State of California
The Resources Agency
Department of Water Resources

RIVER FLOW EFFECTS ON EMIGRATING JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER
SP-F10 TASK 4A

Oroville Facilities Relicensing
FERC Project No. 2100

DECEMBER 2003

ARNOLD SCHWARZENEGGER Governor State of California	**MICHAEL CHRISMAN** Secretary for Resources The Resources Agency	**LINDA S. ADAMS** Director Department of Water Resources

State of California
The Resources Agency
Department of Water Resources

RIVER FLOW EFFECTS ON EMIGRATING JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER
SPF10 TASK 4A

Oroville Facilities Relicensing
FERC Project No. 2100

This report was prepared under the direction of

Terry J. Mills..Environmental Program Manager, DWR

by

Jason Kindopp .... Environmental Scientist, DWR

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 SUMMARY

Task 4A of SP-F10 was completed by conducting a literature review and an analysis of empirical data collected on the lower Feather River to determine the timing of emigration and the potential effects of river flow on emigrating juvenile salmonids.

As part of a 1983 agreement between the Department of Water Resources and the Departement of Fish and Game, minimum discharge into the Low Flow Channel (LFC) increased from approximately 400 cfs to 600 cfs in 1988. Significant deviations from this pattern primarily occur during flood releases. Consequently, mean daily flow (cfs) throughout the year is normally slightly above 600 cfs. Since 1988, mean daily flow has exceeded 1,000 cfs approximately 7% of the time. High flow events in the LFC (greater than 10,000 cfs) have occurred in 9 of the last 22 years. These higher flow events could have encouraged emigration of juvenile Chinook salmon and steelhead in the nine years they were experienced.

In the High Flow Channel (HFC), the flow regime is not stable, but would not be characterized as natural (State Water Project operations and regulatory requirements often dictate HFC flow patterns). The HFC operates under a seasonal flow requirement that usually reduces the chance of a long-term constant flow situation. Additionally, since 1967, the HFC has experienced flows greater than 10,000 cfs approximately 67% of the time in a 22 year period. In all but two of those years, the high flows occurred during the winter or spring, a time period that could encourage Chinook emigration.

Rotary screw trap sampling was performed between 1997 and 2003 to investigate the potential of environmental variables to affect chinook emigration behavior. DWR data (collected between 1997 and 2003) indicates that the peak emigration of Chinook fry in the LFC and HFC is consistently between January and March, regardless of flow variations. Regression analysis performed on Chinook catch between 1997 and 2003 illustrates that emigration timing is often poorly explained by environmental variables. In one model, flow, temperature and female spawn timing collectively accounted for 95% of the variation in catch at the Thermalito Rotary Screw Trap (RST) between 2001 and 2003. However, flow was not found to be a statistically significant influence. A similar analysis performed for the 1998-1999 and 1999-2001 screw trap catch at both Thermalito and Live Oak provided similar results. Similar to all years except 1997-1998 (Live Oak), regression analysis failed to show a significant flow effect for either Thermalito or Live Oak.

Emigration patterns for chinook salmon in the Feather River were similar throughout the period of study (and similar to previous studies) in that they emigrate very early and at small sizes. The percentage of salmon that were categorized as smolts or intermediate between parr and smolt was less than 2% at Thermalito, and 15% at Live Oak. Most were smaller than 50 mm (97% at Thermalito and 81% at Live Oak). The high

percentages of pre-smolt fish and fish smaller than 50 mm indicate that most salmon undergo smoltification downstream of Live Oak.

RST sampling in the Feather River is difficult or impossible when flows approach 15,000 cfs (primarily at Live Oak). Consequently, monitoring Chinook catch and associated environmental variables becomes problematic. Due to the difficulties associated with sampling at higher flows, no Feather River data are available to address the effect of these extreme events on emigration of juvenile Chinook salmon or steelhead. However, it is probable that substantial increases in flow released at the appropriate time could enhance emigration success. Under present operations, more subtle influences such as food availability, temperature and adult spawn timing likely have more influence on emigration patterns than flow, both in the LFC and during low or consistent flow periods in the HFC. This does not infer, however, that high flow events are not valuable and preferential to low flow conditions. It simply means that in the absence of flow variation, Chinook salmon continue to emigrate the lower Feather River (past RM 42-Live Oak) approximately the same time every year.

Juvenile steelhead in the lower Feather River were captured in DWR sampling programs March through September, with peak capture occurring from March through mid-April (DWR 2000, 2002b). RST catch of wild juvenile or yearling steelhead at Thermalito is inconsistent (especially for larger steelhead) between years, while catch at Live Oak is extremely low in all years. It is very likely that prior to emgiration many steelhead grow to a size large enough to avoid capture at the RSTs. Additionally, the varied life history of steelhead makes capture or monitoring emigration at any life stage difficult. Empirical data, literature review, and observational data suggest that steelhead potentially emigrate during all months of the year in the lower Feather River. The lack of quality data on steelhead emigration patterns impairs our ability to draw reliable conclusions about steelhead emigration behavior in the Feather River.

Although no detailed analysis of steelhead emigration patterns is available, certain aspects of project operations are important to the success of wild steelhead in the Feather River. Certainly, large increases in flow followed by quick reductions could cause significant stranding in both the LFC and HFC. Additionally, prolonged low flow conditions in either the LFC or HFC are unlikely to benefit steelhead. Increased and, at times varying flows, in both sections of river are likely to provide additional rearing habitat, cover and food resources (assuming stranding issues are addressed). Many of the issues regarding adequate flow conditions are directly related to temperature and are better addressed in SP F-10, Task 4B. In general, flow (and correspondingly temperature) preferences of juvenile steelhead must be addressed when considering in-stream flow operational scenarios.

2.0 PURPOSE

The purposes of Task 4A of Study Plan (SP)-F10 are to describe the relationship between river flow and juvenile salmonid emigration patterns, and to evaluate potential project effects on juvenile salmonid emigration in the Feather River downstream from the Fish Barrier Dam. Salmonids present in the Feather River include the Central Valley (CV) Evolutionarily Significant Unit (ESU) spring-run Chinook salmon (*Oncorhynchus tshawytscha*), the CV ESU fall-run Chinook salmon, and the CV ESU steelhead (*Oncorhynchus mykiss*). On September 16, 1999, naturally spawned CV ESU spring-run Chinook salmon were listed as threatened under the federal Endangered Species Act (ESA) by the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) (NOAA 1999). The CV spring-run Chinook salmon 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 Feather River (NOAA 1999). On March 19, 1998, naturally spawned CV ESU steelhead were listed as threatened under the federal Endangered Species Act (ESA) by NOAA Fisheries (NOAA 1998). The CV 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 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 CV spring-run Chinook salmon and CV steelhead.

In addition to the ESA, 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 (Code of Federal Regulations 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact from on-going and future operations. As a subtask of SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam*, Task 4A fulfills a portion of the FERC application requirements by describing the relationship between river flow and juvenile salmonid emigration patterns, and evaluating the potential project effects on juvenile salmonid emigration in the Feather River downstream from the Fish Barrier Dam. In addition to fulfilling statutory requirements, the conclusions from this analysis may be used as the basis for developing or evaluating potential Resource Actions focused on providing appropriate flow regimes in the Feather River for emigrating juvenile salmonids.

3.0 BACKGROUND

3.1 STUDY AREA

The study area in which the results of Task 4A of SP-F10 apply includes the reach of the lower Feather River extending from the Fish Barrier Dam downstream to the confluence with the Sacramento River (Figure 5.1-1). This is the geographic range within the lower Feather River that encompasses areas through which juvenile salmonids emigrate. There are two distinct reaches within the study area: the upstream reach and the downstream reach. The upstream reach, typically referred to as the Low Flow Channel (LFC), extends from the Fish Barrier Dam at river mile (RM) 67.25 downstream to the Thermalito Afterbay Outlet at RM 59. The downstream reach, typically referred to as the High Flow Channel (HFC), extends from the Thermalito Afterbay Outlet downstream to the confluence with the Sacramento River at RM 0. The flow and water temperature regimes associated with each of these reaches are distinct, and are summarized below.

Minimum flows in the lower Feather River were established in the August 1983 agreement between the California Department of Water Resources (DWR) and the California Department of Fish and Game (DFG) (DWR 1983). The agreement established criteria for flow and water temperature in both the LFC and HFC reaches. The agreement also specified that DWR release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. Therefore, the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet is operated at approximately 600 cfs year-round, with variations in flow occurring infrequently. Most flow deviations from 600 cfs occur during flood control releases, in the summer to satisfy downstream temperature requirements for salmonids, or for maintenance and monitoring purposes. Water temperatures in the LFC of the lower Feather River are typically lower than temperatures in the HFC, because the upstream reach of the Feather River is supplied directly by water taken from Lake Oroville's hypolimnion in order to meet Feather River Hatchery and other downstream water temperature requirements.

