*."

For this model, redd size is a part of the calculation of redd superimposition rates and because higher redd superimposition rates are considered to have larger negative impacts on juvenile salmon initial-year-class strength, the best case redd size is considered to be the low endpoint of the range of reported redd areas. Conversely, the worst case redd size is considered to be the high endpoint of the range of reported redd areas. Therefore, utilizing the best case redd size would result in the lowest superimposition rates given a fixed spawning area and number of spawning adults, and the worst case redd size would result in the highest superimposition rates given a fixed spawning area and number of spawning adults. The best and worst case redd sizes were calculated by taking the mean of the respective endpoints of the ranges of reported redd areas reviewed. Therefore, the low end of the reported range of redd sizes provided by Burner (1951), Chapman et al. (1986), Vronskiy (1972) *in* Healey (1991), Nielson and Banford (1983) *in* (Healey 1991)) and (Moyle 2002) were used to calculate the best case redd area for Lake Oroville tributaries while the high endpoints of the ranges provided by these authors were used to calculate the worst case redd area. Because sampling methodologies and redd area quantification techniques were not standardized between reports reviewed, using the mean of the low endpoints of the reported ranges of redd size was considered appropriate.

Calculation of best case redd size based the ranges of redd size reported by Burner (1951), Chapman et al. (1986), Vronskiy (1972) *in* Healey (1991), Nielson and Banford (1983) *in* Healey (1991) and Moyle (2002), the best case redd size in the tributaries to Lake Oroville was 27 ft^2. Worst case redd size was calculated to be 223 ft^2.

Because superimposition rates have been calculated by Sommer et al. (2001) in the lower Feather River based on the average redd size of spawning fall-run Chinook

salmon, 55 ft^2 was chosen as the expected average redd size for the tributaries to Lake Oroville. Utilization of the same redd area as Sommer et al. (2001) allows for redd superimposition rates to more accurately be compared between the lower and upper Feather River than if redd areas from other studies were used to determine the expected redd size. Additionally, comparison of superimposition rates between the upper and lower Feather River could aid decision makers in determining the appropriate number of female adult Chinook salmon to transport above Oroville Dam.

Based on reported redd areas from multiple studies, best, expected, and worst case Redd Size is 27 ft^2, 55 ft^2, and 223 ft^2 respectively.

2.3 EGG PRODUCTION PER FEMALE

Definition of Terms

- Egg production per female is defined as the average number of viable eggs produced per female adult Chinook salmon.

Assumptions

- Water temperatures and other environmental factors in the upper Feather River tributaries are appropriate to allow average egg production per female.

- Angling restrictions would be enforced to minimize stress and the potential for egg retention in spawning adult female Chinook salmon.

Biological Justification

Using a regression model developed to predict Sacramento River spring-run Chinook salmon fecundity, DFG (1998) estimated that female spring-run Chinook salmon produce between 1,350 and 7,193 eggs per female with a weighted average of 4,161 eggs per female (DFG 1998; DFG 2003).

In addition to DFG estimates, Feather River Chinook salmon egg production from 2001 through 2002 in the Feather River hatchery was examined. According to hatchery records, female Chinook salmon produced an average of 6,000 eggs per female and 5,662 eggs per female in the 2001 and 2002 spawning runs, respectively. Average egg production reportedly was calculated by dividing the estimated total number of eggs retrieved by the total number of females spawned (Kastner 2002; Kastner 2003).

Although the number of eggs retrieved during hatchery operations provides reasonably accurate estimates of the average number of eggs produced by adult female Chinook salmon, the estimates do not necessarily reflect the number of eggs deposited in the gravel by wild spawning females (DFG 2003; Healey 1991). It has been reported that

egg retention represents an important potential loss in egg production (Healey 1991). Egg retention rates ranging from 0.5% to 1.3% were reported for spawning female adult Chinook salmon, however estimates of 20% to 25% were reported in females that were harassed (Vronskiy 1972, Major and Mighell 1969, and Shepherd 1975 *in* (Healey 1991). Egg retention rates of 25% also have been reported in adult female Chinook salmon with gill infections (Pauley 1967 *in* (Healey 1991). A mean egg retention estimate of 0.8% was calculated based on the reported range of egg retention estimates obtained from healthy, unstressed adult female Chinook salmon.

For modeling purposes, hatchery calculated estimates of Feather River Chinook salmon egg production were considered representative of the upper Feather River tributaries. Additionally, the calculated mean egg retention estimate of 0.8% was subtracted from the reported range of average number of eggs produced per female for Feather River Chinook salmon to obtain the best case and worst case egg production for the upper Feather River tributaries. The estimate of mean egg retention was subtracted from the mean number of eggs produced per Feather River Chinook salmon female, calculated by averaging the egg production estimates from the 2001 and 2002 spawning runs, to obtain the expected egg production for the upper Feather River tributaries. Therefore, for modeling purposes, the best case, expected, and worst case egg production is 5,520, 5,365, and 5,209 eggs per female.

2.4 SUPERIMPOSITION MORTALITY RATE

2.4.1 Definition of Terms

- The redd superimposition rate is the percentage of previously constructed Chinook salmon redds that are subjected to disturbance by subsequently spawning females.

- The Superimposition Mortality Rate is the percentage of eggs in a redd that suffer mortality due to being superimposed upon by another redd.

2.4.2 Assumptions

- Redds are either fully superimposed upon or not, no partial superimposition occurs.

- Superimposition rates of spring- and fall-run Chinook salmon are the same.

- Each adult female Chinook salmon constructs only one redd.

- All available spawning habitat is utilized before superimposition begins to occur.

- Redd size is 55 ft^2.

2.4.3 Biological Justification

Redd superimposition occurs when female salmonids construct redds on top of previously constructed redds. Superimposition rates are a function of spawning density, streamflow, available spawning habitat and other factors. High rates of superimposition typically occur in river systems where spawning habitat is limited Fukushima (1998).

In the Low Flow Channel (LFC) of the lower Feather River, Chinook salmon reportedly used 773,732 ft^2 for spawning, with the greatest area concentrated just below the Fish Barrier Dam. The uppermost three miles of the LFC contained more than 60 percent of the defined spawning area. The majority of spawning occurred in riffles and glides. The LFC spawning escapement estimate based on the carcass survey by DFG in 1995 was 44,111. The estimated superimposition index in the LFC was 1.57 (Sommer et al. 2001). Theoretically, a superimposition index of 1.0 represents no superimposition. The superimposition index results are similar to those reported by Painter (1977). The high superimposition indices calculated for the LFC suggest that spawning habitat in this reach is limiting (Sommer et al. 2001). In the High Flow Channel (HFC), Chinook salmon reportedly used 1,480,085 ft^2 for spawning. Areas used for spawning were evenly distributed throughout the HFC, with glide habitats used most extensively. The HFC spawning escapement estimate based on the carcass survey by DFG in 1995 was 15,572. The estimated superimposition index in the HFC was 0.47 (Sommer et al. 2001). The results are similar to those reported by Painter (1977).

Redd superimposition may result in incubating egg and alevin mortality (Healey 1991). In Auke Creek, Alaska, maximum daily egg loss for pink salmon resulting from redd superimposition was estimated to range from 278,000 to 398,000 eggs (Fukushima 1998). During 1963 and 1964, a 46 percent egg mortality rate was reported for pink salmon due to superimposition by chum salmon in the Qualicum River, Canada (Walker and Lister 1971).

Reported results from Kindopp (1999) suggest that redds constructed later in the spawning season have higher survival rates. One possible explanation for this observation is that redds constructed later in the spawning season may be less likely superimposed upon. However, differences in early and late spawning season water temperature also likely would affect egg survival rates.

Sommer et al. (2001) reported that historical data from the lower Feather River suggest that superimposition significantly reduces egg survival. Within the LFC of the lower Feather River, egg survival is reportedly reduced as a result of superimposition (Sommer et al. 2001). The average egg survival rate below Thermalito for 1968 through 1972 was reported to be 84 percent. The highest survival rate for Chinook salmon eggs in the LFC was reportedly 93 percent (Sommer et al. 2001). Egg survival rates for the Feather River from the Fish Barrier Dam to the Thermalito Afterbay Outlet reportedly

ranged from 93.5 percent in 1968 to 31.6 percent in 1969. However, in some years spawning was reported to be so intense that it was difficult to identify individual redds; most were contiguous or obviously superimposed (Painter et al. 1977).

Superimposition is probably one of the key factors driving Chinook salmon egg mortality in the Feather River (Kindopp 1999). The high density of spawners in the upper three miles of the Low Flow Section creates extreme competition for quality habitat resulting in high superimposition. Potentially further exacerbating Chinook salmon redd superimposition is the armoring of spawning gravels in the LFC, further reducing the available spawning habitat.

Literature was not located regarding the mortality rates incurred by incubating eggs and alevins in redds superimposed upon by subsequently spawning female Chinook salmon. Therefore, an estimate of the superimposition mortality rate could not be determined through literature review. For modeling and analysis purposes, a superimposition mortality rate of 20 percent was arbitrarily selected. Each incidence of redd superimposition results in 20 percent mortality of the incubating eggs or alevins. A second incidence of redd superimposition results in an additional 20 percent mortality incurred by the original redd, and 20 percent mortality to the second redd.

2.5 EGG DEPOSITION – EMERGENCE SURVIVAL

Definition of Terms

- Egg Deposition – Emergence Survival is the survival rate from egg deposition through fry emergence.

- The survival rate from egg deposition through fry emergence is defined as the percentage of eggs deposited in a redd that progress through embryonic development, hatching, and emergence.

Assumptions

- No distinction is made between deposition of unfertilized eggs and embryo or alevin mortality.

- Water temperatures protective of Chinook salmon incubation would be provided.

- Flow reductions and subsequent redd dewatering during the incubation period are assumed not to occur.

- There is no difference in survival from egg deposition through emergence between spring-run Chinook salmon and fall-run Chinook salmon.

Biological Justification

Bradford (1995) collected published and unpublished literature on salmon egg survival and analyzed 40 cases in which at least 10 years of data was available. In most cases potential egg deposition versus the estimated number of fry emerging the following spring was examined to obtain estimates of egg to fry survival rates. The average salmon egg to fry emergence survival rate across all species examined was eight percent. However, it was reported that, on average, Coho salmon egg to fry emergence survival was greater than of chum salmon, pink salmon, or sockeye salmon. The average egg to fry emergence survival rate reported for pink salmon, chum salmon, and sockeye salmon was seven percent whereas the average Coho salmon egg to fry emergence survival rate was reported to be 19 percent (Bradford 1995). Estimates of Coho salmon egg to fry emergence survival rates were also calculated for Deer Creek, Needle Branch, and Flynn Creek where survival rates where reported to be 54.4%, 25.1% and 13.6%, respectively (Koski 1966). Koski (1966) reported that according to Wales and Coots (1955) egg to fry emergence survival for Fall creek Chinook salmon ranged from seven percent to 32% during a four year study period. In a study evaluating the effects of the Coffelt System 91 Electroanesthesia Unit on survival of egg to fry stages of Chinook salmon, it was reported that the average egg to fry mortality was 6.6 percent for progeny of electroshocked adults and 11.8 percent for progeny of control adults (Tipping and Gilhuly 1996). Therefore, the Chinook salmon egg to fry emergence survival rate was 88.2 percent for progeny of control adults and 93.4 percent for progeny of electroanesthetized adults. According to Bradford (1995) Chinook salmon egg to smolt survival rates should be higher than those for other pacific salmon species because Chinook salmon have a larger body size, which allows them to "*spawn in larger rivers, use larger gravels, and deposit their eggs deeper in the streambed, all of which may contribute to higher egg to fry survival* (Chapman 1988, Healey 1991, M. J. Bradford, unpublished data *in* (Bradford 1995)."

An analysis of the egg to fry emergence survival rates reported for each species indicates that there is a great deal of variability between studies. Environmental factors such as incidence of floods, droughts and freezing (Wickett 1958 *in* (Bradford 1995) as well as spawning habitat characteristics such as gravel quality and density of spawning adults (Chapman 1988 *in* (Bradford 1995) were reported to affect the survival of salmon eggs and alevins. In addition, Koski (1966) reported that gravel composition, gravel permeability, dissolved oxygen and gravel stability also are associated with egg survival to emergence.

Although egg to fry emergence survival rates for Coho salmon, pink salmon, chum salmon, sockeye salmon, and Chinook salmon were examined, the reported Chinook salmon survival rates were chosen to represent the best case, expected, and worst case egg to fry emergence survival rates for the upper Feather River tributaries. Because the variability in reported egg to fry emergence survival estimates vary substantially between species, it was assumed that Chinook salmon egg to fry

emergence rates reported from Fall Creek by Wales and Coots (1955) *in* (Koski 1966) were more representative of Feather River Chinook salmon than other species. Egg to fry emergence survival rates obtained from Tipping and Gilhuly (1996) were not considered representative of Feather River Chinook salmon egg to fry emergence survival rates because the experiment produced substantially higher egg to fry emergence rates in an electroanesthetized experimental group than in the control group.

The range of egg to fry emergence survival rates reported for Fall Creek Chinook salmon was seven percent to 32% (Wales and Coots 1955 *in* (Koski 1966). The mean egg to fry emergence rate calculated from the reported egg to fry emergence rates of Fall Creek Chinook salmon was 19.5%. Therefore, for modeling purposes, the best case, expected, and worst case egg to fry survival rates were 32%, 20%, and seven percent, respectively.

3.0 JUVENILE COLLECTION

3.1 LOW TRIBUTARY FLOW – SCREEN

3.1.1 Proportion of Juvenile Capture

Definition of Terms

- The proportion of the emigrating juvenile Chinook salmon population captured by the tributary low flow fish screens is defined as the Proportion of Juvenile Capture.

Assumptions

- Fish screens are functional during periods of the year characterized by relatively low flows.
- The low flow period of the year for the major tributaries to Lake Oroville extends from July through November.
- Juvenile spring- and fall-run Chinook salmon emigration timing in the lower Feather River is similar to, and representative of, the potential emigration timing of juvenile Chinook salmon in the Lake Oroville tributaries.
- Rotary screw trap data is not biased by fish size.