Unlike the relatively constant flow regime in the LFC of the lower Feather River, the flow regime in the HFC of the lower Feather River varies depending on runoff and month. The HFC reach extends from the Thermalito Afterbay Outlet (RM 59) to the confluence with the Sacramento River (RM 0). Minimum flow requirements in the HFC of the lower Feather River range from 1,000 to 1,700 cfs (DWR 1983), depending upon the percentage of normal runoff and the month. Although the minimum flow requirements range from 1,000 to 1,700 cfs, flow in the HFC typically ranges from the minimum flow requirement up to 7,500 cfs (DWR 1982). Flow in the HFC is, therefore, more varied than flow in the LFC. Flow in the HFC is additionally influenced by small flow contributions from Honcut Creek (RM 44) and the Bear River (RM 13), and by larger flow contributions from the Yuba River (RM 29). Water temperature in the HFC of the lower Feather River is typically warmer than water temperature in the LFC of the lower Feather River. Water temperature in the HFC is directly influenced by water releases from the Thermalito Afterbay Outlet. Because the Thermalito Afterbay is a large, shallow reservoir, water released from the Thermalito Afterbay Outlet is typically warmer than the water originating from the LFC of the main channel of the lower Feather River. Typically, the contribution to the total flow in the Feather River from the Thermalito Afterbay Outlet is greater than flow contribution from the LFC of the lower Feather River. Water temperatures in the river downstream of the Thermalito Afterbay Outlet are generally warmer than water temperatures in the reach upstream of the Thermalito Afterbay Outlet. The ability of the Oroville operations to control or influence water temperature and its downstream extent under varying flow regimes and environmental conditions is being evaluated in study plans SP-E1, SP-E6, and SP-E7.

For the purpose of this analysis, the study area has been divided into two major reaches: (1) the LFC from the Fish Barrier Dam to the Thermalito Afterbay Outlet; and (2) the HFC from the Thermalito Afterbay Outlet to the mouth of the Feather River at its confluence with the Sacramento River.

3.2 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, power generation, to improve water quality in the Delta, provide recreation, and 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 3.2-1. 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.

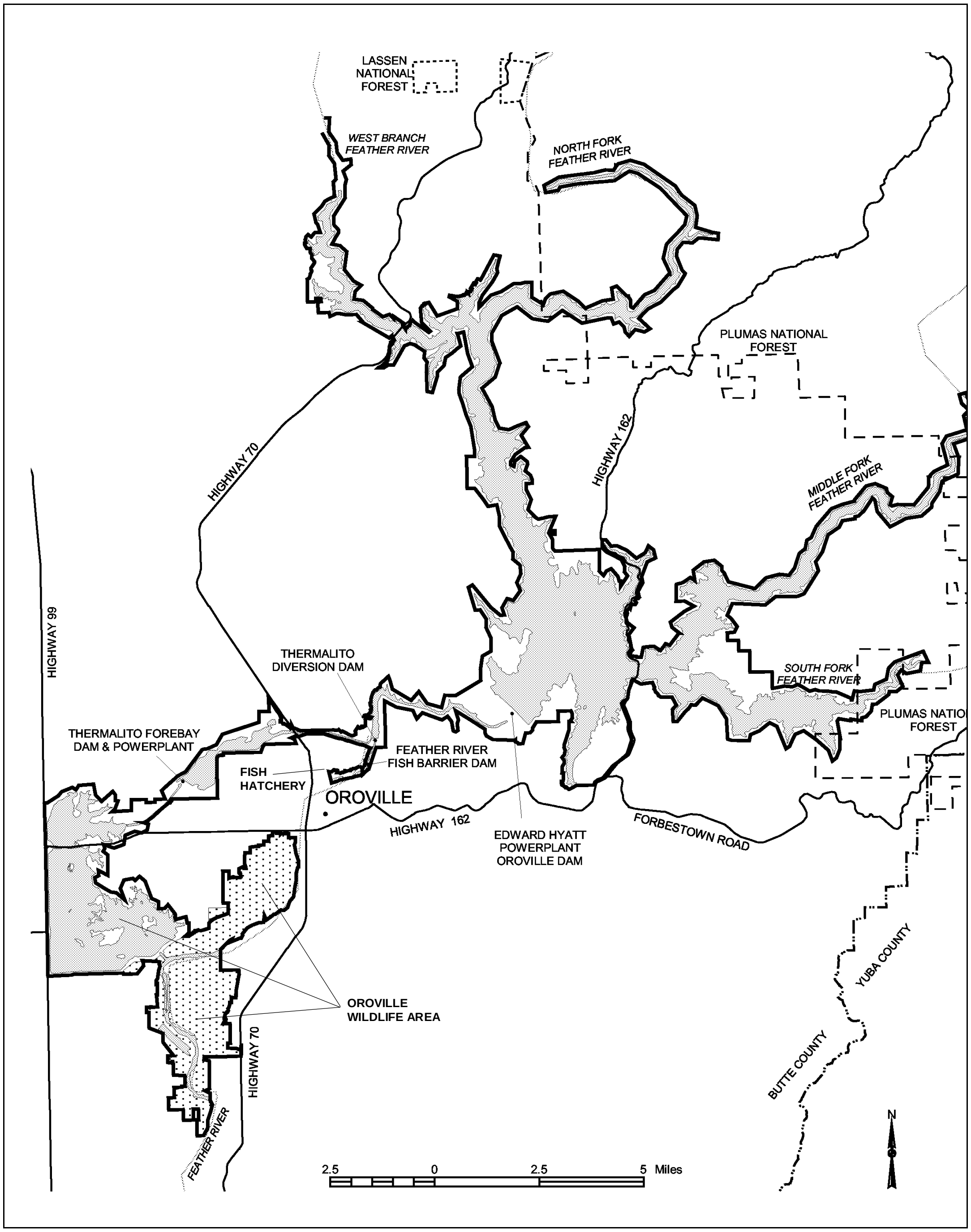

Figure 3.2-1. Oroville Facilities FERC Project Boundary

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.

3.3 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.

3.3.1 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.

3.3.1.1 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.

3.3.1.2 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.

The National Marine Fisheries Service 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 $\leq 65^{o}$ 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.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

3.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) af 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.

3.3.1.4 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.

3.3.2 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.

3.4 LIFE HISTORIES - AN OVERVIEW OF SAMPLING PROGRAMS IN THE LOWER FEATHER RIVER

Eggs from adult Chinook salmon and steelhead are deposited in appropriate gravel beds and, after incubation, embryos hatch to live as alevin (sac-fry) within interstitial spaces of gravel substrates. The length of time alevins reside in gravel substrates varies, but usually lasts until the yolk sac is fully absorbed (Moyle 2002). Young Chinook salmon and steelhead are referred to as fry upon emergence from gravel beds. During the transition from fry to parr, juvenile salmonids grow in size and spend more time utilizing deeper and higher velocity habitats for feeding and rearing (Moyle 2002). The parr-smolt transformation involves morphological, physiological, and behavioral changes. In general, these changes gradually occur while juvenile salmonids are en-route from natal streams to the ocean. Among the many morphological changes that take place, the external body silvering, change in body shape, and darkening of fin margins are the most widely used visual cues separating parr from smolt (Hoar 1976; Wedemeyer et al. 1980). However, it is the physiological changes that truly separate the two life stages. Smoltification, or the parr-smolt transformation, is the process by which juvenile salmonids undergo physiological changes necessary to successfully transition from a freshwater to a saltwater environment. Therefore, a true smolt has begun physiological change. These physiological changes include an increase in gill ATPase activity, decrease in condition in association with a decrease in total body lipids, decrease in nitrogen protein, and a loss of glycogen from the liver (Hoar 1988; Zaugg and Wagner 1973). Behavioral changes that take place during smoltification include an increase in migratory behavior, and a stronger tendency to school and swim at mid-depth (Kalleberg 1958). Pinder and Eales (1969) reported that smolts maintained larger volumes of air in their swim bladder than parr, causing greater buoyancy (Pinder and Eales 1969). Wedemeyer et al. (1980) suggested increased buoyancy could make it difficult for juvenile salmonids to maintain residence at or near the river bottom, which may facilitate downstream migration (Wedemeyer et al. 1980). Saunders (1965) suggested that increased buoyancy during smoltification is likely a response in preparation for pelagic existence in the ocean, as opposed to bottom dwelling in rivers (Saunders 1965). Factors associated with initiation and progression of smoltification include water temperature, photoperiod, and flow (Berggren and Filardo 1993; Zaugg and Wagner 1973). Smoltification, and the associated changes occurring during this life stage, is often associated with an increased tendency for downstream migration behavior.

Emigration can be defined as the downstream movement, or migration, of juvenile salmonids. The term emigration is used broadly to describe short and long distance movements in association with habitat utilization, as well as to describe true seaward migrations. Within the context of this report, emigration refers to general downstream movements of juvenile salmonids without reference to purpose or extent of movement, unless otherwise stated.

Various historical monitoring data pertain to the emigration of juvenile salmonids in the lower Feather River. Painter et al. (1977) sampled juvenile Chinook salmon using fyke nets at Live Oak (RM 42). Length at capture, date of capture, and weekly mean catch per fyke net day were reported. DWR conducted seining surveys in the lower Feather River between January 1997 and August 2001 to document fish distribution and abundance (DWR 2002a). Sampling sites were located between the Fish Barrier Dam (RM 67.25) and Boyd's Pump (RM 23). Data were pooled for all sample sites. Length at capture and numbers captured by year and month were reported for juvenile Chinook salmon and steelhead. The total catch by species was also reported for each year in the LFC and the HFC. Although seining surveys provide information regarding the relative abundance, distribution, and size of juvenile Chinook salmon and steelhead, seining is not designed specifically to assess the characteristics of emigration. Consequently, seining data provides information about both rearing and emigrating juvenile salmonids.