Biological Justification

The variation in life history strategies exhibited between spring- and fall-run Chinook salmon results in differences in the temporal distribution of juvenile emigration (Healey 1991; Moyle 2002). According to Moyle (2002), fall-run Chinook salmon emigration peaks during spring (March and April), and spring-run Chinook salmon emigration peaks during winter (January to February) and then again in spring (April).

For the purposes of model development, juvenile Chinook salmon downstream migrant trapping data from Butte Creek (Ward and McReynolds 2001) and the lower Feather River (DWR 2002) was reviewed to estimate the proportion of fish that emigrated during "high flow" and "low flow" months. The lower Feather River data reported emigration timing for spring- and fall-run Chinook salmon based on juvenile outmigrant length-at-date from the Sacramento River Daily Length Table (Green 1992 *in* (DWR 2002)). Ward and McReynolds (2001) reported spring-run juvenile Chinook salmon emigration timing for Butte Creek, which was utilized for comparison to spring-run Chinook salmon emigration timing in the lower Feather River (Ward and McReynolds 2001). Juvenile Chinook salmon emigration patterns in the lower Feather River are assumed to be

representative of potential emigration patterns in the upper tributaries (i.e., there is no difference in emigration timing between upstream tributaries and the lower Feather River).

Flow records obtained from the California Data Exchange Center (DWR 2003a) were examined to characterize the "low flow" period of the year for tributaries to Lake Oroville. Data were available for North Fork Feather River at Pulga, Middle Fork Feather River at Merimac, and West Branch Feather River at Miocene Canal. Data were available from 1996 through 2001 for the North Fork Feather River, from 1998 through 2002 for the Middle Fork Feather River, and from1986 through 2002 for the West Branch Feather River. For the purposes of model development, July through November was considered to represent the low flow period in all upper Feather River tributaries. Examination of the data revealed that flow in the west Branch of the Feather River was significantly lower than flow in either the Middle Fork Feather River or North Fork Feather River. Examination of flow records in the Middle Fork and North Fork Feather River revealed that flows exhibited similar trends in monthly flow distribution. Particularly for the Middle Fork, flow decreases rapidly during spring, from May to July. Flows of only 1/3 of the average monthly June flow remain throughout summer, gradually increasing during fall. Average monthly flows during November are about 2/3 of the flows that occur during June, and slightly more than ½ of those occurring during December.

An estimate of the proportion of juvenile spring- and fall-run Chinook salmon that typically emigrate from July through November was obtained by evaluating the juvenile Chinook salmon downstream migrant trapping data from Butte Creek and the lower Feather River (DWR 2002; Ward and McReynolds 2001). For the purposes of model development, it was assumed that rotary screw trap data is not size-biased, and reflects true migration patterns of emigrating juvenile salmonids.

To assess the run migration timing of Butte creek spring-run Chinook salmon, a combination of biweekly screen trap and screw trap catch data from Parrott-Phelan Diversion Dam from 1998 through 2000 was examined. Based on these data, the percentage of juvenile spring-run Chinook salmon in Butte creek that emigrated during July through November was determined to be approximately 0.32 percent over the two-year period.

Feather River Thermalito rotary screw trap catch distribution data collected from 1999 through 2001 was utilized to estimate the proportion of spring- and fall-run juvenile Chinook salmon emigrating from July through November. DWR (DWR 2002) assigned a race to all juvenile Chinook salmon captured using the length/date criterion set forth in the Sacramento River Daily Length Table (Green 1992 *in* DWR, 2002). Using the catch distribution data, the percentage of spring- and fall-run juvenile Chinook salmon in the lower Feather River that emigrated from July through November was calculated to be approximately 1.4 and 0.0 percent, respectively, over the three-year period.

Although an indeterminate level of error is associated with the length-at-date size classification criteria used to identify juvenile Chinook salmon races in DWR (2002), for the purposes of model development, the identification error was assumed to be negligible.

Because most fall-run Chinook salmon reportedly do not emigrate during the low-flow period (DWR 2002), the best, expected and worst case Proportion of Juvenile Captured during low flow (July through November) represents only emigrating juvenile spring-run Chinook salmon, and is 2.0, 1.0, and 0.0 percent respectively.

3.1.2 In-River Survival Rate

Definition of Terms

- In-River Survival Rate is the percentage of juvenile salmon that survive from emergence to capture. Factors influencing juvenile Chinook salmon survival rates include, but are not limited to, predation, water temperature, flow, disease, and density dependent variables such as competition.

- In-River Survival Rate is the complement of in-river mortality rate.

Assumptions

- Because fall-run Chinook salmon emigrate shortly after emergence, juvenile fall-run Chinook salmon in-river survival is assumed to be high. Therefore, In-River Survival Rates only were calculated for emigrating spring-run Chinook salmon.

- Predation is the most common cause of mortality among fry and fingerling Chinook salmon.

- Only a proportion of juveniles will be preyed upon.

- The proportion of juveniles preyed upon depends on juvenile Chinook salmon emigration timing, size at time of emigration, and the species and abundance of predators present at the time of migration.

- Water temperature protective of emigrating juvenile Chinook salmon shall be provided (i.e., there will be no water temperature related mortality).

- The survival rates of migrating juveniles are influenced by river flows.

- Flow fluctuations during the juvenile Chinook salmon emigration period would be minimized.

- Flows recommended for protection of emigrating juvenile Chinook salmon would be provided during the juvenile Chinook salmon emigration period.
- The incidence of disease is dependent on water temperature.
- Mortality rates resulting from competition are independent of whether inter- or intraspecific competition occurs.

Biological Justification

Predation reportedly is the principal cause of mortality among fry and fingerling Chinook salmon (Foerester and Ricker 1941 and Hunter 1959 *in* (Healey 1991). Evanson et al. (1981) *in* (Fresh 1997) reported that the average annual loss of wild Chinook salmon and steelhead over a three year period due to predation by hatchery fish was 9.7% in the Rogue River, Oregon. Martin et al. (1993) *in* (Fresh 1997) reported that 95% of juvenile Chinook salmon were preyed upon in the Tucannon River, Washington within 4.5 months following a release of juvenile steelhead. Smallmouth bass within the Columbia River, Washington were reported to consume 1.4 (May 2-3) to1.0 (June 20-21) salmonids per predator daily. Northern pikeminnow were reported to consume from 0.55 (May 2-3) to 0.34 (June 20-21) salmonids per predator per day (Tabor et al. 1993). Northern pikeminnow reportedly consumed 21% to 35% of emigrating juvenile salmonids in 1992, 22% to 32% in 1994, and 9% to 20% in 1995 downstream from the Bonneville Dam on the Columbia River (Zimmerman and Ward 1999). Rogers et al. (1972) *in* (Fresh 1997) reported that Artic char consumed 33% to 66% of outmigrating sockeye salmon smolts in one year in the Agulowak River, Alaska. In 1914, striped bass were introduced into the Coos River, Oregon and a predation model developed by Johnson et al. (1992) reportedly estimated that striped bass in this system would consume between 42,000 and 383,000 juvenile salmonids (Fresh 1997). In addition to fish predation on juvenile salmonids, studies on the Big Qualicum River, Vancouver Island reported avian predation rates on juvenile Chinook salmon ranging from 10.4% to 65% (Mace 1983 and Wood 1987 *in* (Roby et al. 1997)). In the Columbia River system, Roby et al. (1997) estimated the number of PIT tagged smolts consumed by the Rice Island Caspian tern colony and found that mortality estimates for outmigrating juvenile salmonid smolts that reached the estuary were in the range of 6 percent to 25% in 1997.

Water temperature also is an important factor influencing survival and growth of juvenile salmonids (Moyle 2002). It has been reported that Sacramento River fall-run Chinook salmon mortality was lowest at water temperatures of 43.5°F to 57.5°F (6.4°C to 14.2°C), and exceeded 80% when water temperatures exceeded 61°F (16.1°C) (Healey 1977). A laboratory study that was conducted on the survival of rearing Sacramento River fall- and winter-run Chinook salmon reported that at water temperatures of 52°F to 54°F (11.1°C to 12.2°C), the mortality rate for rearing juvenile fall-run Chinook salmon was 23%. The mortality rate for rearing juvenile fall-run Chinook salmon at water

temperature ranges of 56°F to 64°F (13.3°C to 17.8°C), ranged from 56% to 94% (USFWS 1999). Additionally, it was reported that at water temperature ranges of 56°F to 58°F (13.3°C to 14.4°C), the mortality rate for rearing juvenile winter-run Chinook salmon was 25%. The mortality rate for rearing juvenile winter-run Chinook salmon at water temperature ranges of 60°F to 62°F (15.6°C to 16.7°C) ranged from 45% to 81% (USFWS 1999). The mortality rate of rearing juvenile winter-run Chinook salmon was reported to be 18% at 56°F (13.3°C). At 50 °F (10°C) the mortality rate reported for rearing juvenile fall-run Chinook salmon was 16% (USFWS 1999). However, it is assumed that water temperatures protective of emigrating juvenile Chinook salmon would be provided during the emigration period. Therefore, water temperature induced mortality rates would be negligible.

In addition to predation and water temperature, flow also influences juvenile Chinook salmon survival rates. Survival estimates for Chinook salmon emigrating through the San Joaquin River system were calculated as part of the Vernalis Adaptive Management Plan (VAMP) during 2002. Emigrating juveniles were evaluated during emigration from Durham Ferry, Mossdale, and Jersey Point on the San Joaquin River to Antioch and Chipps Island in the Sacramento-San Joaquin Delta (Delta). During the evaluation, survival was estimated under two different flow regimes. After a 1,500 cfs increase in flow, the survival rate of juvenile Chinook salmon reportedly increased from 8% to 15% (San Joaquin River Group Authority 2002). It is assumed that adequate flows would be provided in the upper Feather River tributaries during the emigration period of juvenile Chinook salmon. Therefore, survival rates would not be adversely affected by flows in the upper Feather River tributaries.

Flow fluctuations reportedly could influence emigrating juvenile Chinook salmon survival rates when receding flows isolate fry from the main river channel (Bauersfeld 1978; DWR 2003c; SWRI 2004). Fluctuating flows reportedly result in considerable stranding and loss of fall-run Chinook salmon juveniles in the lower American River. For example, on May 31, 1990, a flow reduction in the lower American River resulted in the stranding of several thousand juvenile Chinook salmon and steelhead in the vicinity of Fair Oaks below Nimbus Dam. The associated mortality rate for stranded juveniles during that flow reduction reportedly was near 100%. During stranding events, sources of mortality include acute thermal stress, and predation by fish and avian predators (SWRI 2004). Because flows adequate for juvenile Chinook salmon emigration would be provided during the emigration period of juvenile Chinook salmon, it is assumed that flow fluctuations would be minimized and not contribute substantially to juvenile Chinook salmon mortality rates in the upper Feather River tributaries.

Bacterial Kidney Disease (BKD) is a systemic infection affecting salmonids that is normally slowly progressive and frequently fatal (Banner et al. 1983 *in* (Pacific Fishery Management Council 2003)). Because a primary function of fish kidneys is osmoregulation, a consequence of BKD infection, is a lack of ability of emigrating juvenile salmonids to acclimatize to seawater. The mortality rate of infected Coho

salmon smolts reportedly was 17.2% in freshwater (Fryer and Sanders 1981 *in* (Pacific Fishery Management Council 2003)). BKD reportedly can cause mortality in a wide range of water temperatures, however, the onset and magnitude of mortality is dependent on water temperature (Sanders, Pilcher and Fryer 1977 *in* (Pacific Fishery Management Council 2003)). Because water temperatures protective of emigrating juvenile Chinook salmon would be provided, it is assumed that BKD infection rates would be minimized and associated mortality rates would be negligible.

Competition between non-native species and native salmonid species has been reportedly as one cause of anadromous salmonid population declines in the Columbia River system (Kaczynski and Palmisano 1992; Bevan et al. 1994 *in* (Fresh 1997). In the Columbia River the abundance of American shad reportedly recently increased to the highest historic levels concurrently with declines to critical levels of salmon and steelhead (Fresh 1997). Competition between hatchery spawned and wild salmonids reportedly is often cited as a mechanism to explain how hatchery fish introductions have impacted native salmonids (Fresh 1997). Nickelson et al. (1986) *in* Fresh (1979) reported a 44% decline in the abundance of wild juvenile Coho salmon in Oregon coastal streams following the release of hatchery spawned juvenile Coho salmon (Fresh 1997). Nielsen (1994) *in* Fresh (1977) reported that agonistic encounters between hatchery and wild juvenile Coho salmon resulted in the displacement of 83% of the wild juveniles from their usual microhabitats in the Noyo River, California. Competition between non-native species and density dependant competition between juvenile Chinook salmon could potentially influence in-river survival rates of emigrating juvenile Chinook salmon.

Because water temperatures and flows protective of emigrating juvenile Chinook salmon would be provided in the upper Feather River tributaries, for modeling purposes overall in-river mortality rates would likely not be influenced directly by water temperature and flow, or by those factors directly influenced by water temperature or flow such as disease or juvenile stranding. Therefore, for modeling purposes, in-river survival rates were considered to be influenced by predation, and inter- and intraspecific competition.

In-River Survival Rate is defined as the complement of in-river mortality rate, or the proportion of juvenile Chinook salmon that survive in-river predation, and inter- and intraspecific competition. Therefore, the survival rates associated with in-river predation and competition were used to calculate best, expected, and worst case In-River Survival Rates.

Literature was reviewed to determine in-river survival rates representative of the upper Feather River tributaries. Reportedly 9% to 35% of emigrating juvenile salmonids were preyed upon by northern pikeminnow from 1992 through 1995 in the Columbia River (Zimmerman 1999). Therefore, survival rates of juvenile salmonids associated with northern pikeminnow predation in the study ranged from 65% to 91%. Juvenile Chinook

salmon predation rates reportedly ranged from 6% to 25% when preyed upon by Caspian terns in the Columbia River system (Roby et al. 1997). Therefore, juvenile Chinook salmon survival rates associated with avian predation in the study ranged from 75% to 94%. Because Sacramento pikeminnow are relatively abundant in the upper Feather River tributaries (DWR 2003b), and the species is similar to northern pikeminnow, for modeling purposes, predation rates reported for northern pikeminnow on juvenile salmonids were considered representative for the suite of predators in the upper Feather River tributaries (DWR 2003b). For modeling purposes, juvenile Chinook salmon survival rates associated with avian predation in the Columbia River were considered representative of the upper Feather River tributaries because terns are an abundant avian predator in the lower Feather River. In order to determine the range of survival rates for juvenile Chinook salmon exposed to piscivorous fish and avian predators in the upper Feather River tributaries, the reported ranges of survival rates were combined. For example, the low end of the range of reported survival rates due to fish predation was multiplied by the low end of the range of reported survival rates due to avian predation to determine the low end of the range of in-river predation. Therefore, for modeling purposes, the range of survival rates associated with predation in the upper Feather River tributaries was considered to be 49% to 86%.

For the purposes of modeling, mortality rates influenced by competition include inter- and intraspecific competition. However, mortality rates due to competition were not reported in the literature reviewed. Therefore, for modeling purposes, the reported decline in abundance and displacement of Coho salmon is considered representative of mortality rates that could occur due to competition. Fresh (1997) reported various studies in which juvenile Coho salmon abundance declined 44% due to competition and in which 83% of juvenile Coho salmon were displaced due to competition. Because model calculations utilize survival rates, the assumed range of mortality rates due to competition was converted to a survival rate range of 17% to 56%.

The range of spring-run Chinook salmon In-River Survival Rates was calculated by combining the range of predation related survival rates with the range of competition related survival rates. Therefore, the spring-run Chinook salmon In-River Survival rates selected for the passage model ranges from 8% to 48%. The mean of the endpoints of the range of In-River Survival Rates was chosen to represent the expected In-River Survival Rate. Therefore, for modeling purposes, the best, expected, and worst case spring-run Chinook salmon In-River Survival Rates are 48%, 28%, and 8% respectively. Because fall-run Chinook salmon were assumed to emigrate shortly after emergence, the best, expected, and worst case fall-run Chinook salmon In-River Survival Rate chosen for modeling purposes was 95%, 90%, and 80%, respectively.

3.1.3 Screen Capture Efficiency

Definition of Terms

- For the purposes of model development, Screen Capture Efficiency is defined as the proportion of emigrating juvenile Chinook salmon captured and passed beyond the screen. Screen Capture Efficiency includes, but is not limited to, the proportion of emigrating juveniles captured by the screen, and the proportion of juveniles surviving capture.

Assumptions

- In-river flows are optimal for maximum Screen Capture Efficiency.

- In-river conditions are optimal for maximum survival of juvenile Chinook salmon captured and passed (i.e. water temperatures provided are below those that cause stress in juvenile Chinook salmon).

Biological Justification

After emergence, juvenile Chinook salmon emigrate or rear in the river for several days to several months (Moyle 2002). During emigration, juveniles hatched upstream from a passage barrier would be required to pass below the barrier in order to complete their life cycles. One method of capturing juveniles for passage below Oroville Dam would be the use of instream screens.

Although screens are utilized in anadromous salmonid passage programs at various facilities, little information exists regarding exclusion barrier Screen Capture Efficiency. Efficiency rates have been reported for submersible traveling screens (STS) preventing juvenile salmonids from entering turbines at the Bonneville Second Powerhouse on the Columbia River (Gessel et al. 1991), although STS use differs substantially from the collection screens proposed for use in the upper Feather River tributaries. Therefore, criteria developed by NOAA Fisheries for fish screen use in the Klamath Hydroelectric Project were examined (pers. com., D. White, 2003). According to NOAA Fisheries (2003), juvenile survival through fish screens should meet or exceed 95%.

Because NOAA Fisheries developed the fish screen criteria for juvenile salmonid passage, it was assumed that the minimum fish screen efficiency recommended for the Klamath Hydroelectric Project would suffice as the worst case Screen Capture Efficiency for the upper Feather River Tributaries. Additionally, because screens would only capture emigrating juvenile Chinook salmon during relatively low flow (July through November) periods, it is assumed that the proportion of emigrating juvenile Chinook salmon captured by the screens is equal to the proportion of juveniles that encounter the screens. That is, all juveniles not subjected to in-river mortality are captured by the

screens when they are in place and operating correctly. Also, during relatively high flow periods, screens would not be used and all emigrating juveniles would be captured by the downstream gulper system in the reservoir arms.

Although NOAA Fisheries (2003) criteria suggest fish screen capture efficiency meeting or exceeding 95%, it is assumed that 100% efficiency would not be obtained. Therefore, it is expected that actual fish screen efficiency would range between 95% and 99%. Therefore, for modeling purposes, Screen Capture Efficiency of 99%, 97%, and 95% were estimated as best, expected, and worst cases respectively.

3.2 HIGH TRIBUTARY FLOW - GULPER

3.2.1 In-reservoir Survival Rate

Definition of Terms

- In-Reservoir Survival Rate is the percentage of emigrating juvenile salmon that survive from reservoir entrance until capture at the gulper. Factors influencing juvenile Chinook salmon survival rates include, but are not limited to, predation, water temperature, flow, disease, and density dependent variables such as competition.

- In-Reservoir Survival Rate is the complement of in river mortality rate.

Assumptions

- Predation is the most common cause of mortality among fry and fingerling Chinook salmon.

- Only a proportion of juveniles entering the reservoir will be preyed upon.

- The proportion of juveniles preyed upon depends on emigration timing, the size of emigrating juveniles, and the species and density of predators present at the time of migration.

- Water temperatures protective of emigrating juvenile Chinook salmon shall be provided (i.e. Water temperatures consistent with those recommended by the regulatory agencies such as NOAA Fisheries would be provided)

- Flow fluctuations during the juvenile emigration period will be minimized.

- The incidence of disease is dependent on water temperatures.

- Mortality rates associated with competition are independent of whether inter- or intraspecific competition occurs.

- For modeling purposes, residualization is considered equal to mortality.

Biological Justification

It has been reported that significant mortality occurs within reservoirs, primarily due to predation from piscivorous fish and birds, water temperature changes, and disease. It also has been reported that predators commonly cause the greatest mortality among fry and fingerling Chinook salmon and, in some cases, predation has been reported to be responsible for heavy losses (Foerster and Ricker 1941 and Hunter 1959 *in* (Healey 1991).

Although a majority of the literature reviewed regarding in-reservoir predation focuses on predation by piscivorous fish, current research suggests that avian predation may also be an important source of juvenile salmonid mortality (Roby et al. 1997). The reportedly high juvenile salmonid mortality rates (low survival rates) in reservoirs is often attributed to the dams, which can cause emigrating juvenile salmonids to be disoriented, delay juvenile salmonid emigration, and expose emigrating juveniles to high water temperatures. In addition to causing direct mortality, disorientation, delayed emigration, and exposure to high water temperatures increase the susceptibility of emigrating juvenile salmonids to predators (Rieman et al (1991), Beamesderfer and Rieman (1991), and Vigg et al. 1991 *in* (Poe et al. 1991)).

To quantify the effect of predation by fish on emigrating juvenile salmonids a literature review was conducted to determine predator gut contents (Poe et al. 1991), prey consumption rates (Vigg et al. 1991), and abundance of predators in reservoirs through which emigrating salmonids, including yearling Chinook salmon, subyearling Chinook salmon, juvenile Coho salmon, juvenile sockeye salmon, and juvenile steelhead migrate (Rieman et al. 1991). In studies conducted in the John Day Reservoir on the Columbia River from 1983 through 1986, four main predator species, Northern squawfish, walleye, small mouth bass, and channel catfish, were identified during the period from April through August, reportedly the salmonid emigration period at the John Day Dam (Poe et al. 1991). Stomach content samples also were used to estimate the relative proportions of salmon and steelhead consumed by each predator (Rieman et al. 1991).

The average density of predators was reported to be 85,000 northern pikeminnow, 10,000 walleye, and 35,000 smallmouth bass. Channel catfish population estimates were not available. Approximately 18 million salmon and 1.3 million steelhead were estimated to have entered the John Day Reservoir in each migration season during the study period (April through August 1983 through 1986). The evaluation revealed a mean seasonal loss of 2.7 million juvenile salmon and steelhead resulting in an estimated loss of 15 percent with confidence limits ranging from 9 to 19 percent. Juvenile salmon were reported to be the most consumed prey species in all months (Rieman et al. 1991). In order to obtain an estimate of in-reservoir predation survival rate in the upper Feather River for modeling purposes, the complement of the reported

John Day Reservoir mortality rate was used. Therefore, fish predation survival rates of juvenile Chinook salmon in the upper Feather River tributaries are assumed to be similar to those of in the John Day Reservoir. For the purposes of calculating total In-Reservoir Survival Rates, the fish predation survival rates in Lake Oroville are of 91%, 86%, and 81% as the best case, expected and worst case estimates of in-reservoir predation survival (%).

According to Roby et al. (1997), a substantial source of mortality to juvenile salmonids can be attributed to avian predators. In the Columbia River system, estimates of the number of PIT tagged smolts consumed by the Rice Island Caspian tern colony ranged from 6% to 25% in 1997 (Roby et al. 1997). Therefore, juvenile Chinook salmon survival rates associated with avian predation in the study ranged from 75% to 94% and were included in the calculation of In-Reservoir Survival Rate.

Little information was available in reviewed literature on the effects of high water temperatures, disease, and residualization on in-reservoir mortality rates of juvenile Chinook salmon. Because it is reported that water temperature is a limiting factor in juvenile Chinook salmon survival (Moyle 2002), it is assumed that water temperatures protective of emigrating juvenile Chinook salmon would be provided, and therefore water temperature related mortality would be minimized.

Disease also is a potential source of juvenile salmonid in-reservoir mortality. However, it is assumed that in-reservoir residence time will be between one and five days, depending on the location of the gulper. Therefore, disease related mortality in the reservoir would be minimal. Additionally, latent mortality associated with disease contracted in the upstream tributaries is considered as in-river mortality downstream from release.

For the purposes of modeling, residualization of emigrating juvenile Chinook salmon would also be considered as part of the in-reservoir mortality rate. A PIT tag study conducted at the Lower Snake River Reservoir reported that between 1.7 to 2 percent of Fall-run Chinook salmon residualized in the Snake River or Columbia River reservoirs (Downing and Prentice 2003). Therefore, if residualization rates are considered as mortality rates, residualization survival rates would range from 98% to 98.3%. For modeling purposes it is assumed that residualization rates in the Lower Snake River Reservoir are similar to those in the upper Feather River tributaries.

Of the reviewed literature, one study reported an estimate of reservoir survival (Smith et al. 2002). However, because overall mortality rates were extrapolated from a study that looked at mortality between tailraces on the lower Snake River and because the study ignored additional potential sources of mortality such as in-river predation, it was concluded that the mortality rates reported would not represent potential emigrating juvenile salmonid In-River Mortality Rates in the arms of Lake Oroville.

The range of In-Reservoir Survival Rates was calculated by combining the range of predation survival rates with the range of residualization survival rates. In order to determine the range of survival rates for juvenile Chinook salmon exposed to piscivorous fish and avian predators in Lake Oroville, the reported ranges of survival rates were combined. For example, the low end of the range of reported survival rates due to fish predation was multiplied by the low end of the range of reported survival rates due to avian predation to determine the low end of the range of in-reservoir predation. The expected in-reservoir predation survival rate of 86% was used with the mean avian predation rate to determine the expected in-reservoir predation rate. Therefore, for modeling purposes, the range of survival rates associated with predation in Lake Oroville was considered to be 68% to 76%. The expected in-reservoir predation rate was considered to be 73%.

Calculation of In-Reservoir Survival Rates was performed by combining in-reservoir predation survival rates with residualization rates. Therefore, for modeling purposes the best case, expected, and worst case In-Reservoir Mortality Survival Rates were considered to be 66%, 72% and 75% respectively.

3.2.2 Gulper Capture Efficiency

Definition of Terms

- For the purposes of model development, Gulper Capture Efficiency is defined as the proportion of emigrating juvenile Chinook salmon captured and passed to an adjacent sorting mechanism. Gulper Capture Efficiency includes, but is not limited to, the proportion of emigrating juveniles captured by the gulper, and the proportion of juveniles surviving capture.

Assumptions

- All emigrating juvenile Chinook salmon not collected at the instream low velocity screens and not subjected to in-river mortality would be available to be captured at the gulpers.

- Water temperatures protective of emigrating juvenile Chinook salmon would be provided.

- The gulpers would be positioned in the reservoir arms in locations where velocities through associated guide nets would not exceed 0.1 fps.

Biological Justification

After emergence, juvenile Chinook salmon emigrate or rear in the river for several days to several months (Moyle 2002). During emigration, juveniles hatched upstream from a

passage barrier would be required to pass below the barrier in order to complete their life cycles. During higher flows (i.e. above 1,170 cfs), when screens are ineffective at capturing emigrating juvenile salmonids gulper systems can be utilized (Puget Sound Energy 2002b).

During a study conducted at the Upper Baker lake fish gulper in 2002, acoustic tags were used to track the behavior of Coho and Sockeye salmon as they moved through the forebay of the reservoir toward the gulper. Analysis of the results revealed that large amounts of fish reportedly crossed the mouth of the surface collector mechanism utilized with the gulper, but did not enter the collection barge. Reportedly, 21 percent of the tagged juvenile Coho and Sockeye salmon were collected by the gulper (Puget Sound Energy 2002b). Earlier studies at the Upper Baker Lake gulper from 1988 to 1992, used fixed location hydroacoustics to determine guidance effectiveness (FERC 1993). FERC (1993) reported that guidance efficiencies over the test period ranged from 67 percent to 79 percent. Survival associated with fish gulpers is assumed to be high but limited information is available regarding injury related to the use of gulpers to guide and capture fish.

Because limited information on gulper devices is available, the Upper Baker Lake Gulper studies were utilized to determine best case, expected, and worst case gulper efficiencies in the arms of Lake Oroville. Additionally, because gulper devices require narrow inflow ranges in which to operate, it is assumed that the position of the gulper in Lake Oroville would provide similar conditions to those in Upper Baker Lake.