From December 1997 through June 2003, DWR sampled juvenile salmonids in the lower Feather River using two rotary screw fish traps (RST) in order to assess the timing and general abundance of emigrating juvenile salmonids and other fish species (DWR 2002b). One RST (the Thermalito RST) was stationed at RM 60.1, upstream of the Thermalito Afterbay Outlet, and the second RST was stationed in the HFC near the town of Live Oak. Results were reported for each RST and included size-based separation, using daily fork length tables (Greene 1992) of fall-run and spring-run Chinook salmon.

Rotary screw trap data suggests most downstream movement of juvenile salmonids occurs at night (DWR 2002b). During the day, nearshore habitat is utilized for resting, protection, and feeding. Thus, a variety of microhabitat types are utilized by emigrating juvenile salmonids.

4.0 METHODOLOGY

The purpose of Task 4A of SP-F10 is to describe the relationship between river flow and juvenile salmonid emigration patterns, and to evaluate potential project effects on juvenile salmonid emigration in the Feather River downstream from the Fish Barrier Dam. Rotary screw trap, snorkel, escapement and beach seining data gathered by DWR was the primary source of empirical data used for the analysis of Feather River Chinook and steelhead emigration behavior. A literature review was conducted to determine the timing and duration of emigration for juvenile salmonids in other systems, and how flow affects the emigration patterns observed.

For the purposes of this report, no distinction is made between spring-run juvenile Chinook salmon and fall-run juvenile Chinook salmon. The effects of flow on emigrating spring-run juvenile Chinook salmon and fall-run juvenile Chinook salmon are analyzed together over a range of months encompassing both spring-run and fall-run emigration periods. Available data does not suggest significantly different emigration periods for juvenile spring-run and fall-run Chinook salmon (DWR 2002b). Furthermore, most spring-run sized fish were nearly identical in size to the fall-run emigrating at the same time, illustrating the uncertainties of using the Daily Length Table alone as an indicator of race (DWR 2002b). Therefore, analyzing flow related effects during the collective emigration time period would be more efficient, effectively eliminating repeat analyses for certain periods.

4.1 PLACEMENT OF ROTARY SCREW FISH TRAPS

Since 1996 DWR has operated two rotary screw fish traps in the lower Feather River. The Thermalito RST was located near the end of the LFC (RM 60.1) and the Live Oak RST was located in the HFC near the town of Live Oak (RM 46 and RM 42). This trapping arrangement was designed to investigate the potential of environmental variables such as flow, temperature and turbidity to affect juvenile Chinook emigration behavior. Between December 1997 and January 2001 the Live Oak trap was placed at River Mile 42, approximately two miles below Honcut Creek. In January 2001 the Live Oak trap was moved to River Mile 46 to avoid unregulated flow and debris loads associated with discharge from Honcut Creek. Six complete trapping seasons have been accomplished since inception of the program (1998-2003). Even though the screw traps capture steelhead, the trapping program was not specifically intended to determine emigration behavior of juvenile steelhead.

4.2 ANALYSIS OF ROTARY SCREW TRAP AND ADULT SPAWNING DATA

Each trap was ordinarily serviced once per day from December through June. All Chinook salmon captured were counted and assigned to a race according to the criteria described by Greene (1992). Fork length was measured to the nearest millimeter for the first 50 individuals captured of each race. Measured individuals were also inspected for determination of life stage (i.e., parr, parr/smolt, and smolt).

RST catch of Chinook salmon for both the Thermalito and Live Oak traps was expanded to determine a passage estimate for the LFC (Thermalito RST) and the river (Live Oak RST). The daily expanded catch or passage estimate is determined by a series of mark and recapture experiments performed at each RST during the peak emigration period (generally January 1 through March 31). For a detailed description of the calculations used to generate the passage estimate please revisit "*Emigration of Juvenile Chinook Salmon in the Feather River, 1998-2001* (DWR, 2002b). For the purposes of this analysis, the 1997-1998, 1998-2000 and 2000-2003 trapping seasons were treated separately due to complications with combining the data sets. For the 1997-1998 trapping season, flow, temperature and turbidity were the only variables examined for emigration influences (DWR, 1999). Although river flow, temperature and turbidity are often the key variables used to examine Chinook emigration behavior, other variables were also investigated in the 1998-2000 and 2000-2003 analyses. Specifically, adult salmon spawning behavior (timing) was investigated as an alternative variable that may explain emigration patterns (expanded catch estimate) observed at the RSTs.

Since 2000, DWR has been gathering detailed information on adult Chinook spawning distribution and success. Adult Chinook salmon escapement (carcass) data is collected every fall between September and December. The intent of the survey is to determine the number of chinook spawning naturally in the river channel. An integral part of the survey is determining the number of adults spawning in pre-determined river sections. Consequently, an estimate can be made of the number of successfully spawning females in both the LFC and HFC. Because the survey reaches are broken down between the LFC and HFC, this data can be analyzed with the Chinook salmon expanded catch estimates (for LFC and HFC) to determine if a relationship exists between them. More specifically, the LFC estimate of spent females between 2000 and 2002 (or all adults, male and female) was paired with LFC emigration data between 2001 and 2003 (and other variables) in the regression analysis described below.

Linear regression analysis was used to determine the relationship between the dependent variable, Chinook emigration, and four independent variables; flow, temperature, turbidity and adult escapement. In order to perform this analysis, two-week periods of juvenile emigration, temperature, turbidity and flow were paired with two-week periods of spent female escapement. Spent females were used (2000-2003 analysis only) because only they directly contribute offspring. Adding 90 days from the time of egg deposition determined the matching emigration period Ninety days is the approximate amount of time it would take a fertilized Chinook salmon egg to develop into a fry capable of capture at the Thermalito RST (Murray and McPhail 1988; pers. Comm., Kastner 2003; Kindopp 1999,). All spent females from two consecutive survey weeks were paired with the emigrating juveniles captured at the Thermalito trap in the corresponding two-week block beginning 90 days later. For example, the number of spent females spawning between 09/3/01 and 09/16/01 were paired with the total number of juvenile salmon estimated to have passed the Eye Riffle screw trap (determined from trap efficiencies) between 12/3/01 and 12/16/01. Two-week intervals were used (2000-2003 analysis only) because uncertainty with adult spawner mortality/egg deposition, in-river embryo development rates and emigration patterns make restricting the analysis to one-week or shorter intervals problematic. Live Oak RST and corresponding HFC escapement data were not used in the 2000-2003 analysis. This data was eliminated in the more recent analysis due to uncertainties with Live Oak RST catch (peak emigration periods were not sampled due to high flows in some years) and potential differences in emigration behavior of Chinook salmon between the LFC and HFC. However, weekly estimates of all adults spawning and the corresponding weekly passage estimate were used in the 1999-2001 analysis for both Thermalito and Live Oak (Seesholtz et al., in press).

5.0 RESULTS

5.1 EMIGRATION TIMING OF JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER

5.1.1 Central Valley ESU Steelhead

DWR conducted seining surveys in the lower Feather River between January 1997 and August 2001 to document fish distribution and abundance (DWR 2002a). Sampling sites were located between the Fish Barrier Dam (RM 67.25) and Boyd's Pump (RM 23) (Figure 5.1-1). The study area included two sections, the Low Flow Channel (LFC) from the Fish Barrier Dam to the Thermalito Afterbay Outlet (RM 59), and the portion of the High Flow Channel (HFC) from Thermalito Afterbay Outlet to Boyd's Pump. Total catch data were pooled and reported within each section, while length frequency distribution data were pooled and reported for the entire sample area. Only data for 1999, 2000, and 2001 were reported because these years represented complete sampling seasons. Catch data were reported from March through August for each sampling season. Fork length (mm) was measured for the first 50 individuals captured. In 1999, 2000, and 2001 the percentage of steelhead measuring ≤50 mm was approximately 69%, 56%, and 65%, respectively. When sample sizes for measured steelhead were combined for all three sample years, approximately 62% of steelhead measured ≤50 mm. When total catch was combined for the three sample years, approximately 92% of juvenile steelhead were sampled from the LFC. Peak catches occurred in June of 1999, May of 2000, and March of 2001.

From December 1997 through June 2003, DWR sampled juvenile salmonids in the lower Feather River using two rotary screw fish traps (Live Oak and Thermalito) in order to assess the timing and general abundance of emigrating juvenile salmonids and other fish species (DWR 2002b). Between 1998 and 2001, a total of 1,551 juvenile steelhead were captured, primarily from February through June. In 1999, 2000, and 2001 the percentage of steelhead measuring <30 mm was 93%, 96%, and 93%, respectively. In 2000 and 2001, the average size was 25.5 (+/- 5.0 SD) mm at Thermalito and 88.9 (+/- 81.8 SD) mm at Live Oak. Only 1%, 2%, and 2% of all juvenile steelhead captured in 1999, 2000 and 2001, respectively, were captured in the Live Oak RST.

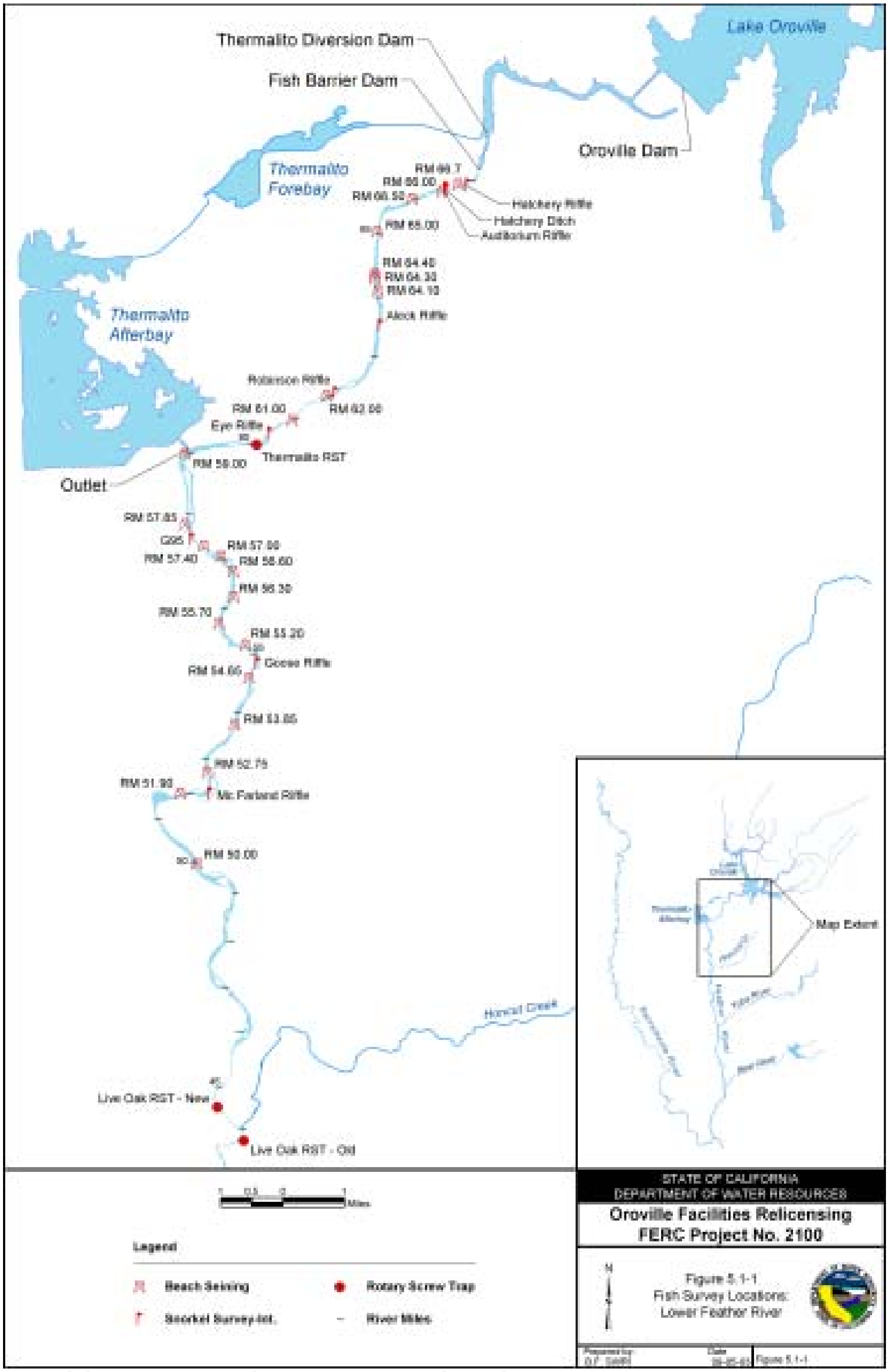

Figure 5.1-1. Fish Survey Locations: Lower Feather River

DWR conducted multi-scale snorkel surveys from 1999 through 2001 to provide information on the seasonal distribution, relative abundance, and habitat use of common Feather River fishes, particularly salmonids, and to identify river conditions, habitats, or ecological interactions which may limit the abundance of salmon and steelhead (Cavallo et al. 2003). The study area consisted of two segments. The Low Flow Channel (LFC) extended from the Fish Barrier Dam (RM 67.25) to the Thermalito Afterbay Outlet (RM 59). The High Flow Channel (HFC) extended from the Thermalito Afterbay Outlet to Gridley Bridge (RM 50.8) (Figure 5.1-1). Based on length frequency data, steelhead less than 100 mm fork length (FL) were classified as age-0, while steelhead greater than 100 mm FL were designated as age-1+. The observational data for all study years combined showed approximately 99% of age-0 steelhead and approximately 97% of age-1+ steelhead were observed in the LFC.

The combined results of these studies indicate: (1) the vast majority of juvenile steelhead were sampled shortly after emergence as fry; (2) juvenile steelhead were sampled in much greater numbers in the LFC than in the HFC; and (3) juvenile steelhead were present in the lower Feather River, to certain degrees, year-round (data is unavailable for September and October) in both the LFC and the HFC. Data indicates that some age-0 steelhead may emigrate from the LFC shortly after emergence in March (Cavallo et al. 2003, DWR 2002b). Because these post-emergent juvenile steelhead were not captured at the Live Oak RST, questions remain regarding the fate of post-emergent juvenile steelhead after they are captured in the Thermalito RST.

Snorkel survey data reveals that a very high percentage of observations of juvenile steelhead came from the LFC. Within the LFC, age-0 steelhead distribution was strongly skewed upstream, with 91%, 77%, and 84% of all observations occurring in the first river mile in each successive survey year, respectively. Snorkel surveys were conducted from March through August and included the section of river from the Fish Barrier Dam (RM 67.25) to Honcut Creek (RM 42). However, an overwhelming percentage of age-0 steelhead were observed within 0.5 mile of the Fish Barrier Dam, near RM 66.5.

5.1.2 Central Valley ESU Chinook Salmon

Several studies have documented emigration patterns of juvenile Chinook salmon in the lower Feather River. Painter et al. (1977) used fyke net catch data to determine the timing of juvenile Chinook salmon migrations in the Feather River, the relative numbers of juvenile Chinook salmon produced each year, and the effect of flows on production and migration patterns of juvenile Chinook salmon. Juvenile salmon were captured in every month, with the vast majority of fish sampled from late January through March. Very few fish were sampled outside of the January through March period, although emigration continued through June. Painter et al. (1977) did not differentiate between juvenile spring-run Chinook salmon and juvenile fall-run Chinook salmon.

DWR conducted seining surveys in the lower Feather River between January 1997 and August 2001 to document fish distribution and abundance (DWR 2002a). Sampling sites were located between the Fish Barrier Dam (RM 67.25) and Boyd's Pump (RM 23) (Figure 5.1-1). The study area included two sections, the Low Flow Channel (LFC) from the Fish Barrier Dam to the Thermalito Afterbay Outlet (RM 59), and the portion of the High Flow Channel (HFC) from Thermalito Afterbay Outlet to Boyd's Pump. Total catch data were pooled for each section while length frequency distribution data were reported combining both sections. Only data for 1999, 2000, and 2001 were reported because these represented complete sampling seasons. Catch data were reported from December through August for each sampling season. In 1999, 2000, and 2001 the percentage of juvenile Chinook salmon measuring ≤50 mm was approximately 74%, 66%, and 81%, respectively. When sample sizes for measured juvenile Chinook salmon were combined for all three sample years, approximately 73% of measured juvenile Chinook salmon were ≤50 mm. During the three years of this study, a total of 35,932 juvenile Chinook salmon were captured and 72% of captures were within the HFC. Juvenile Chinook salmon were captured during all months of the study with January through March accounting for 73% of the catch. In all years, the highest numbers of juvenile Chinook salmon were sampled in February (43% of the catch for all years combined).

In addition to seining, DWR conducted multi-scale snorkel surveys from 1999 through 2001. Size categories were not recorded for juvenile Chinook salmon because nearly all were age-0 (Cavallo et al. 2003). As a result, this study did not differentiate between spring-run and fall-run juvenile Chinook salmon. Large numbers of juvenile Chinook salmon were observed during these surveys in all years. Nearly all juvenile Chinook salmon observations (98%, 100%, and 99%, respectively) were within the LFC. Intermediate-scale surveys were conducted monthly from March through August during each study year. In March and April, juvenile Chinook salmon were abundant and distributed somewhat evenly in both the LFC and the HFC. From May through August, juvenile Chinook salmon were seldom observed in the HFC. The number of juvenile Chinook salmon observations after April decreased substantially at all sites.

DWR sampled juvenile salmonids in the lower Feather River from March 1996 through June 2003 using two RSTs in order to assess the timing and general abundance of emigrating salmonids and other fish species (DWR 2002b). Spring-run sized juvenile Chinook salmon were captured primarily from late November through December, with numbers peaking in December. Most of these fish were <50 mm FL. A smaller pulse of spring-run sized fish occurred in April and May of 1999 and 2000. Fall-run sized Chinook salmon were captured primarily from mid-December through mid-April, with numbers peaking January through March. Most of these fish were <50 mm FL. In all years, small numbers of juvenile fall-run Chinook salmon were captured from late April through June. Combining catch data from three years (1998-2001), the period of January through March accounted for 91% and 97% of the total juvenile Chinook salmon catch at Live Oak and Thermalito, respectively. Chinook salmon measuring 35-38 mm FL dominated length distributions at both RSTs. Of the salmon trapped at Thermalito and Live Oak, 97% and 81% were less than 50 mm FL, respectively. The temporal length-frequency distribution showed little variation within and between RSTs. Also, temporal catch numbers were very similar between RSTs. The percentage of inspected juvenile Chinook salmon that were either smolt or parr/smolt was less than 2% at the Thermalito RST, and 15% at the Live Oak RST. Only 0.2% and 1.3% of the fish caught at Thermalito and Live Oak, respectively, were classified as smolts.