Because the two studies reported a range of efficiencies, the highest and lowest efficiency in either of the studies was chosen to represent the best and worst case, respectively, for the Lake Oroville gulper. The mean of the highest and lowest reported efficiencies was chosen to represent the expected efficiency of the Lake Oroville gulper. Therefore the best case, expected, and worst case gulper efficiencies were estimated to be 79%, 50%, and 21% respectively.

4.0 JUVENILE FISH SORTING

4.1. SORTING FACILITY

4.1.1 Sorting Efficiency

Definition of Terms

- For the purposes of model development, Sorting Efficiency is defined as the proportion of captured emigrating juvenile Chinook salmon successfully identified by species that survive the sorting procedure. Sorting consists of, but is not limited to, the use of sorting devices, physical handling by technicians while separating fish by species, or separating to PIT-tagged from untagged individuals. Devices considered for implementation in a potential Oroville Passage Program include removable mesh separators and bar sorters.

- Removable mesh separators and bar sorters are devices placed in each holding raceway or pool that separates larger fish from emigrating juvenile Chinook salmon.

Assumptions

- Personnel are equally trained and utilize standard operating procedures to readily differentiate between juvenile Chinook salmon and other fish found in the Feather River including other anadromous salmonid species and resident rainbow trout.

- Sorting Efficiency is independent of the sorting device used.

- Sorting occurs first by size, then by species.

- Mortality rates are equal between collection, sorting, and transport.

Biological Justification

Maintaining high levels of Sorting Efficiency involves sorting fish by size and by species, and maximizing survival rates (i.e. minimizing mortality rates) to emigrating juvenile Chinook salmon. Generally, sorting would be considered a two-step process. The first step would involve removing large fish, including adult salmonids and other adult fish, from emigrating juvenile Chinook salmon. The second step would be to sort fish by species. Sorting fish by size would occur using size exclusion devices, while sorting fish by species would be performed by trained technicians.

During the process of sorting captured fish by size, overall sorting efficiency could be decreased by device-induced mortality or the inability of sorting devices to separate emigrating juvenile Chinook salmon from larger fish captured. Because removal of juvenile salmonids from larger fish is simply a function of aperture size in either the removable mesh separator or the bar sorter, it is assumed that the ability of either device to sort fish by size is similar and that the efficiency associated with this portion of the process is high.

Additionally, overall Sorting Efficiency is dependant on technician ability to sort fish by species. Review of available literature revealed no information on devices capable of sorting individuals of similar size by species. Therefore, sorting by species would be performed by hand. It is assumed that experienced technicians are readily able to identify all species likely to be encountered during sorting in the upper Feather River including all salmonid and non-salmonid species. Based on current and historical stocking programs, salmonid species that could potentially be encountered include Chinook salmon, steelhead, Coho salmon, and resident rainbow trout. Because technicians would follow standard operating procedures and because quality control procedures would be in place at all sorting facilities, it is likely that sorting efficiency would not decrease substantially due to human errors during species identification.

During sorting, mortality related to stress and handling could occur. However, review of available literature revealed little information related to sorting induced mortality. According to Ward et al. (1997), reported that estimates of 10%, 15%, and 20% mortality related to collection, handling, and transport of fish is consistent with a variety of literature sources. Based on the literature reviewed by Ward et al. (1997), an average of 15% mortality related to capture, sorting, and transport was assumed. Additionally, because sorting mortality was not reported separately, it was assumed that collection, handling, and sorting each contributed equally to juvenile Chinook salmon mortality in the studies reviewed. Therefore, for modeling purposes, five percent was the chosen as the expected sorting mortality rate. Because survival rate is the complement of sorting mortality rate (% Survival = 1 – % Mortality), the expected sorting survival rate was 95%.

Because overall Sorting Efficiency is determined, in part, by the efficiency of each step during the sorting process, and because it is assumed that device and technician efficiency while sorting by size and species is high, overall Sorting Efficiency is limited by the survival rate of the emigrating juvenile Chinook salmon. An estimated average sorting survival rate of 95% was chosen based on the average of a range of reported combined mortality rates for collection, sorting, and transport. The survival rates estimated for sorting based on the estimated average sorting survival rate (absent survival rates for collection and transport) ranged from 90% to 99%. Therefore, for modeling purposes, best, expected, and worst, case Sorting Efficiency was estimated to be 99%, 95%, and 90%, respectively.

4.2. PIT TAGGING

4.2.1 Tagging Survival Rate

Definition of Terms

- PIT tagging involves surgically implanting a passive integrated transponder tag into the body cavity of an anesthetized fish.
- The PIT Tagging Survival Rate is the percentage of juvenile fish that survive the PIT tagging procedure, and is the complement of the tagging mortality rate.

Assumptions

- PIT tagged fish are exposed to handling stress and stress from tagging
- Fish are anesthetized prior to tagging
- Proper PIT-tagging procedures are followed
- Fish that die only do so due to stress endured during the tagging process, not from other external sources of mortality or previous experiences
- Latent mortality associated with the tagging procedure, or being tagged, is negligible

Biological Justification

PIT tagging is a common procedure utilized for individual fish identification and estimating growth, survival, movement and other characteristics of juvenile salmonids. PIT tags, consisting of an antenna coil bonded to a pad and a integrate circuit chip, are relatively small (usually 11-32 mm) and are suitable for tagging relatively small fish, including juvenile salmonids (Roussel et al. 2000). As opposed to coded wire tags (CWT) which require visual inspection of each individual tag to identify its characteristic code, fish tagged with PIT tags codes can be identified without sacrificing the fish using a powered portable handheld tag interrogation system or a fixed tag monitoring system. Estimates of juvenile salmonid survival for the PIT tagging procedure vary, among others, by species and size of fish tagged.

Venditti et al. (2000) found that in the three years that they tagged naturally produced Chinook salmon of at least 115 mm in fork length (FL) in the Lower Snake River, tagging associated mortalities were 3.2, 1.5, and 2.5 percent, respectively. Prentice et al. (1990) conducted a study to determine the minimum size at which a juvenile Chinook salmon could be PIT tagged and the relationship between fork length and survival.

Juvenile Chinook salmon tagged ranged in size from 56 mm to 120 mm FL. Although individual fish size was reportedly as small as 56 mm FL, the smallest mean experimental group size was 66 mm FL. Survival of experimental groups ranged from 95 to 100 percent. Control group survival, those fish handled but not tagged, was 99 to 100 percent. No association was found between survival and fish size. A similar study conducted using juvenile and smolt sockeye salmon (55 to 107 mm FL) found survival of PIT tagged juvenile sockeye salmon exceeded 96.5 percent in each experimental group. The mean length for each experiment group was 68, 82 and 99 mm FL. Control group survival exceeded 97 percent in three control groups (Prentice et al. 1990). In a study comparing survival of three different tagging methods at Columbia River dams, Prentice et al. (1990) found that PIT tagged juvenile salmonid percent survival at 14-days post-tagging was not measurably different from control groups. Several other field studies using PIT tagging to monitor individual juvenile salmonids reportedly tagged only juvenile fish exceeding 60 mm FL (e.g., Gries and Letcher 2002, Roussel et al. 2000, Hockersmith et al. 2000, Conner et al. 1998). Furthermore, Brakensiek (2002) reported apparent substantially lower survival rates for smaller tagged fish, suggesting one explanation may be a *"…chronic size-dependent mortality due to PIT-tagging…"*.

Experimental mean juvenile Chinook salmon fork lengths for each of the studies examined were always greater than 60 mm. It is assumed that the preponderance of the 60 mm FL size threshold is either due to unacceptably high levels of tagging mortality or an inability to effectively tag fish smaller than 60 mm FL. A PIT tagging size threshold of 60 mm FL was established based on the literature review. Based primarily on the work of Prentice et al. (1990), we assumed that the tagging survival rate is between 95 and 99 percent, with an expected value of 97.5 percent. Thus, the best and worst case, and the expected values of PIT tagging survival rates are 99, 95 and 97.5 percent, respectively.

4.2.2 CWT Tagging Survival Rate

Definition of Terms

- CWT tagging involves injecting a coded wire tag in the area of muscle, connective tissue and cartilage in the snout of an anesthetized fish.
- The CWT Tagging survival rate is the percentage of juvenile fish that survive the CWT tagging procedure, and is the complement of the tagging mortality rate.

Assumptions

- CWT tagged fish are exposed to handling stress and stress from tagging.
- Fish are anesthetized prior to tagging.

- Proper CWT-tagging procedures are followed.
- Fish that die only do so due to stress endured during the tagging process, not from other external sources of mortality or previous experiences.
- Latent mortality associated with the tagging procedure or being tagged is negligible.

Biological Justification

Coded wire tagging has been used as a major salmonid stock identification tool by many fisheries agencies, and was developed over 30 years ago for large-scale studies on migratory salmonids. Each year reportedly over 40 million CWTs are put into Pacific salmon and approximately 300,000 tags are recovered (Johnson et al 1990 *in* (Solomon 2003)). Standard CWTs are a small length of stainless steel wire 1.1 mm in length and 0.25 mm in diameter. Half-length CWTs (approximately 0.5 mm long) are effectively planted into fish as small as salmonid fry (Solomon 2003). CWTs can be detected in live individuals; however, for proper deciphering of the tags characteristic code, the individual fish must be sacrificed. Estimates of survival of the CWT tagging procedure for juvenile salmonids vary among species and size of fish tagged.

Jonasson and Lindsay (1988) reported that during 1978 through 1980, the Oregon Department of Fish and Wildlife (ODFW) CWT tagged a total of 123,000 juvenile fall-run Chinook salmon from the Deschutes River, Oregon. The CWT-associated mortality for ranged from 1.1 to 4.2% (Brun 2003). In the spring of 2002, the ODFW captured over 12,000 juvenile Chinook salmon below and above Sherar's falls on the Deschutes River for CWT. The fork lengths of the juvenile Chinook salmon tagged ranged from 45 to 80 mm. Mortality for the CWT tagged fish below Sherar's falls was 1.06% and above Sherar's falls was 0.85% (Brun 2003).

CWTs were used to estimate survival of juvenile Chinook salmon emigrating through the San Joaquin River system as part of the Vernalis Adaptive Management Plan (VAMP) 2002 test period. Three groups of approximately 25,000 juvenile Chinook salmon were tagged with CWT. The associated tagging mortality rates were 0.48, 0.92 and 1.0 percent for the three groups (San Joaquin River Group Authority 2002). Over 80,000 juvenile Chinook salmon ranging in size from 36 to 95 mm FL were tagged using CWT in the Trinity River in 1991. An estimated 5,330 juvenile Chinook salmon died resulting from the tagging process, equaling a tagging mortality rate of 6.7 percent (Zuspan 1992).

CWT is an acceptable technique for tagging juvenile salmonids as small as approximately 36 mm FL. CWT's utility over PIT tagging is in the ability to mark large numbers of relatively small fish. Survival rates of juvenile Chinook salmon tagged using CWT ranged from less than one to approximately seven percent for the studies

reviewed. Based upon this review, we assumed that the CWT tagging survival rate is between 95 and 99 percent, with an expected value of 97 percent. The expected CWT tagging survival rate was set at 97.5 percent reflecting the approximate average survival rates reported by Brun (2003) and SJRGA (2002). Thus, the best, expected, and worst case values of CWT tagging survival rates are 99, 97, and 95 percent, respectively.

4.2.3 Overall Tagging Survival Rate

Because PIT tagging survival rates and CWT tagging survival rates were equal, overall best, expected, and worst case Tagging Survival Rates were 99, 97, and 95 percent, respectively.

5.0 JUVENILE FISH HOLDING

5.1 HOLDING SURVIVAL RATE

Definition of Terms

- Holding Survival Rate is defined as the proportion of juveniles placed into holding facilities that survive to be subsequently transport, and is the complement of the mortality rate.

- Holding raceways are defined as long, narrow, permanent concrete, or transient floating steel structures adjacent to collection devices in which juveniles would be held for up to three days. One example was reportedly five feet wide by four feet deep by sixty feet long (Puget Sound Energy 2002a; Puget Sound Energy 2002b; USACE 2000).

- Typical net pens reportedly are made from 0.2-inch mesh nets. The nets are suspended from floating platforms and are typically 20 ft by 20 ft with a depth of 7 to 10 feet (Beeman and Novotny 1994). Pens of this size have been used to raise pre-smolt Chinook salmon at densities of 18,000 fish per pen (Beeman and Novotny 1994).

Assumptions

- Water temperature-related mortality is negligible; appropriate water temperatures would be provided.

- Flow through the holding area would be sufficient to maintain dissolved oxygen concentrations at 80% of saturation or higher; with the minimum dissolved oxygen content at no less than 5 ppm (Meehan 1991).

- Loading densities for net pens would not exceed 0.4 to 0.5 pounds of fish per cubic foot of water (Bell 1991).

- Loading densities for raceways would not exceed 1.0 pounds of fish per cubic foot of water (Bell 1991).

Biological Justification

The two most commonly used devices for holding juvenile salmonids reported in the literature reviewed are net pens and raceways; however, reported survival rates associated with each device differ slightly (Matthews et al. 1986a; Rensel et al. 1988).

The rearing and release of salmon using net pens has been practiced at a variety of projects geared toward increasing the survival of hatchery reared salmon after stocking,

as well as for increasing the survival of salmon for the purpose of enhancing fishing and angling. The use of net pens has reportedly resulted in high survival during rearing and upon release, and has become a highly supported method (Commercial Salmon Trollers Advisory Committee 2004). Examples of the successful net pen projects include the Monterey Bay Salmon and Trout Project and the Central Coast Salmon Enhancement project. The Monterey Bay Salmon and Trout Project uses net pens to increase the survival of Feather River Hatchery Chinook salmon prior to their release. The Central Coast Salmon Enhancement project, a fishing and angling enhancement project, has found through coded wire tag studies that *"pen-reared salmon survive to enter the commercial and sport fisheries at exceptional levels"* (Commercial Salmon Trollers Advisory Committee 2004). A five-year study conducted by Rensel et al. (1988), evaluating the use of the marine net pens in Puget Sound, Washington, reported that juvenile coho salmon survival in net pens with 243 cubic meters of immersed volume averaged 98.4 percent.