The end of emigration in all three years was similar to that found in previous studies (DWR 1999). Painter et al. (1977) for example, found that in 1968 through 1975, emigration typically occurred only through the end of June. Similarly, Warner (1955) found that, prior to Oroville Dam, emigration ended near the beginning of June. Although it appears that most salmon emigrate past Live Oak by early April, some salmon remain in the river later in the year. Snorkel surveys (Cavallo et al. 2003) have confirmed that thousands of juvenile salmon probably continue to rear in the Feather River throughout the spring, with as many as several thousand juvenile salmon persisting through the summer, mostly in the LFC. Aside from obvious temperature and habitat constraints, It is unknown how flow operations might affect the emigration patterns of summer rearing Chinook.

The combined results of these studies indicate: (1) the majority of juvenile Chinook salmon were sampled shortly after emergence; (2) the greatest percentages of juvenile Chinook salmon were sampled from January through March; (3) few rearing juvenile Chinook salmon are probably present in the lower Feather River year-round, likely in very low numbers; (4) almost all sampled juveniles had not begun the smoltification process (based on morphological characteristics) (DWR 2002b); and (5) most Chinook salmon emigrate past Live Oak by April 1. Minimal variation in the temporal length-frequencies and catch/observation numbers within and between RSTs, and the similarity of results across studies, suggests juvenile Chinook salmon in the lower Feather River primarily emigrate shortly after emergence as fry. These results are similar to those found in other Sacramento River tributaries (Snider et al. 1997, Yoshiyama et al. 1998).

5.2 RIVER FLOW IN THE LOW AND HIGH FLOW CHANNELS OF THE LOWER FEATHER RIVER AND ASSOCIATED EFFECTS TO EMIGRATING JUVENILE SALMONIDS

5.2.2 Central Valley ESU Chinook Salmon

As previously described in section 3.3.1.1**,** daily minimum discharge into the LFC is maintained near 600 cfs or greater year round. Figure 5.2.2-1 (see also 5.2.2-3) illustrates the mean monthly discharge for the LFC since 1975**.** Of particular interest is the change in minimum discharge from approximately 400 cfs to 600 cfs in 1988. Evaluating the generalities of the Oroville complex operations for the past 35 years can be misleading and problematic. However, with respect to salmonid emigration, a few important trends should be mentioned. Since 1988, mean daily flow has been greater than 1,000 cfs only 7% of the time. In other words, the LFC is a constant flow system most (93%) of the time. However, high flow events in the LFC (greater than 10,000 cfs) have occurred in 9 of the last 22 years.

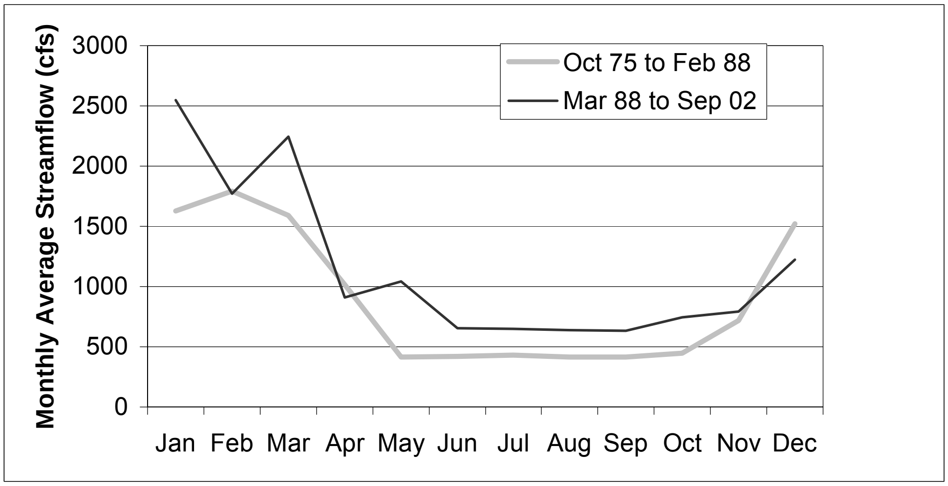

Figure 5.2.2-1. Monthly average streamflow in the LFC, 1975 to 2002 (USGS gauges 11406999 and 11406930).

In the HFC, the flow regime is not stable, but would not be characterized as natural (Figures 5.2.2-2 and 5.2.2-4). The HFC operates under an adjusting flow requirement (see section 3.3.1.1), which normally discourages long-term low flow situations. Additionally, since 1967, the HFC (measured at the Gridley Bridge) has experienced flows greater than 10,000 cfs 67% of the time in a 22 year period. In all but two of those years, the high flows occurred during the winter or spring, a time when juvenile Chinook salmon are present in the system.

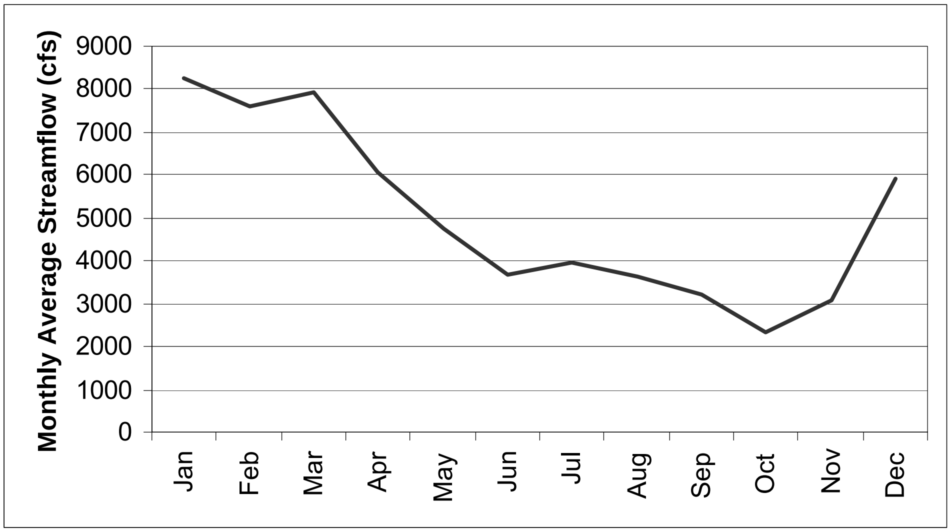

Figure 5.2.2-2. Monthly average streamflow at the Gridley gauge, 1967-2002 (USGS gauge 11407150).

Thermalito rotary screw trap catch data for the period between 1997 and 2003 indicates that Chinook salmon catch varies through time, but is always heaviest January through March (Figures 5.2.2-3). Catch (expanded passge estimate) and flow data for the LFC visually demonstrates the disconnect between flow and emigration. Only two substantial flow pulses have occurred in the last six years in the LFC, demonstrating the perrenial stability of the system. Unfortunately, the pulses (both occurring in 1998) were within one week of each other and no warning was given. Subsequently, the Thermalito screw trap was not positioned to safely capture emigrating salmonids during this period. Therefore, no data was gathered on the effects of this flow pulse on emigrating salmonids. Current and future RST efforts are attempting to gather more information on juvenile Chinook movements during high flow events.

High Flow Channel flow, although highly variable in some years, was generally consistent between 2000 and 2003 (Figure 5.2.2-3). The relationship between river flow and emigration at the Live Oak RST is more uncertain. Regression analysis performed on Chinook catch between 1997-1998 (DWR, 1999), 1998-2001 (Tables 5.2.2-1 and 5.2.2-2; DWR 2002b) and 2000-2003 (Table and 5.2.2-3) illustrates that emigration timing is often poorly explained by environmental variables, especially flow. However, river flow, temperature and turbidity were all, in different years, statistically significant (although weak) predictors of Chinook passage.