Prentice et al. (1990) reports holding survival rates for control groups (groups of fish that are handled but not tagged) of PIT tagging investigations. Survival estimates for control groups reported by Prentice et al. (1990) are likely representative holding survival rates, in general. Survival rates for two control groups of 200 juvenile Chinook salmon with mean fork lengths of 77 mm were 99 and 100 percent over the 135-day test period. Survival rates for control groups of small presmolt, large presmolt and smolt sockeye salmon were 99.5, 98.5 and 97 percent, respectively. Survival of three steelhead and two fall-run Chinook salmon control groups, ranging in mean FL from 67 to 171 mm, were all 100 percent survival after a 14-day holding period. Control groups of yearling Chinook salmon and steelhead held at Lower Granite Dam had survival rates of 95 and 100 percent, respectively, 14 days post-handling. Control groups of age-0 and yearling Chinook salmon held at McNary Dam had survival rates of 96 and 86 percent, respectively, 14 days post-handling (Prentice et al. 1990).

The holding survival rate in raceways ranged from 86 to 100 percent in the literature reviewed. The mean holding survival rate for the investigations reviewed was 97 percent. In the single investigation reviewed for holding survival in net pens, the mean survival rate was 98.4 percent. Because the survival rates between net pen and raceway holding are similar, the expected, best and worse case values will apply to holding in both types. The reported range for holding survival serves as the basis for best and worst case juvenile holding survival. However, because some mortality is expected, 99% was chosen as the best case holding survival rate. Therefore, the best and worst case holding survival rates are 99 and 86 percent, respectively. The mean of the literature-reported holding survival values serve as the expected value, and was determined to be 97 percent. Thus, the expected, best and worst case Holding Survival Rates are 99, 86 and 97 percent, respectively.

6.0 JUVENILE FISH TRANSPORT

6.1 OROVILLE BARGE

6.1.1 Barge Survival Rate

Definition of Terms

- Barge Survival Rate is the percentage of juvenile Chinook salmon that survive being transported from the gulper collection facilities across portions of Lake Oroville to the truck loading facility, and is the complement of the mortality rate.

Assumptions

- Older barges used for fish transport have a capacity of 85,000 gallons of water and an inflow of 5,200 gallons per minute. Newer barges have a capacity of 100,000 gallons and an inflow of 10,000 gallons per minute. The holding criterion for barge transportation is 5 pounds of fish per gallon per minute inflow. Therefore, this allows a maximum of 26,000 and 50,000 pounds of fish for the older and newer barges, respectively (Koski et al. 1990).

- Barge capacity criteria will be observed.

- Barge survival rates depend on the number and size of juvenile Chinook salmon being transported, and the duration of time spent in the barge's tanks.

- Barge survival rates reflect only the impacts of being barged – latent mortality (mortality due to experiences prior to being barged) is assumed to be negligible.

- The barge survival rates for fish barged in Lake Oroville are not different from the barge survival rates for fish barged in the Columbia River system.

- Barge survival rates do not include subsequent delayed mortality resulting from barging-related stresses; this type of mortality is assumed to be expressed in subsequent model steps (e.g. life history stages).

Biological Justification

The reported barge transport mortality rates reviewed vary from less than one to approximately 30 percent, depending on the species, age and distance transported. The barge mortality rate at the Lower Granite Dam, Snake River collection facility was reported to be 1.0 percent for juvenile Chinook and 0.1 percent for steelhead (Hetherman et al. 1997 *in* (Congleton et al. 2000)). Chinook salmon transported by barge from the Lower Granite and Little Goose dams to five miles below Bonneville Dam, on the Columbia River system, were reported to experience a mortality rate of 1.9

percent. The mortality rate for steelhead transported from these same locations was reported as 0.1 percent (Koski et al 1990). Preliminary survival was reported as 86 percent for juvenile salmon transported by barge from the Lower Granite Dam to Little Goose Dam in 1995 and a 70 percent survival rate was reported for juvenile salmonids transported to McNary Dam on the Columbia River during this same year (NW Fishletter 1997). The barge mortality rate for juvenile spring-run Chinook salmon transported from Lower Granite Dam to Bonneville Dam in 1982 was reportedly approximately 13 percent (Matthews et al. 1986a).

Barge transport survival rates were determined based on the reported mortality rates for the juvenile fish barging operations reviewed for the Columbia River system. Based upon this review, we assumed that the barge survival rate is between 70 and 99 percent, reflecting the range of barge survival rates reported in the studies reviewed. Because a barging program in Lake Oroville would require a shorter barging duration than the Columbia River program due to shorter distances required for barging, the expected value for barge survival rate was arbitrarily shifted towards a higher survival rate, and is estimated to be 95 percent. Thus, the best and worst case, and the expected values of barge survival rates are 99, 70 and 95 percent, respectively.

6.2 TANK TRUCK

6.2.1 Truck Survival Rate

Definition of Terms

- Truck Survival Rate is the percentage of juvenile salmon that survive being transported downstream by tank truck, and is the complement of the mortality rate

Assumptions

- Fish hauling tanker trucks have a rating capacity of 3,500 gallons of water per tanker and, at present the present hauling criterion of 0.5 pounds of fish per gallon. Therefore, a fully loaded tanker truck contains approximately 1,750 pounds of fish (Koski et al. 1990).

- Truck capacity criteria will be observed.

- Truck survival rates depend on the number and size of juvenile Chinook salmon being transported, and the duration of time spent in the tanks.

- Truck survival rates reflect only the impacts of being trucked – latent mortality (mortality due to experiences prior to being trucked) is assumed to be negligible.

- Truck survival rates do not include subsequent delayed mortality resulting from truck transport-related stresses; this type of mortality is assumed to be included in subsequent model steps (e.g. life history stages).

Biological Justification

The reported truck transport mortality rates reviewed vary from less than one to approximately 13 percent. The mortality rate for Snake River juvenile Chinook salmon transported by truck from Lower Granite Dam to Little Goose Dam was reported to be two percent (USACE 1993 *in* Ward et al. (1997)). The mortality rate of Chinook salmon transported by truck from Lower Granite Dam to Bradford Island in the Columbia River system was reported to rise from 0.5 percent in 1988 to 0.9 percent in 1989 (Koski et al. 1990). Tank truck transport mortality for juvenile Chinook salmon transported from McNary Dam on the Columbia River was reported to range from 2.0 to 2.2 percent in 1982, 0.9 to 1.3 percent in 1983, 0.8 to 1.2 percent in 1984, 1.3 to 3.4 percent in 1985, 1.4 to 2.5 percent in 1986, 1.4 to 3.5 percent in 1987, 1.1 to 1.9 percent in 1988 and 1.6 to 2.0 percent in 1989 (Koski et al. 1990). The truck mortality rate for juvenile salmon transported from Lower Granite Dam on the Snake River to Bonneville Dam on the Columbia River in 1982 was reportedly approximately 12 percent (Matthews et al. 1986b).

Truck transport survival rates were determined based on the reported mortality rates for the juvenile fish trucking operations reviewed for the Columbia River system. Based upon this review, we assumed the truck survival rate is between 88 and 99 percent, reflecting the range of truck survival rates reported in the studies reviewed. The expected value for the truck survival rate was determined by averaging the reported values from the studies reviewed, and is 98 percent. Thus, the best and worst case, and the expected values of truck survival rates are 99, 88 and 98 percent, respectively.

7.0 JUVENILE FISH RELEASE LOCATION

7.1 JUVENILE RELEASE SURVIVAL RATE

Definition of Terms

- Juvenile release survival rate is defined one of three ways depending the type and location of release:

(1) The proportion of juvenile Chinook salmon that survive in-river mortality associated with delayed stress due to transport, and mortality due to predation, and other natural causes, during downstream migration to San Pablo Bay, subsequent to their release into the lower Feather River.
(2) The proportion of juvenile Chinook salmon that survive being transported from the Feather River to San Pablo Bay *via* floating net pen.
(3) The proportion of juvenile Chinook salmon that survive being transported *via* truck downstream to San Pablo Bay.

Assumptions

- All juvenile Chinook salmon will be transported from the tributaries upstream of Lake Oroville to their specific release location by truck.

- Those fish trucked to San Pablo Bay and subsequently released are subjected only to trucking-related mortality.

- Those fish transported downstream *via* floating net pen are assumed to have survival rates equal to juvenile fish transported *via* river barge.

- Survival rates for the three juvenile release types include latent mortality associated with previous handling (e.g., capture at tributary mouths, barging across Lake Oroville, sorting, tagging, etc.).

- Survival rates for the three juvenile release types do not include subsequent delayed mortality resulting from transport-related stresses; this type of mortality is assumed to be expressed in subsequent model steps (e.g., life history stages).

Biological Justification

Information regarding the survival rates of juvenile Chinook salmon emigrating downstream was not readily available. Cramer and Chapman (2002) showed overall survival (smolt-to-adult return) was more than double for fish released in San Pablo Bay compared to fish released into the Feather River. Assuming sources of mortality were similar post-salt water entry for the fish released in Feather River and those released directly into San Pablo Bay, this result suggests in-river mortality of emigrating juvenile Chinook salmon must be substantial. The data indicates a 3.5 percent survival rate for

fish released near the hatchery and a 7.2 percent survival rate for fish released in San Pablo Bay. This reported result suggests, therefore, in-river survival may be as low as 50 percent. Refer to *Section 3.1.2, In-River Mortality Survival Rate*, for a more thorough discussion regarding the literature reviewed on emigrating juvenile salmonid survival rates.

Section 3.1.2, In-River Mortality Survival Rate, concluded that the best, expected and worst case In-River Mortality Rates are 48, 28 and 8 percent, respectively, for juvenile Chinook salmon emigrating their natal tributaries upstream of Lake Oroville to collection facilities in Lake Oroville. These survival rates also will be applied to juvenile Chinook salmon emigrating to the estuary, which have been released into the lower Feather River after being transported downstream from collection facilities in Lake Oroville.

Because specific information regarding floating net pen survival was not located, the juvenile release survival rate for Chinook salmon transported downstream *via* a floating net pen is assumed to be the same as the barge survival rate. Refer to *Section 6.1.1, Barge Survival Rate*, for the discussion regarding the determining of the barge survival rate. Based on the information presented in *Section 6.1.1*, the best and worst case, and the expected values for juvenile release survival rate for Chinook salmon transported downstream *via* a floating net pen are 99, 70 and 95 percent, respectively.

Juvenile Chinook salmon transported to San Pablo Bay are only subjected to trucking-related mortality. Refer to *Section 6.2.1, Truck Survival Rate*, for a detailed discussion of juvenile Chinook salmon mortality resulting from trucking. Based on the review presented in Section 6.2.1, the best and worst case, and the expected values for juvenile release survival rate for Chinook salmon transported downstream *via* a truck are 99, 88 and 98 percent, respectively.

8.0 OCEAN CYCLE SURVIVAL

8.1 OCEAN SURVIVAL RATE

Definition of Terms

- Ocean Survival Rate is defined as the percentage of smolts entering saltwater that return to freshwater one to four years later as adults, and is the complement of ocean mortality rate.

Assumptions

- Sources of ocean mortality include, but are not limited to, predation by marine mammals, sport and commercial fishery harvest and natural sources of mortality including disease.

- Ocean survival is highly dependent on ocean and climatic conditions.

- Survival rates of returning Feather River Fish Hatchery adult Chinook salmon are representative of the entire Feather River Chinook salmon population (this assumption is consistent with recent findings by Nielsen et al. (2003) based on genetic analyses of Central Valley salmonid populations).

Biological Justification

Healey (1991) reviewed two early papers on ocean mortality of Chinook salmon and reported annual mortality rates for studies conducted in the 1950s' and early 1960s' ranging from 34 percent for an Alaskan population to 36 percent for a Columbia River population (64 to 66 percent annual survival). Kastner (2003) reports that the majority of Feather River Chinook salmon return as three and four year-olds. Healy (1991) however, reported an average age of 4.18 for Sacramento River Chinook salmon indicating a significant number of five year olds. A 64 to 66 percent annual survival rate would yield an overall ocean survival rate of 26 to 29 percent for three-year-old fish, 17 to 19 percent survival for four-year-old fish and 11 to 13 percent survival for five-year-old fish. In contrast, Thedinga et al. (1998) in a more recent review, concluded that Alaskan Chinook salmon spending three years at sea survived at a rate of 0.7 to 4.4 percent. Ocean survival studies on British Columbia stocks of Chinook salmon reported three-year ocean survival rates ranging from 0.4 to 17.0 percent (Pacific Fisheries Resource Conservation Council 2001). Sholes and Hallock reported ocean survival rates for Feather River Chinook salmon ranging from 0.6 percent to 2.0 percent for three different years in the early 1970s. Pahlke (1995) reported ocean survival for a 1993 brood year Alaskan population of Chinook salmon to be 2.7 percent. This compares to earlier studies that reported an ocean survival rate of 1.0 and 4.6 percent for brood year 1985 and 1986, respectively.

Periodic variations in ocean conditions resulting from climatic variation are believed to heavily influence survival of salmon in the ocean. In Healy's (1991) review of ocean survival in the 1960s, ocean conditions were much more favorable to salmon survival. Likewise, high survival rates referenced in PFRCC studies were reportedly associated with favorable ocean conditions, while lower survival rates were associated with El Nino events (Pacific Fisheries Resource Conservation Council 2001). The studies reviewed by Thedinga, took place during an El Nino cycle where ocean conditions were believed to be less favorable. Sholes and Hallock's study (1979) was also conducted during an El Nino event (Environmental News Network 2004). Lackey (2003) reported that historical data suggests that the size of salmon runs varies inversely between the northern and southern halves of the Pacific salmon distribution. This reciprocal relationship in ocean conditions, referred to as the Pacific Decadal Oscillation (PDO), appears to be driven by climatic conditions. The PDO, although believed to substantially affect Pacific salmon population dynamics, is not well understood, but appears to reverse every 20 to 30 years (Lackey 2003). The literature reviewed on Chinook salmon ocean survival is consistent with the testimony provided by James J. Anderson, Associate Professor of Fisheries, University of Washington, before the House of Representatives Committee on Resources in 2000. Anderson (2000) reported very poor Chinook salmon marine survival in the early 1990s, during an El Nino cycle, while dramatic improvements were observed beginning in 1997.

The ocean survival rates reported in the above references were based on coded wire tag recovery data, and were defined as survival from the time of tagging to adult recaptured. Therefore, the tagged fish may have incurred mortality in marine or freshwater environments, as juveniles or adults. Freshwater mortality has been reported to be significant, and includes sources such as predation, disease and other forms of natural mortality and angler harvest. Directly utilizing the information reported in the literature is not applicable for the fish passage model because survival of emigrating juveniles, ocean survival, straying and in-river survival of adults each are defined and calculated separately in the fish passage model. Additionally, the literature reports survival rates for Chinook salmon regardless of race. Therefore, utilization of the reported ocean survival rates requires adjusting for mortality incurred in freshwater and for Chinook salmon race, and is discussed below.

Based on the literature reviewed, the ocean survival rates ranging from 0.6 to 2 percent reported by Sholes and Hallock (1979) for Feather River Chinook salmon were deemed appropriate to use for the fish passage model. An expected value of 1.3 percent was determined using the mid-point of the range reported by Sholes and Hallock (1979). Although these estimates were based on data collected in the 1970s, and hatchery practices, Sacramento/San Joaquin Delta and the Sacramento River system conditions have since changed, review of additional information suggests that these estimates are still appropriate. The estimated ocean survival rate range reported by Sholes and Hallock (1979) is consistent with results from preliminary analyses of the Regional Mark

Information System (RMIS) species survival analysis on brood years 1997 and 1998 Feather River Hatchery Chinook salmon. RMIS calculated ocean survival rates for juvenile Chinook salmon released in the estuary ranging from 0.26 to 1.36 percent (mean = 1.1 percent) and 0.01 to 3.93 percent (mean = 1.8 percent) for brood years 1997 and 1998, respectively (Pacific States Marine Fisheries Commission 2004)). The ocean survival rate values reported by Sholes and Hallock (1979) are also consistent with reported Chinook salmon ocean survival rates in other regions.

The ocean survival estimates reported by Sholes and Hallock (1979) include adult losses associated with upstream migration, including straying and in-river mortality from sportfishing harvest. Because the passage model utilizes parameter values for these components separately, reported estimates for ocean survival rate require adjustment to factor out straying rates and in-river mortality associated with freshwater migration. Because the ocean survival rates reported by Sholes and Hallock were for juvenile Chinook salmon released in the estuary, there was no mortality component associated with juvenile emigration. Thus, by basing estimates of best and worst case, and expected values for ocean survival rate on Sholes and Hallock (1979), and adjusting those values using the expected values determined for Homing Rate (46 percent for juveniles released in San Pablo Bay – Section 9.2) and In-river Survival Rate (75 percent – Section 9.1), an expected Ocean Survival Rate of 3.8 percent was calculated. The best and worst case Ocean Survival Rate was calculated to be 5.8 and 1.7 percent, respectively. Thus, the best, expected, and worst case values for Ocean Survival Rate are assumed to be 5.8, 3.8, and 1.7 percent, respectively, for the fish passage model.

Because spring-run Chinook salmon rear in freshwater longer, and enter saltwater at a larger size, than fall-run Chinook salmon (Healey 1991), ocean survival rates for spring-run Chinook salmon were expected to be higher than for fall-run Chinook salmon. Therefore, one-percent was added to the best, expected, and worst case values for Ocean Survival Rates of spring-run Chinook salmon to compensate for their average larger size at the time of salt water entrance.

9.0 ADULT IMMIGRATION

9.1 IN-RIVER SURVIVAL RATE

Definition of Terms

- In-river adult survival is defined as that proportion of returning adult fish entering freshwater that survive migration to the spawning ground or adult collection facility, and is the complement of the in-river mortality rate.

- Escapement is the number of fish that successfully migrate upstream to the spawning grounds.

Assumptions

- Other than catastrophic in-river events, factors determining in-river survival are reasonably constant (i.e. sportfishing harvest).

- The majority of in-river mortality of immigrating adult Chinook salmon results from sportfishing, although other sources may include catch-and-release and incidental hooking mortality, predation and other forms of natural mortality.

Biological Justification

Returning adult Chinook salmon entering freshwater are subject to freshwater sport fisheries in the Sacramento/San Joaquin Delta and the Sacramento and Feather rivers. These fisheries may have a significant impact on the proportion of adult Chinook salmon that reach the spawning grounds or adult collection facility. Likewise, any change in sportfishing regulations (i.e., changes in license fees, season or limits) could effect in-river survival on a year-to-year basis. Angler harvest rates of Chinook salmon in the Klamath/Trinity River system varied from four to nine percent during the five-year period of 1995 to 1999 (DFG 1999). The Pacific Fisheries Management Council (PFMC) (2003), in its annual review of ocean salmon harvest, estimated that angler harvest in the Sacramento River system averaged 25 percent over the eight years it was extensively studied between 1990 and 2000.

The in-river harvest information provided by PFMC was deemed to be most appropriate for model development purposes. Therefore, the expected in-river survival rate for immigrating adult Chinook salmon is assumed to be 75 percent. Because no information was reviewed that suggested an upper and lower bounds on the in-river survival rate, the best and worst case estimates were arbitrarily set at 85 and 65 percent, respectively.

9.2 HOMING RATES

Definition of Terms

- The Homing Rate is defined as the proportion of surviving Feather River fish passage program adult Chinook salmon that return to the Feather River, upstream of the Yuba River confluence.

Assumptions

- For model development purposes, the homing rate is the complement of the straying rate (i.e., homing rate is equal to one minus the straying rate)
- The homing rate is largely dependent upon the manner in which the returning adult fish emigrated as a juvenile to saltwater (e.g., in-river migration, transported by barge or truck) and their release location (e.g., into the Feather or Sacramento rivers, directly into San Pablo Bay)
- Project fish are marked in some way that allows identification
- Mark used differentiates release location

Biological Justification

Cramer and Chapman (2002) analyzed straying rates for Chinook salmon reared at the Feather River Hatchery and released at different locations in the Feather River and San Pablo Bay. Mean straying rates of fish released in the Feather River were estimated to be less than 8 percent, while the straying rates of fish released in San Pablo Bay were estimated to be approximately 54 percent. Cramer and Chapman also reported a steady decrease in straying rate from both release locations over time. An explanation of this trend was not suggested, or is it clear where the trend continued passed 1994.

Homing rates determined for Coleman National Fish Hatchery Chinook salmon were estimated to be 92 percent for on-site releases and 46 percent for off-site releases (DFG 2001). This same report cited straying rates for the American River's Nimbus Hatchery Chinook salmon of 8 percent from on-site releases and 32 percent for fish released in the estuary. Quinn and Fresh (1984) reported straying of less than two percent for Chinook salmon released at the Cowlitz River Hatchery in Washington (Quinn and Fresh 1984). Quinn et al (1991) reported straying rates of 9.9 to 27.5 percent in separate studies conducted at five different hatcheries on the Columbia River on the 1977, 1978 and 1979 brood years. Quinn et al. (1991) reported that the observed straying rates are higher than generally reported for salmon and suggested that ash from the Mount St. Helen's eruption may have been influenced by influenced straying rates.

Based on the literature reviewed specifically regarding the Feather River (Cramer and Chapman 2002), the expected value for adult Chinook salmon homing rate for fish released in-river as juveniles is 92 percent. The literature reviewed suggested that homing rates for Chinook salmon could be as high as 98 percent (Quinn and Fresh 1984) and, thus, 98 percent represents the assumed best case homing rate. The worst case homing rate is arbitrarily assumed to be 86 percent, reflecting a deviation value equal to the best case (i.e., six percent).

The expected homing rate for returning adult Chinook salmon released in San Pablo Bay as juveniles is assumed to be 46 percent, based on the Feather River information. The best case homing rate is assumed to be 68 percent, based on the information for Nimbus Hatchery. The worst case homing rate is arbitrarily assumed to be 24 percent, reflecting a deviation value equal to the best case (i.e., 22 percent).

10.0 ADULT COLLECTION

10.1 FISH LADDER CAPTURE EFFICIENCY

Definition of Terms

- Fish Ladder Capture Efficiency is defined as the proportion of returning adult Chinook salmon, which are progeny of the fish passage program, that choose to, and are able to, ascend the Feather River Hatchery fish ladder to the collecting pools above the Fish Barrier Dam.

Assumptions

- Returning fish from the passage program will display a propensity to return to the Feather River Hatchery.
- The fish ladder will be operational the duration of immigration period.
- Appropriate fish ladder attraction flows will be provided.

Biological Justification

Two critical design considerations for fish passage facilities (i.e., fish ladders) include appropriate attraction flows and the ability of the facilities to pass adult salmonids upstream once they enter the passage facility. Monk et al. (Monk et al. 1989), examining fish ladder designs at John Day Dam on the Columbia River, found fish ladder passage efficiencies ranging from 94 to 97 percent. A second study investigating the fish ladders bypassing four Columbia River dams over a three-year period, found both Bonneville and McNary dams had passage efficiencies of 95 percent all three years. Fish passage efficiencies at The Dalles Dam ranged from 93 to 95 percent and at John Day Dam ranged from 88 to 95 percent over the three-year period (Burke et al. 2001). Ferguson et al. (2002) suggest that upstream fish passage facilities should allow for greater than 95 percent efficiency.

Bjornn et al. (1999) examined attraction flows at John Day Dam on the Columbia River. The John Day Dam incorporates two fish ladders for allowing adult salmonid upstream passage. The outflow from a powerhouse is near the south shore and most fish are attracted to that location. Bjornn et al. (1999) reported that during periods of low flow, passage would be improved if fish could be attracted to the north shore ladder. They found that during periods of no spill, 16 percent of the steelhead approached the north shore ladder. When spill on the north side was increased to 1.1 percent of the total river flow, 19 percent of steelhead approached the north shore ladder. Ferguson et al. (2002) suggest that fish ladder location in relation to river flow is critical in improving upstream fish migration and recommend a fish passage facility attraction flow of three to

five percent of total river discharge. This criterion is designed to provide attraction to entrances that will cause minimal delay at a dam for adult migrants (preferably less than 24 hours) and is recommended for situations where the attraction flow has to compete with a large volume of powerhouse discharge spread across a wide area (Ferguson et al. 2002). Adult immigration delays caused by fish passage impediments can be considerable. Dauble and Mueller (1993) investigated fish ladders at Snake River dams and reported delays of 2 to 18 days from the time fish arrived at the ladder until the time the ladder was entered. An overall fish passage efficiency was not reported.

For modeling purposes, based on averaging the values reported in literature for fish ladder capture efficiency, the expected value is assumed to be 94 percent. The range of values reported in the literature for fish ladder capture efficiency was 88 to 97 percent. Thus, these values represent the assumed worst and best cases for fish ladder capture efficiency, respectively. Additionally, based on Ferguson et al. (2002), fish passage facility attraction flows should be maintained at a minimum of three percent of the total river streamflow (e.g., 18 cfs for the LFC of the lower Feather River (three percent of 600 cfs)).

11.0 ADULT HOLDING AND SORTING

11.1 ADULT HOLDING AND SORTING SURVIVAL RATE

Definition of Terms

- The Adult Holding and Sorting Survival Rate is defined as the percentage of adult Chinook salmon that are identified correctly (e.g., spring- versus fall-run Chinook salmon), and survive the sorting/handling process, prior to transportation to Lake Oroville or its tributaries.

Assumptions

- Personnel are properly trained in species identification.
- Differentiation of spring- and fall-run Chinook is based on time of capture.
- Male to female ratios in the collection facility are not biased, and be representative of the Feather River Chinook salmon population.
- Progeny of fish passage program fish cannot be identified visually.
- The adult holding period is short, no more than 2 to 4 days.
- If a longer holding period were determined to be more likely, then the estimates of the Adult Holding Survival Rates would likely correspondingly decrease.
- Adults Chinook salmon will be held at densities that do not exacerbate or result in increased stress or mortalities.
- Fish that are handled would be anaesthetized.
- Mortality during the returning adult holding period may result from conditions experienced or impacts incurred by immigrating adult Chinook salmon upon entry into freshwater through the time they are deposited into the holding pens prior to upstream transportation. This type of mortality is considered latent mortality, that is, it results from previous conditions or impacts, not those currently being experienced. For example, water temperature catch-and-release stress incurred while immigrating through the lower Feather River may result in mortality experienced while being held prior to upstream transportation. This mortality is reflected in the Adult Holding Survival Rate, despite the belief that the stresses that ultimately lead to death were experienced prior to holding.
- Mortality also may directly result from holding itself, including mortality resulting from disease, stress, fright, rapid environmental change, exhaustion and others.

- There is no difference between spring- and fall-run Chinook salmon responses to holding.

Biological Justification

Adult Chinook Salmon Sorting

Adult Chinook salmon are readily identified by external examination. Chinook salmon are the only salmonid that would appear in the collection facility with a black mouth and gums, large black spots on the back and both lobes of the caudal fin and a narrow caudal peduncle (DFG 2002). Current practices at the Feather River Hatchery define spring-run Chinook salmon as those fish ascending the fish ladder from September 1 through September 15 of each year. Chinook salmon captured subsequent to September 15 are defined as fall-run Chinook salmon (Kastner 2003). Given these factors, sorting by species should be 100 percent efficient and, by definition, sorting by Chinook salmon race is 100 percent efficient.

Adult Chinook Salmon Holding

Handling and releasing, with associated mortality due to stress, of adult anadromous salmonids is not as common as the handling and release of juveniles, therefore little information on the subject was reviewed. Bernard et al. (1999) reported a one percent mortality associated with trapping and fitting radio transmitters to adult migrating Chinook salmon (Bernard et al. 1999). From this study, a 99 percent survival of the sorting process could be inferred. In studying the effect of elevated holding temperatures on adult spring-run Chinook salmon reproductive success, Berman (1990) *in* (McCullough 1999) had 100 percent survival of adults held at 14°C. Adult Chinook salmon held in a semi-natural pool at the Quinault Indian Nation's Salmon River hatchery for one and three weeks, exhibited survival rates of 100 and 90 percent, respectively. In general, survival in holding tanks is good (near 100 percent) for periods of up to one week, and survival of 75 percent for periods longer than two weeks in fairly common. These fish are generally handled once a week to determine readiness for spawning (pers. com., R. Rhodes, 2003).