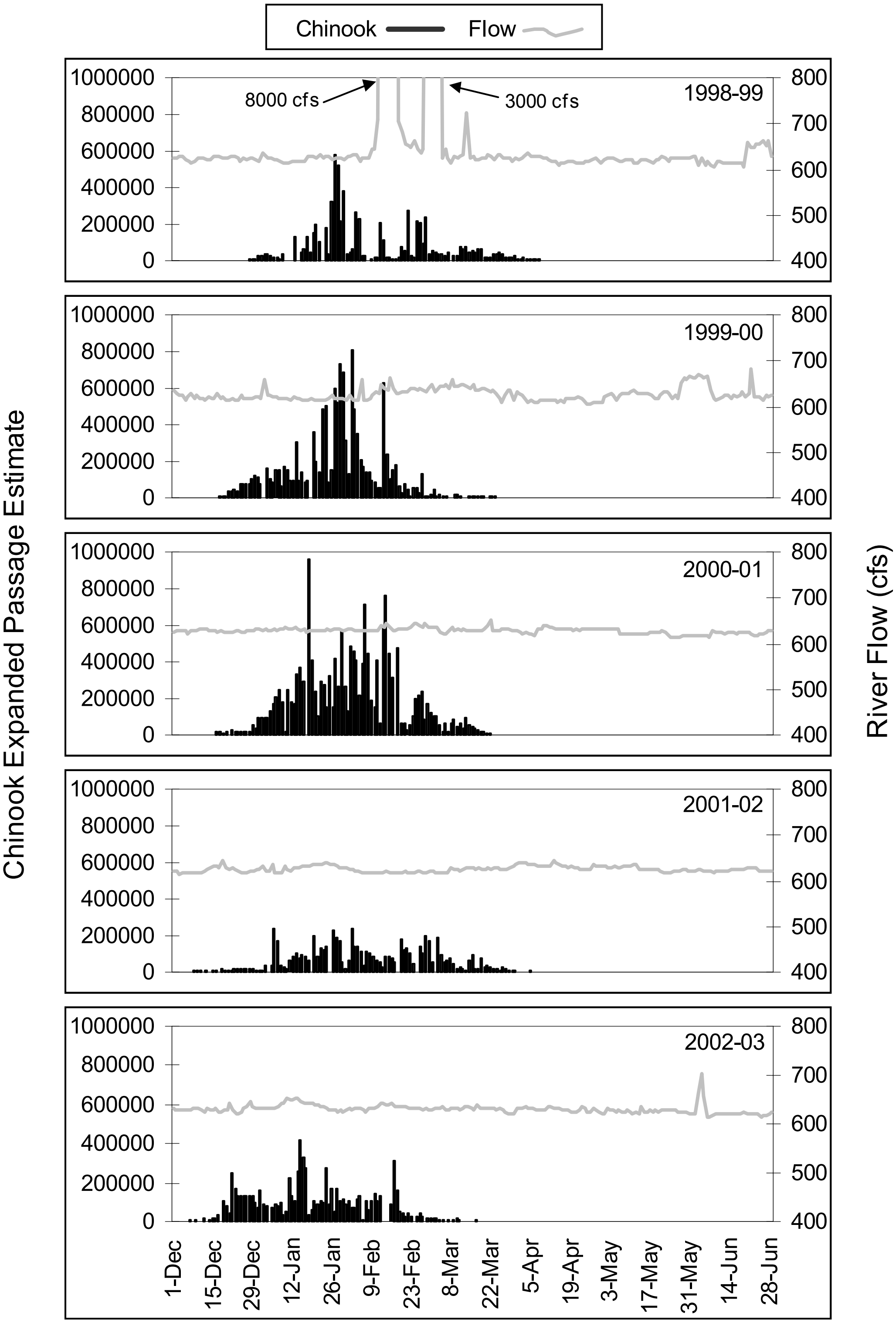

Figure 5.2.2-3. Thermalito rotary screw trap expanded catch and daily river flow, 1998- 2003.

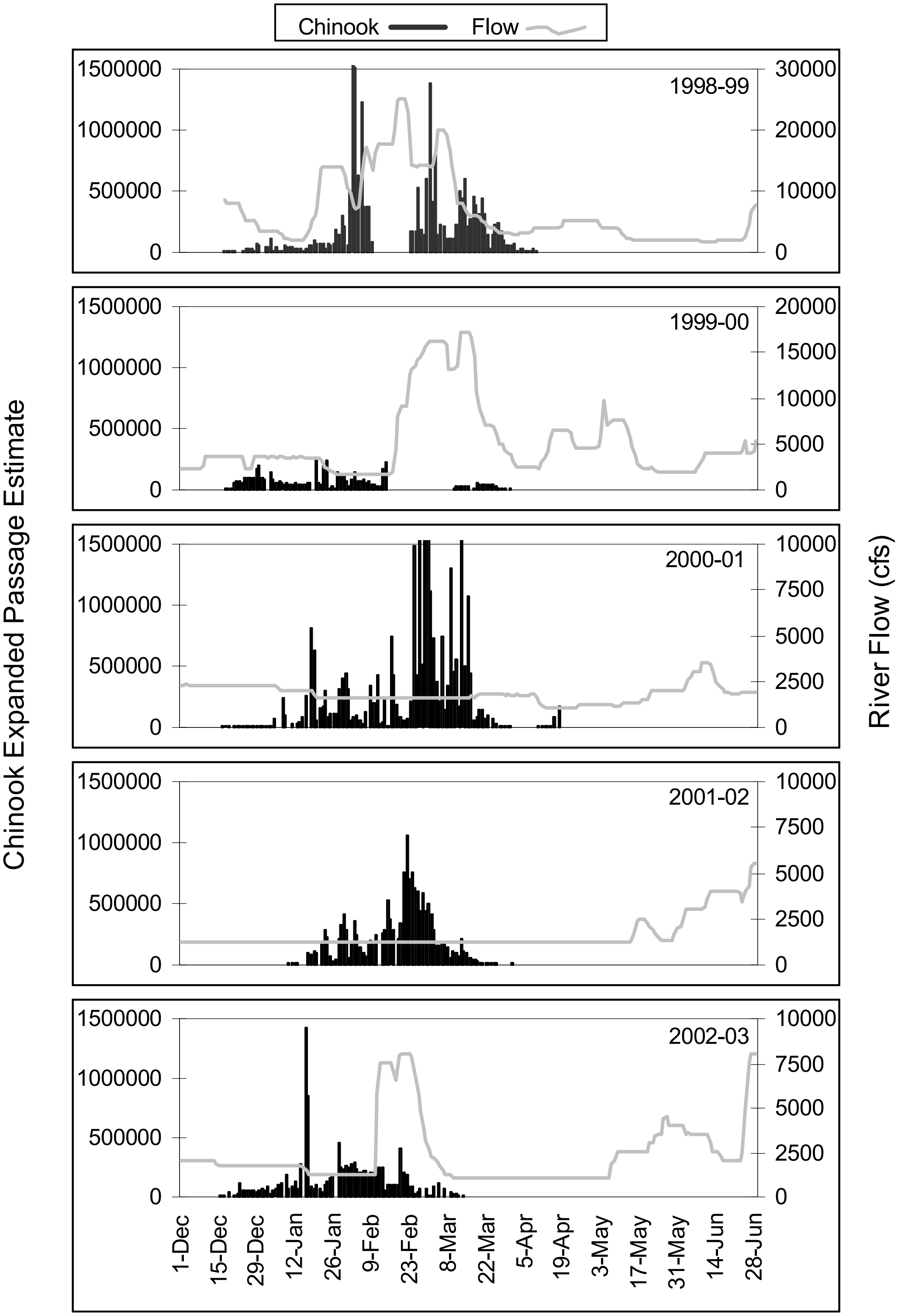

Figure 5.2.2-4. Live Oak rotary screw trap expanded catch and daily river flow, 1998-2003

Table 5.2.2-1. Results from 1998-1999 regression analysis of Chinook catch per unit effort.

Thermalito RST 1998-1999

Effect	Coefficient	Std. Error	t	P
Flow	0.003	0.014	0.036	0.851
Temperature	-7.134	21.959	1.257	0.280
Secchi	10.895	6.363	0.246	0.627

Adjusted R^2 = 0.000

Live Oak RST 1998-1999

Effect	Coefficient	Std. Error	t	P
Flow	0.023	0.019	1.556	0.234
Temperature	3.629	18.907	0.037	0.851
Secchi	55.893	164.422	0.116	0.739

Adjusted R^2 = 0.000

Table 5.2.2-2. Results from 1999-2001 regression analysis of Chinook catch per unit effort.

Thermalito RST 1999-2001

Effect	Coefficient	Std. Error	t	P
Flow	-1.619	2.684	-0.600	0.550
Temperature	-24.103	11.025	-2.190	0.036
Secchi	11.454	23.947	0.480	0.635
All Spawn	0.024	0.004	5.350	0.000

Adjusted R^2 = 0.674

Live Oak RST 1999-2001

Effect	Coefficient	Std. Error	t	P
Flow	-0.005	0.005	-0.910	0.371
Temperature	-6.607	3.441	-1.760	0.087
Secchi	-69.141	24.174	-2.860	0.007
All Spawn	0.001	0.003	0.520	0.606

Adjusted R^2 = 0.488

Table 5.2.2-3. Results from 2000-2003 regression analysis of Chinook catch per unit effort.

Thermalito Expanded Chinook Passage 2000-2003

Effect	Coefficient	Std. Error	t	P
Flow	12.524	120.852	0.104	0.921
Temperature	-567.172	177.581	-3.194	0.024
Spent Females	1.554	0.362	4.288	0.008
				Adjusted R^2 = 0.952

Flow, temperature and female spawn timing collectively accounted for 95% of the variation in catch at the Thermalito RST between 2000 and 2003 (Table 5.4.2-3). However, flow was not found to be a statistically significant variable (p = 0.921). A similar analysis performed for the 1998-1999 and 1999-2001 screw trap catch at both Thermalito and Live Oak provided similar results (Tables 5.4.2-1 and 5.4.2-2). Similar to all years except 1997-1998, regression analysis failed to show a significant flow effect for either Thermalito or Live Oak. In 1997-1998 there was a positive relationship between river flow and emigration in the HFC (DWR 1999 r = 0.6, p<.05). However, discharge from Honcut Creek could have skewed the interpretation of these results since unregulated flows form Honcut Creek could not be accounted for in the1999 flow analysis. Additionally, in the 1999-2001 analysis, secchi depth proved to be statistically significant at Live Oak (negatively correlated). Because secchi depth (water clarity) is often related to variations in discharge (correlated), its significance must be carefully evaluated. It is possible that local surface or unregulated (ungauged) tributary runoff that can significantly affect water clarity without significantly affecting flow may be an important factor for salmonid emigration.