Base upon the above information, for the purposes of model development, the expected Adult Holding and Sorting Survival Rate is assumed to be 98 percent. The best and worst case Adult Holding and Sorting Survival Rate is assumed to be 100 and 95 percent, respectively. The expected, best and worst case Adult Holding and Sorting Survival Rates are assumed to be applicable for a holding period of 2 to 4 days.

11.2 PIT TAG DETECTION RATE

The ability to detect a returning adult Chinook salmon that has been previously PIT tagged is dependent on the tag retention rate of adult Chinook salmon that were tagged

as juveniles and the efficiency with which the PIT tag interrogation device used to detect PIT tagged individuals operates. An overall PIT tag detection rate can be determined from an evaluation of each of these components.

11.2.1 PIT Tag Retention Rate

Definition of Terms

- PIT Tag Retention Rate is defined as the percentage of PIT tags retained by returning adult Chinook salmon from the passage program that were tagged as emigrating juveniles.

Assumptions

- PIT tagging is performed by properly trained personnel.
- Sixty mm FL is the minimum size threshold for a juvenile salmonid to be PIT tagged.

Biological Justification

The Yakima River Project report 100 percent tag retention in juvenile Chinook salmon held for up to five months (Biomark 2004). Dare (2003) reported PIT tag retentions for Chinook salmon of over 99 percent. Ramstad and Woody (2003) reported tag retentions of 98 percent for sockeye salmon. Prentice et al. (1990), in a study of over 2,000 PIT tagged juvenile fall-run Chinook salmon, reported PIT tag retention frequencies between 99 and 100 percent for fish observed over a 2.5-month period. In another study examining PIT tagging several size classes of juvenile salmonids, Prentice et al. (1990) reported 100 percent tag retention and no tag migration within the peritoneal cavity over a 14-day period. In investigating the effects of PIT tags and the tagging procedure on maturing Atlantic salmon, Prentice et al. (1990) reported 100 percent tag retention in maturing and mature fish ranging from 61 to 80 cm. Seventeen percent of the female Atlantic salmon were reported to pass their PIT tags when spawned by hand (Prentice et al. 1990). In a study of 300 PIT tagged fall-run Chinook salmon held for a 570-day period, Prentice et al. (1990) reported a tag retention frequency of 98 percent. During the study period, the juvenile Chinook salmon underwent smoltification and were transferred to seawater (Prentice et al. 1990).

Based on the literature reviewed, the PIT Tag Retention Rate range reported was 98 to 100 percent retention. Thus, the best, expected, and worst case values for PIT Tag Retention Rate are assumed to be 99, 98 and 97 percent, respectively.

11.2.2 PIT Tag Scanning Efficiency

Definition of Terms

- PIT Tag Scanning Efficiency is defined as the proportion of PIT tagged adult Chinook salmon that are collected in passage program facilities that are successfully identified as being PIT tagged.

Assumptions

- Initial implanting of PIT tags is done by properly trained personnel.
- Scanning equipment is not subject to failure and is properly used.
- The inability to detect a PIT tagged individual is only the result of: (1) the individual fish was never tagged; (2) the individual fish shed its PIT tag; and (3) the PIT tag is functioning improperly.
- 100 percent of PIT tags function properly.

Biological Justification

The Cowlitz Falls Fish Facility in Washington reports a greater than 95 percent PIT tag reading efficiency. This system automatically diverts fish to any of three different collection vessels upon PIT tag activation (Biomark 2004). In a review of the performance of PIT tag interrogation systems at Bonneville and McNary dams, Downing and Prentice (2003) reported detection frequencies of 98.2 and 99.2 percent for two different systems.

Based on the information reviewed, the expected value for PIT Tag Scanning Efficiency is assumed to be 98 percent. The best and worst case values for PIT Tag Scanning Efficiency are assumed to be 99 and 95 percent, respectively.

11.2.3 PIT Tag Detection Rate Summary

Combining the results from the expected, best and worst case values for PIT Tag Retention Rate and PIT Tag Scanning Efficiency results in an expected PIT Tag Detection Rate of 97 percent. The best and worse case PIT Tag Detection Rates are assumed to be 99 and 93 percent, respectively.

12.0 ADULT FISH TRANSPORT

12.1 ADULT TRUCKING SURVIVAL RATE

Definition of Terms

- Adult Trucking Survival Rate is the percentage of adult Chinook salmon that survive the process of being loaded into a truck, transported upstream and released into the reservoir or upstream tributaries.

- The survival rate is calculated by dividing the number of live adult Chinook salmon released upstream (in the reservoir or its tributaries) by the number of live adult Chinook salmon transferred from the holding facilities to the transport truck.

Assumptions

- Transport time short; decreased survival may result from increased trucking transport times.

- Chemicals used to reduces stress, slime loss, etc.

Biological Justification

"Biological Opinion on Effects of Issuing an ESA Section 10 Permit to the Corps of Engineers for Operation the Elk Creek Dam Trap-and-Haul for the 1998/99 & 1999/00 Fish Passage Seasons" (1998) reports that one to three adult coho salmon are injured or killed annually as a result of transfer to the transport truck and associated activities, including sampling for biological data and marking (NOAA 1998; Pacific Fishery Management Council 2003). Between 38 and 1053 adults are transported annually. No mortality associated with the actual trucking and release process was reported; this mortality rate is assumed to be zero. The survival rates associated with the above data were estimated to range from approximately 92.1 percent (35 out of 38 adults survive) to 99.9 percent (1,052 out of 1,053 adults survive). The estimated time-in-truck for these adults was 45 minutes.

During the October 1995 through September 1996 period, 2,196 spring-run Chinook salmon were transported via truck upstream in the lower Umatilla River. A total of 8 adult spring-run Chinook salmon died during trucking, equally a trucking survival rate of approximately 99.6 percent (Zimmerman and Duke 1996). The length of time required to transport the adult fish upstream was not reported, but assumed to be less than one hour.

Based upon the information reviewed, for the purposes of model development, the expected Adult Trucking Survival Rate is 96 percent (approximately the midpoint of the survival rates estimated for the Elk Creek program given above). The best and worst case Adult Trucking Survival Rate is assumed to be 99 and 92 percent, respectively. The expected, best and worst case Adult Trucking Survival Rates are assumed to be applicable for a transport period of less than one hour.

13.0 ADULT FISH RELEASE LOCATION

13.1 MARINA ADULT RELEASE EFFICIENCY (%)

Definition of Terms

- Marina Adult Release Efficiency is the percentage of adult Chinook salmon that successfully migrate to spawning tributaries upstream of Lake Oroville after, upon capture at the Feather River Fish Hatchery ladder, being released directly into Lake Oroville.

Assumptions

- Sources of mortality upon release into Lake Oroville include sport fishery harvest and other natural forms of predation, disease and other natural forms of mortality and water temperature-related causes, especially resulting from being transferred from the truck into the warm epilimnion of Lake Oroville in early summer through the fall

- Latent mortality may result from stresses incurred during lower Feather River immigration (e.g., related to water temperature, disease, catch-and-release and incidental hooking, etc.), handling and sorting at adult collection facilities, truck transportation and release into Lake Oroville

- Sources of effective mortality (i.e., removal of adult Chinook salmon from the spawning population other than through death) include thermal barriers (either within spawning tributaries or resulting from a thermocline and warm epilimnion in Lake Oroville), which may prevent timely immigration into the spawning tributaries, and residualization (i.e., cessation of spawning-related activities and taking up residence in the reservoir)

- Fecundity and egg viability are dependent upon the thermal regime experienced and the reservoir residence time

Biological Justification

Literature regarding the scenario presented in the fish passage model of releasing adult spring- and fall-run Chinook salmon directly into Lake Oroville and requiring the immigrating fish to locate, and ascend, appropriate spawning tributaries was not located. Natural spawning of land-locked Chinook salmon, and other anadromous salmonids including coho salmon and steelhead, has been documented in the Great Lakes tributaries, and others. Chinook salmon spawned in at least 10 Lake Superior tributaries in during 1990 to 1994 (Peck 1996). The Wisconsin Department of Natural Resources reports that no successful natural Chinook salmon reproduction occurs in

the Wisconsin tributaries to Lake Michigan (http://www.dnr.state.wi.us, accessed January 2004), although adult Chinook salmon are harvested annually in 8 out of the 9 Wisconsin counties with tributaries to Lake Michigan. Approximately 20 to 30 percent of the estimated total population of adult Chinook salmon and steelhead reportedly are naturally produced in Lake Michigan (NOAA Fisheries – Great Lakes Environmental Research Laboratory, http://www.glerl.noaa.gov, accessed January 2004). Although this information pertains to naturally reproducing populations and hatchery populations stocked as juveniles, it is reasonable to assume that some proportion of adult Chinook salmon transported from the lower Feather River into Lake Oroville will successfully locate and ascend upper tributaries to spawn. Furthermore, recent observations in Lake Huron suggest Chinook salmon successfully spawn gravel shoals, potentially increasing the spawning habitat available to Chinook salmon (Powell and Miller 1990).

Adult Chinook salmon would be subjected to several potential sources of stress and mortality upon being transplanted into Lake Oroville, including latent mortality stresses incurred during lower Feather River immigration (e.g., related to water temperature, disease, catch-and-release and incidental hooking, etc.), handling and sorting at adult collection facilities, truck transportation and release into Lake Oroville. Other major sources of stress and mortality include sportfishing impacts and harvest, disease and water temperature impacts.

Sportfishing in Lake Oroville could potentially remove a substantial portion of adult Chinook salmon transplanted. For example, annual harvest of Lake Michigan Chinook salmon between 1986 and 1996 ranged from approximately 180,000 to 950,000 fish. During that same time period, harvest rates (number of fish per angler-hour) ranged from approximately 0.03 to 0.08 (Benjamin and Bence, in-press). Although Lake Michigan supports a much different Chinook salmon fishery than would be expected in Lake Oroville because, it provides an example of the potential popularity a Chinook salmon fishery could obtain in the reservoir.

Adult Chinook salmon may be eliminated from the potential spawning population by other means than direct mortality. Inappropriately high water temperatures in Lake Oroville tributaries may present thermal barriers to adult Chinook salmon migration, thus precluding them from spawning without directly causing mortality. Similarly, warm epilimnetic water in Lake Oroville during late spring, summer and fall may also present thermal barriers to migration, restricting adult Chinook salmon to cooler hypolimnetic waters, effectively eliminating them from the potential spawning population. Lastly, adult Chinook salmon planted in Lake Oroville may cease normal immigration and spawning behavior, a process known as residualization, and take up residence in the reservoir. Although documentation of this particular scenario was not located, residualization of juvenile salmonids is well documented (e.g., Muir et al. 1999, McMichael et al. 2001, Viola and Schuck 1995) and adult residualization remains a possibility.

A cursory review of preliminary Lake Oroville surface water temperature data suggests that average surface water temperatures during June through September often equal or exceed 23°C (DWR, unpublished data). Boles (1988) reported that water temperatures exceeding 21°C blocked the upstream migration of adult Chinook salmon in the San Joaquin River and Delta. Oregon Department of Water Quality (1995) also reports that water temperatures exceeding 21°C create migrational blockages for several species of salmonids. Warm water temperatures also have been implicated in disease outbreak in adult Chinook salmon (Spence et al. 1996).

Chinook salmon egg viability has been reported to decrease as water temperature adults are exposed to increases. McCullough (1999) states, *"…when ripe adult [Chinook salmon] females are exposed to temperatures beyond the range of 13.3°C - 15.6°C,…the survival of the eggs to the eyed stage decreases."*

Because specific information was found that could provide a reasonable means of estimating the Marina Adult Release Efficiency, for analysis and modeling purposes, arbitrary values for best, expected and worst case were selected. Based upon a review of the potential sources of stress and mortality adult Chinook salmon may encounter upon release into Lake Oroville prior to successfully locating and ascending a spawning tributary, the best case, expected and worst case values for Marina Adult Release Efficiency are 75, 50 and 25 percent.

14.0 REFERENCES

Bauersfeld, K. 1978. Stranding of Juvenile Salmon by Flow Reductions at Mayfield Dam on the Cowlitz River, 1976. Technical Report 36. Olympia, WA: State of Washington, Department of Fisheries.

Beeman, J. W. and J. F. Novotny. 1994. Pen Reading and Imprinting of Fall Chinook Salmon - Final Report. Project No. 82-3 13. U.S. Department of Energy.

Bell, M. C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. Sacramento, CA: U. S. Army Corps of Engineers, Fish Passage Development and Evaluation Program.

Benjamin, D.M. and J.R. Bence. In Press. Spatial and temporal changes in the Lake Michigan Chinook Salmon fishery, 1985-1996. Michigan Department of Natural Resources, Fisheries Division, Fisheries Research Report.

Bernard, D. R., J. J. Hasbrouck, and S. J. Fleischman. 1999. Handling-Induced Delay in Downstream Movement of Adult Chinook Salmon in Rivers. Fisheries Research 44:37-46.

Biomark. Accessed on January 8, 2004. Field Projects. Available at www.biomark.com

Bradford, M. J. 1995. Comparative Review of Pacific Salmon Survival Rates. Canadian Journal of Fisheries and Aquatic Science 52:1327-1338.

Brun, C. 2003. Juvenile Fall Chinook Salmon Coded Wire Tagging Feasibility Study in the Deschutes River, Oregon. Final Report.

Burke, B. J., M. L. Moser, T. J. Bohn, L. C. Stuehrenberg, and T. C. Bjornn. 2001. Adult Fall Chinook Fishway Use: A 3-Year Summary (In Press).

Chapman, D. W., D. E. Weitkamp, T. L. Welsh, M. B. Dell, and T. H. Schadt. 1986. Effects of River Flow on the Distribution of Chinook Salmon Redds. Transactions of the American Fisheries Society 115:537-547.

Commercial Salmon Trollers Advisory Committee. Accessed on January 6, 2004. Commercial Salmon Stamp Project. Available at www.calkingsalmon.org

Congleton, J. L., W. J. La Voie, C. B. Schreck, and L. E. Davis. 2000. Stress Indices in Migrating Juvenile Chinook Salmon and Steelhead of Wild and Hatchery Origin Before and After Barge Transportation. Transactions of the American Fisheries Society 129:946-961.

DFG. 1998. A Status Review of the Spring-Run Chinook Salmon (*Oncorhynchus Tshawytscha*) in the Sacramento River Drainage. Candidate Species Status Report 98-01. Sacramento, CA: Department of Fish and Game.

DFG. 2001. Report of the Subcommittee on Off-Site Release and Straying of Hatchery Produced Chinook Salmon. Appendix I through V.

DFG. 2002. 2002 Fresh Water Sport Fishing California Regulations.

DFG. Accessed on December 30, 2003. Feather River Hatchery Facility. Available at http://www.dfg.ca.gov/lands/fh/feather/facility.htm

Downing, S. and E. F. Prentice. 2003. Overview of the Performance of PIT-Tag Interrogation Systems for Adult Salmonids at Bonneville and McNary Dams. Technical Report 2002. Bonneville Power Administration.

DWR. 2002. Emigration of Juvenile Chinook Salmon in the Feather River, 1998-2001. Sacramento, CA: Department of Water Resources, Division of Environmental Services.

DWR. Accessed on December 10, 2003a. California Data Exchange Center. Available at http://cdec.water.ca.gov

DWR. 2003b. Fish Distribution in the Feather River Below the Thermalito Diversion Dam to the Confluence With the Sacramento River- Draft Report, SP-F3.2, Task 1B.

DWR. 2003c. Redd Dewatering and Juvenile Steelhead and Chinook Salmon Stranding in the Lower Feather River , 2002-2003: Interim Report SP-F10, Task 3C. Sacramento, CA: DWR, Division of Environmental Services.

DWR. 2004. Potential Effects of Facility Operations on Spawning Chinook Salmon-Interim Draft, SP-F10, Task 2B.

Environmental News Network. Accessed on January 8, 2004. Environmental News Network Homepage.

FERC. 1993. Fish Facility Operations Annual Report for 1992-1993. Baker River Project FERC Project No. 2150.

Ferguson, J. W., J. G. Williams, and E. Meyer. 2002. Recommendations for Improving Fish Passage at the Stornorrfors Power Station on the Umealven, Umea, Sweden. Seattle, WA: National Marine Fisheries Service, Northwest Fisheries Science Center.

Fresh, K. L. 1997. The Role of Competition and Predation in the Decline of Pacific Salmon and Steelhead *in* Pacific Salmon & Their Ecosystems: Status and Future Options. Stouder, D. J., Bisson, P. A., and Naiman, R. J. (ed.), New York: Chapman and Hall. pp. 245-275.

Gessel, M. H., J. G. Williams, D. A. Brege, and R. F. Krcma. 1991. Juvenile Salmonid Guidance at the Bonneville Dam Second Powerhouse, Columbia River, 1983-1989. North American Journal of Fisheries Management 11:400-412.

Healey, M. C. 1991. Life History of Chinook Salmon (*Oncorhynchus Tshawytscha*) *in* Pacific Salmon Life Histories. Groot, C. and Margolis, L. (ed.), Vancouver B.C.: UBC Press. pp. 311-393.

Healey, T. P. 1977. The Effect of High Temperature on the Survival of Sacramento River Chinook (King) Salmon, *Oncorhynchus Tshawytscha*, Eggs and Fry. Anadromous Fisheries Branch Administrative Report No. 79-10.

Kastner, A. 2002. Feather River Hatchery- Draft Annual Report 2001-2002. Wildlife and Inland Fisheries Division Administrative Report. California Department of Fish and Game.

Kastner, A. 2003. Feather River Hatchery- Draft Annual Report 2002-2003. Wildlife and Inland Fisheries Division Administrative Report. California Department of Fish and Game.

Koski, K. V. 1966. The Survival of Coho Salmon (*Oncorhynchus Kisutch*) From Egg Deposition to Emergence in Three Oregon Coastal Streams. Oregon State University,

Lackey, R. T. 2003. Pacific Northwest Salmon: Forecasting Their Status in 2100. Reviews in Fisheries Science 11:35-88.

Matthews, G. M., D. L. Park, S. Achord, and T. E. Ruehle. 1986a. Static Seawater Challenge Test to Measure Relative Stress Levels in Spring Chinook Salmon Smolts. Transaction of the American Fisheries Society 236-244.

Matthews, G. M., D. L. Park, S. Achord, and T. E. Ruehle. 1986b. Static Seawater Challenge Test to Measure Relative Stress Levels in Spring Chinook Salmon Smolts. Transactions of the American Fisheries Society 115:236-244.

McCullough, D. A. 1999. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, With Special Reference to Chinook Salmon. Report No. EPA 910-R-99-010. Seattle, WA: EPA, Region 10.

McMichael, Geoffrey A., Pearsons, Todd N. 2001: Upstream Movement of Residual Hatchery Steelhead into Areas Containing Bull Trout and Cutthroat Trout**.** North American Journal of Fisheries Management. 21: 943–946.

Meehan, W. R. 1991. Summer Habitat Use by Young Salmonids and Their Responses to Cover and Predation in a Small Southeast Alaskan Stream. Transaction of the American Fisheries Society 120:474-485.

Monk, B., D. Weaver, C. Thompson, and F. Ossiander. 1989. Effects of Flow and Weir Design on the Passage Behavior of American Shad and Salmonids in an Experimental Fish Ladder. North American Journal of Fisheries Management 9:60-67.

Moyle, P. B. 2002. Inland Fishes of California. Berkeley: University of California Press, Los Angeles.

Muir, W. D., S. G. Smith, E. E. Hockersmith, M. B. Eppard, W. P. Connor, T. Anderson, and B. D. Arnsberg. 1999. Fall Chinook salmon survival and supplementation studies in the Snake River and Lower Snake River Reservoirs, 1997. Annual report (DOE/BP-10891-8) to Bonneville Power Administration, Portland, OR, Contracts DE-AI79-93BP10891 and DE-AI79-91BP21708, Projects 93-029-00 and 91-029-00, 71 p. (BPA Report DOE/BP-10891-8).

NOAA. 1998. Biological Opinion on Effects of Issuing an ESA Section 10 Permit to the Corps of Engineers for Operation of the Elk Creek Dam Trap-and-Haul for the 1998/99 and 1999/00 Fish Passage Seasons.

NOAA. nd. NOAA Fisheries– Great Lakes Environmental Research Laboratory, http://www.glerl.noaa.gov, accessed January 2004

Pacific Fisheries Resource Conservation Council. 2001. Pacific Fisheries Resource Conservation Council: Third Annual Report.

Pacific Fishery Management Council. 2003. Review of 2002 Ocean Salmon Fisheries. Portland, OR: Pacific Fishery Management Council.

Pacific States Marine Fisheries Commission. Accessed on January 6, 2004. Regional Mark Information System. Available at www.rmis.org

Painter, R. E., L. H. Wixom, and S. N. Taylor. 1977. An Evaluation of Fish Populations and Fisheries in the Post-Oroville Project Feather River.

Peck, J. W. 1996. Contribution of hatchery fish to Chinook salmon populations and sport harvest in Michigan waters of Lake Superior, 1990-94. Fisheries Research Report No. 2023. Michigan Department of Natural Resources.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of Predaceous Fishes on Out-Migrating Juvenile Salmonids in John Day Reservoir, Columbia River. Transaction of the American Fisheries Society 120:405-420.

Powell, M.J. and M. Miller. 1990. Management Brief – Shoal spawning by Chinook salmon in Lake Huron. North American Journal of Fisheries Management 10: 242-244.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of Using Implantable Passive Integrated Transponder (PIT) Tags in Salmonids *in* Fish-Marking Techniques- American Fisheries Society Symposium 7. Parker, N. C., Giorgi, A. E., Heidinger, R. C., Jester, D. B., Prince, E. D., and Winans, G. A. (ed.), Bethesda, MD: American Fisheries Society.

Puget Sound Energy. 2002a. Draft Report on Smolt Radiotelemetry Migration Study in Baker Lake, Washington- unpublished work.

Puget Sound Energy. 2002b. Draft Report on the Near-Field Smolt Behavior Study in Baker Lake, Washington- unpublished work.

Quinn, T. P. and K. Fresh. 1984. Homing and Straying in Chinook Salmon (Oncorhynchus Tshawytscha) From Cowlitz River Hatchery, Washington. Canadian Journal of Fisheries and Aquatic Science 41:1078-1082.

Rensel, J. E., R. P. Harris, and T. J. Tynan. 1988. Fishery Contribution and Spawning Escapement of Coho Salmon Reared in Net-Pens in Southern Puget Sound, Washington. North American Journal of Fisheries Management 8:359-366.

Rhodes, R. Adult Chinook Salmon Handling- Phone Conversation. October 10, 2003.

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated Loss of Juvenile Salmonids to Predation by Northern Squawfish, Walleyes, and Smallmouth Bass in John Day Reservoir, Columbia River. Transaction of the American Fisheries Society 120:448-458.

Roby, D. D., D. P. Craig, and S. Adamany. 1997. Avian Predation on Juvenile Salmonids in the Lower Columbia River. BPA Report No. DOE/BP-33475-1. Annual Report 1997 to Bonneville Power Administration.

Roussel, J. M., A. Haro, and R. A. Cunjak. 2000. Field Test of a New Method for Tracking Small Fishes in Shallow Rivers Using Passive Integrated Transponder (PIT) Technology. Canadian Journal of Fisheries and Aquatic Science 57:1326-1329.

San Joaquin River Group Authority. 2002. Chapter No. 5. Salmon Smolt Survival Investigations *in* Vernalis Adaptive Management Plan- 2002 Technical Report. pp. 30-59.

Smith, S. G., W. D. Muir, J. G. Williams, and J. R. Skalski. 2002. Factors Associated With Travel Time and Survival of Migrant Yearling Chinook Salmon and Steelhead in the Lower Snake River. North American Journal of Fisheries Management 22:385-405.

Snider, B. and K. Vyverberg. 1995. Chinook Salmon Redd Survey Lower American River Fall 1995. Stream Flow and Habitat Evaluation Program. Department of Fish and Game.

Solomon, D. J. 2003. Coded Wire Tag Project Manual, Guidelines on Planning and Conducting Projects Using CWT and Associated Equipment. Shaw Island, WA : Northwest Marine Technology, Inc.

SWRI. 2004. Aquatic Resources of the Lower American River: Draft Baseline Report. Sacramento, CA: Surface Water Resources, Inc.

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on Juvenile Salmonids by Smallmouth Bass and Northern Squawfish in the Columbia River Near Richland, Washington. North American Journal of Fisheries Management 13:831-838.

Tipping, J. M. and G. J. Gilhuly. 1996. Survival of Electroanesthetized Adult Steelhead and Eggs of Fall Chinook Salmon. North American Journal of Fisheries Management 16:469-472.

USACE. 2000. Final Submittal for Alternatives Report for Fish Passage Cougar Lake WTC Project. Portland, OR: U.S. Army Corps of Engineers, Portland District.

USFWS. 1999. Effect of Temperature on Early-Life Survival of Sacramento River Fall- and Winter-Run Chinook Salmon. Final Report.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of Consumption of Juvenile Salmonids and Alternative Prey Fish by Northern Squawfish, Walleyes, Smallmouth Bass, and Channel Catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Viola, A.E. and M.L. Schuck. 1995: A Method to Reduce the Abundance of Residual Hatchery Steelhead in Rivers. North American Journal of Fisheries Management. 15: 488–493. .

Walker, C. E. and D. B. Lister. 1971. Results for Three Generations From Transfers of Pink Salmon (*Oncorhynchus Gorbuscha*) Spawn to the Qualicum River in 1963 and 1964. Journal Fisheries Research Board of Canada 28:647-654.

Ward, P. D. and T. R. McReynolds. 2001. Butte and Big Chico Creeks Spring-Run Chinook Salmon, *Oncorhynchus Tshawytscha*, Life History Investigation 1998-2000.

White, D. NOAA Fisheries Performance Criteria for Potential Fish Passage Facilities, Options for Klamath Hydroelectric Project- E-Mail Communication. November 18, 2003.

Wisconsin Department of Natural Resources (http://www.dnr.state.wi.us/) accessed January 2004.

Williams, J. G. 2001. Chinook Salmon in the Lower American River, California's Largest Urban Stream *in* Contributions to the Biology of Central Valley Salmonids: Volume 2. Brown, R. L. (ed.), Sacramento, CA: California Department of Fish and Game. pp. 1-38.

Zimmerman, B. C. and B. B. Duke. 1996. Trapping and Transportation of Adult and Juvenile Salmon in the Lower Umatilla River in Northeast Oregon, 1995-1996. Annual Progress Report. U.S. Department of Energy, Bonneville Power Administration.

Zimmerman, M. P. 1999. Food Habits of Smallmouth Bass, Walleyes, and Northern Pikeminnow in the Lower Columbia River Basin During Outmigration of Juvenile Anadromous Salmonids. Transactions of the American Fisheries Society 128:1036-1054.

Zimmerman, M. P. and D. L. Ward. 1999. Index of Predation on Juvenile Salmonids by Northern Pikeminnow in the Lower Columbia River Basin, 1994-1996. Transactions of the American Fisheries Society 128:995-1007.

Zuspan, M., T. Mills, and C. Wilson. 1991. Trinity River Basin Salmon and Steelhead Monitoring Project: Annual Report, 1988-1989 Season. California Department of Fish and Game.

Zuspan, M. 1992. Capture and Coded-Wire Tagging of Naturally Produced Chinook Salmon in the Trinity River Basin. Annual Report, 1990-1991 Season. Trinity River Basin Salmon and Steelhead Monitoring Project.

Appendix B

Model Output