6.0 DISCUSSION

6.1 FLOW EFFECTS ON EMIGRATING SALMONIDS

The amount of research that has focused on the effects of environmental variables on salmonid emigration behavior is extensive. Many variables, such as river flow, temperature, precipitation, turbidity, photoperiod, smolt density, moon phase, age and food resources have been thought to stimulate emigration behavior in salmonids (Gaines and Martin 2001, Painter 1977, Taylor 1990, Unwin 1986, Jager 1997). A few variables, such as temperature and river flow, are thought to directly affect survival and are often key targets for restoration activities (Jensen and Johnsen 1999). Many recent restoration projects, some in California, detail timing and magnitude of peak and base flows as the primary restoration objective. Poff et al. (1997) consider stream-flow a “master variable” that limits the distribution and abundance of riverine species. More specifically, high flows can provide the following beneficial results, including, but not limited to; removal and transportation of sediments, importation of woody debris, connectivity to floodplain resources, excavation of soils for riparian plant germination and environmental cues for life-cycle transition of river fishes (emigration, immigration, spawning, etc.). Furthermore, flow timing can have significant impacts on entire food webs. Shifting scouring flows from winter to summer increased the relative abundance of predator-resistant invertebrates on the Eel River, CA (Wooten et al. 1996).

Many researchers agree that high spring flows are likely to increase the survival of emigrants to the estuary (Jager and Rose 2003, Moyle and Yoshiyama 1997). The primary reasons often given for increased survival from high flows include reduced temperature related mortality and reduced predation (Jager and Rose, 2003). Furthermore, the mechanisms by which higher spring flows are thought to increase survival are well defined. First, high spring flows provide the indirect benefit of slowing the rise in water temperature during late spring and summer. Clearly, elevated water temperature can have both chronic and acute effects on salmonid survival. Second, high spring flows may reduce predation in several ways, including 1) increasing turbidity, 2) floodplain access to cover and food, 3) the tendency for salmonids to school or form large aggregations, and 4) shortening the duration of exposure to predation risk in the river. If high spring flows can create all of the aforementioned conditions, some increase in survival to the estuary will almost certainly be realized. Sommer et al. (2001) reported that juvenile Chinook salmon grew faster on a large Central Valley floodplain (Yolo Bypass) than in the adjacent river channel, a likely result of increased invertebrate prey base and consumption. However, if spring flows are not high enough to significantly increase turbidity or inundate floodplains and occur after the peak of emigration, the increase in survival to the estuary may be minimal or potentially reduced. For example, increasing river flow to a level that greatly speeds emigration without providing the expected benefits gained from increased cover, schooling or food resources simply accelerates the transition from a predatory environment to a highly predatory one. Furthermore, hastening the emigration process provides less time for juveniles to grow and undergo smoltification, making them even easier targets for predatory delta fishes. Jensen and Johnsen (1999) found that there was a significant negative correlation between spring peak flows and year class strength of Atlantic salmon in Norway. Juvenile salmon subjected to high flows immediately after emergence were less capable of handling the physical demands of a high flow environment. It is critical that high or increased spring flows target not only the species of interest but the river morphology as well. Any flow regime that ignores the physical process necessary to drive the biological progression is not likely to achieve the desired outcome of increased juvenile survival.

Unfortunately, the current level of understanding with regard to specific variables that drive Chinook emigration in most Central Valley rivers is minimal. As in most other systems, high winter and spring flows (and the associated benefits) are often discussed as important for salmonid emigration. However, little is known about the necessary level and duration of flow events. Moyle and Yoshiyama (1997) suggest that the highest survival of Chinook salmon in the San Joaquin River occurs when naturally high flow events coincide with smolt emigration. Cramer (1997) showed that experimental pulse flows in the Stanislaus River stimulated out-migrants in the short term (2 days), but little additional benefit was realized from prolonged high flows. Demko et al. (1998) further concluded that smolt size Chinook will emigrate the Stanislaus River in the spring, even in the absence of flow increases. A similar pattern of emigration is observed on the Feather River. Without flow variation, Chinook consistently emigrate the Feather River (past Live Oak) between January and March each year (DWR 2002b, DWR 1998, DWR unpublished data). This pattern may imply a more inherent source driving emigration behavior, perhaps the ultimate expression of the ocean-type life-history of fall-run Chinook in the Central and San Jaoquin Valleys.

The early downstream migration of juvenile salmon in the lower Feather River is consistent with findings from other Central Valley and San Joaquin rivers. In the American River, for example, it is reported that most juvenile salmon leave by mid-May (Snider and Titus 1995, Williams 2001). On the Sacramento River below Red Bluff, Gaines and Martin (2001) report that most fall-run chinook pass their screw traps between January and March. Demko (1998) reports that Chinook passage peaked in January and February on the Stanislaus. This ocean-type life history pattern is seen in other systems as well. Healey (1991) reported that a large downstream movement of chinook salmon fry immediately after emergence is typical of many populations. He further reported that, “the downstream migration of stream- and ocean-type chinook fry, when spawning grounds are well upstream, is probably a dispersal mechanism that helps distribute fry among the suitable rearing habitats.”

There are a number of possible explanations for the early emigration of juvenile Chinook salmon in the Central Valley. Warmer water temperatures experienced during the incubation and rearing period is an explanation given by some authors (Connor et al. 2002; Williams 2001). Salmon might emigrate early to avoid high temperatures on the Sacramento Valley floor in the spring and summer (see SP F-10, Task 4B). Warmer waters experienced in the Central Valley (as opposed to the foothills) might cause fry to develop and emerge a week to a month earlier, perhaps sooner than the river food-web is capable of supporting them. Historically, salmon may have emerged a month later and exploited more abundant resources created by slightly warmer spring and summer temperatures. Fyke traps operated on the American River in 1945-1947 suggest that chinook salmon now emigrate earlier in the year (Snider and Titus 1995). However, Painter et al. (1977), sampling between 1968 and 1973 on the Feather River found emigration patterns very similar to those observed in current studies. The early downstream migration of juvenile salmon rearing below Central Valley terminal dams may reflect an adaptation to local conditions or simply a lack of quality habitat. Grant et al. (1998) suggest that territory (in terms of spatial requirements for a population) is more critical than food supply. They further suggest that doubling the productivity of a stream (i.e. food resources) would increase fish abundace 1.32 times, whereas doubling juvenile habitat would presumably double juvenile abundance. Preliminary analysis of Feather River invertebrates and stomach contents of juvenile salmon suggests that food supply in the winter and early spring may be limiting for certain juvenile life-stages (Esteban 2002). It is possible that large spawning populations (relative to currently available habitat) may be subject to intense competition for food, such that density-dependent downstream dispersal occurs en masse. Unwin (1986), for example, found that the bulk migration of chinook salmon fry in Glenariffe stream, New Zealand, was most likely a result of competition for rearing habitat. He also reports that fluctuations in Chinook catch was not obviously related to environmental variables.

Environmental cues for emigration, including flow and temperature, may be more important for salmon rearing in the river for an extended period (into summer). Chinook remaining in the river for several months grow larger and may have an advantage during emigration. They may be more adept at avoiding predators, finding food and may be more physically prepared to smolt. Flain (in Unwin 1986) reported that chinook juveniles that reared in fresh water for several months to a year comprised 76% of the adult angler catch in the Rakaia River, although they comprised only 5% of the juvenile population. It is possible that a similar pattern of prolonged stream residence is more successful on the Feather River and other Central Valley streams where summer environmental conditions are suitable. Chemical analysis of otolith microstructure (Weber 2002) from spawning adult chinook salmon (currently being collected in the Feather River) may eventually provide some answers to this question.

Long term RST sampling is providing valuable information with regard to the effects of environmental variables and emigration. However, the lack of consistent data gathered at higher flows precludes analysis of emigration patterns during important hydrologic events. It is clear, however, that in the absence of flow variation, Feather River Chinook salmon quickly emigrate the LFC and subsequently past Live Oak. It is certain that water clarity, temperature and flow can all contribute to the observed emigration patterns. Additionally, food availability, lunar phase, rainfall and competition for space could also be key variables in certain years. What is uncertain, however, is the importance of each variable to successful emigration and subsequent adult recruitment. In any given year, water clarity, flow, temperature or food availability could be the major impetus for emigration. Furthermore, in the absence of observable changes in flow, Chinook will still quickly emigrate past Live Oak, clearly demonstrated by the RST catch data.

It is difficult to determine the emigration time frame of juvenile steelhead in the lower Feather River based on a review of seining, rotary screw trap, and snorkeling data. Juvenile steelhead have been reported to rear in natal streams and rivers for up to three years before emigrating out to sea (Boydstun 1977; McEwan and Jackson 1996; Moyle 2002). It seems reasonable to suspect that if juvenile steelhead emigrated downstream at a life stage most susceptible to capture (evidenced by Thermalito RST data), that more individuals would have been sampled at downstream sites, particularly at the Live Oak RST. One potential scenario is that between the Thermalito RST and the Live Oak RST, steelhead rear and grow to a size allowing them to avoid capture at the RST. It is very possible the large numbers of steelhead fry sampled from February through March at the Thermalito RST may simply reflect peak emergence dates, and not substantial downstream movements. If this is the case, it is possible many emigrating juvenile steelhead are of a larger size, thus the difficulty of capturing them at either RST. The lack of data for larger individuals makes it very difficult to define the emigration timing of juvenile steelhead. A review of pertinent literature, combined with empirical studies conducted by DWR, suggests juvenile steelhead probably rear year-round, primarily in the LFC, and that emigration is probably a gradual process occurring during most months of the year. It seems most appropriate to combine results from the recent DWR studies with what is known of the life history of juvenile steelhead in other river systems to use as a basis to delineate emigration timing of juvenile steelhead in the lower Feather River.

7.0 CONCLUSIONS

One of the goals for most RST sampling programs, which are now common throughout Central Valley rivers, is to determine environmental factors which cue downstream migration of juvenile chinook salmon. Seasonal high-flow events are often thought to be particularly important in cueing and aiding downstream migration. However, our RST sampling on the Feather River suggests that cues from flow are not necessary to trigger downstream migration of juvenile salmon. At the Live Oak RST, secchi depth showed the strongest statistical relationship (1999-2001 analysis), even though the model explained only a moderate portion of the overall variation. It is unclear whether decreased water clarity encourages downstream migration or simply lowers trap avoidance for salmon migrating independently of turbidity. In the LFC, the best correlates for emigration timing may be the timing of adult salmon spawning and temperature. Linear regression from the Thermalito RST shows that peaks in emigration correspond very well with peaks in escapement. In general, salmon do not appear to be waiting for an environmental cue to trigger emigration. Feather River Chinook appear to emigrate past Live Oak well before smolting, an indication that significant rearing occurs between Live Oak and the Sacramento-San Joaquin Delta.

DWR (2002b, DWR unpublished data) data indicates that the peak emigration of Chinook fry in the LFC and HFC is consistently between January and March, regardless of flow variation. However, RST sampling in the Feather River is difficult or impossible when discharges approach 15,000 cfs (primarily at Live Oak). Consequently, monitoring Chinook catch and associated environmental variables becomes problematic. Due to the difficulties associated with sampling at higher flows, no data is available (specific to the Feather River) to support or refute the potential of higher flows to affect emigration. However, it is very likely that substantial increases in flow could enhance emigration, providing cover from predators (via increased turbidity and increased submerged vegetation as shelter) and an immediate downstream dispersal mechanism. More subtle influences such as food availability, temperature and adult spawning behavior likely have more influence on emigration patterns than flow, however, both in the LFC and during low flow periods in the HFC. This does not infer, however, that high flow events (greater than 10,000 cfs) are not valuable and preferential to low flow conditions. It simply means that in the absence of flow variation, Chinook salmon continue to emigrate the lower Feather River (past Live Oak). It is critical, however, that high winter or spring flows target not only the species of interest but the river morphology as well. Any flow regime that ignores the physical processes necessary to drive the biological productivity is not likely to achieve the outcome of increased juvenile survival.

With the exception of four seining sites, most data concerning the timing and characteristics of emigrating juvenile Chinook salmon in the lower Feather River have come from sample locations above (upstream) the Live Oak RST. Little information is available regarding juvenile Chinook salmon emigration in the downstream-most 42 miles of the lower Feather River. Therefore, inferences can only be applied to the section of river upstream of Live Oak. The emigration patterns of juvenile Chinook salmon are unknown once they pass downstream of the Live Oak RST.

Because monitoring steelhead movement is so problematic, it is difficult to determine if the flow operations of the Oroville Project has any effect on emigration behavior. Rotary screw trap catch of wild juvenile or yearling steelhead at Thermalito is inconsistent (especially for smolt size steelhead) between years, while catch at Live Oak is extremely low in all years (DWR, 2002b). It is very likely that steelhead grow to a size large enough to avoid capture at the screw traps. Additionally, the varied life history of steelhead makes capture or monitoring emigration at any life stage difficult. Current sampling efforts are unlikely to provide detailed information on the emigration behavior of juvenile or yearling steelhead.

Although no detailed analysis of steelhead emigration patterns is available, certain aspects of project operations are clearly important to the success of wild steelhead in the Feather River. Certainly, high flow pulses followed by quick flow reductions between April and August could cause significant stranding of steelhead in both the LFC and HFC. Additionally, prolonged low flow conditions in either the LFC or HFC are unlikely to benefit steelhead. Moderately increasing and varying flows in both sections of river are likely to provide additional rearing habitat, cover and food resources (assuming stranding issues are addressed). Many of the issues regarding adequate flow conditions are directly related to temperature and are better addressed in Study Plan F-10, Task 4B. Even though specifics about juvenile steelhead emigration patterns are scarce, flow (and correspondingly temperature) patterns that will clearly affect the ability of juvenile steelhead to successfully feed and migrate must be addressed when considering operational scenarios.

8.0 REFERENCES

Beckman, B.R., D.A. Larsen, C. Sharpe, B. Lee-Pawlak, C.B. Schireck, and W.W. Dickoff. 2000. Physiological Status of Naturally Reared Juvenile Spring Chinook Salmon in the Yakima River; Seasonal Dynamics and Changes Associated With Smolting. Transactions of the American Fisheries Society 129; 727-753.

Berggren, T. J. and M. J. Filardo. 1993. An Analysis of Variables Influencing the Migration of Juvenile Salmonids in the Columbia River Basin. North American Journal of Fisheries Management 13:48-63.

Boydstun, L. B. 1977. California's Steelhead Program. 26-30.

Cavallo, B., R. Kurth, J. Kindopp, A. Seesholtz, and M. Perrone. 2003. Distribution and Habitat Use of Steelhead and Other Fishes in the Lower Feather River, 1999-2001. Report # Interim Report SP-F10 Task 3A. Department of Water Resources, Division of Environmental Services.

Code of Federal Regulations. April 1, 2001. Title 18. Section 4.**51.**

Connor, W.P., H.L. Burge, J.R. Yearsley, and T.C. Bjornn. 2003. Influence of Flow and Temperature on Survival of Wild Subyearling Fall Chinook Salmon in the Snake River. North American Journal of Fisheries Mangement 23:362-375.

Cramer, S.P. 1997. Use of Managed Pulses In Flow To Stimulate Outmigration of Juvenile Salmon. Environmental and Coastal Hydraulics. Pages 563-568 *in* S.Y. Wang and T. Carstens, editors. Environmental and coastal hydraulics: protecting the aquatic habitat. Proceedings of theme B, water for a changing global community, 27th Congress of the International Association for Hydraulic Research. American Society of Civil Engineers, New York.

Demko, D.B. and S.P. Cramer. 1998. Evaluation of Juvenile Chinook Migration Characteristics in the Stanislaus River. 1998 Annual Report

DFG. 1998. A Status Review of the Spring-Run Chinook Salmon (*Oncorhynchus Tshawytscha*) in the Sacramento River Drainage.

DWR. 1982. Upper Feather River Instream Flow Study.

DWR. 1983. CDWR & CDFG 1983 Agreement.

DWR. 1999. Feather River Study, Chinook Salmon Emigration Survey, December 1997-June 1998.

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

DWR. January, 2001. Initial Information Package. Relicensing of the Oroville Facilities. Federal Energy Regulatory Commission License Project No. 2100.

DWR. 2002a. Distribution of Fishes in the Lower Feather River in Relation to Season and Temperature, 1997-2001.

DWR. 2002b. Emigration of Juvenile Chinook Salmon in the Feather River, 1998-2001.

Esteban, E.M. 2002. Salmonid Prey Selection: Evaluating a Food Availability Model in Northern California with Young-of-the-Year Chinook Salmon (*Oncorhynchus Tshawytscha*) and Steelhead Trout (*Oncorhynchus mykiss*). Masters Thesis. California State University, Chico.

Flain, M. 1982. Quinatt Salmon Runs 1965-1978 in the Glenariffe Stream, Rakaia River, New Zealand. Fisheries Research Division, New Zealand Ministry of Agriculture and Fisheries, information leaflet no. 8. 17 p.

Gaines, P.D. and C.D. Martin. 2001. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14. U.S. Fish and Wildlife Service, Red Bluff, CA.

Grant, J.W.A., S.O. Steingrimsson, E.R. Keeley, and R.A. Cunjak. 1998. Implications of territory size for the measurement and prediction of salmonid abundance in streams. Can. J. Fish. Aquat. Sci. 55. 181-190.

Greene, S. 1992. Daily Fork-Length Table From Data by Frank Fisher, California Department of Fish and Game. Sacramento: DWR, Environmental Services Department.

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

Hoar, W. S. 1976. Smolt Transformation: Evolution, Behavior, and Physiology. Journal of the Fisheries Research Board of Canada 33:1233-1252.

Hoar, W. S. 1988. The Physiology of Smolting Salmonids. Fish Physiology 11:275-343.

Jager. H.I., H.E Cardwell, M.J. Sale, M.S. Bevelhimer, C.C. Coutant, and W.V. Winkle. Modelling the linkages between flow management and salmon recruitment in rivers. Ecological Modelling 103:171-191.

Jager, H.I and K.A. Rose. 2003. Designing Optimal Flow Patterns for Fall Chinook Salmon in a Central Valley, California, River. North American Journal of Fisheries Management 23:1-21.

Jensen, A.J. and B.O. Johnsen. 1999. The functional relationship between peak spring floods and survival and growth of juvenile Atlantic Salmon (*Salmo salar*) and Brown Trout (*Salmo trutta*). Functional Ecology. 13:778-785.

Kalleberg, H. 1958. Observations in a Stream Tank of Territoriality and Competition in Juvenile Salmon and Trout (Salmo Salar L. and S. Trutta L.). Institute of Freshwater Research, Drottningholm 39:55-98.

Kindopp, J.E. 1999. Intragravel Egg Survival of Fall Run Chinook Salmon in the Lower Feather River, Butte County, California. Masters Thesis. California State University, Chico.

McEwan, D. and T. A. Jackson. 1996. Steelhead Restoration and Management Plan for California. California Department of Fish and Game.

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

Moyle, P.B. and R.M. Yoshiyama. 1997. The Role Of Adaptive Management In Restoring Chinook Salmon To The Tuolumne River. Environmental and Coastal Hydraulics. Pages 557-562 *in* S.Y. Wang and T. Carstens, editors. Environmental and coastal hydraulics: protecting the aquatic habitat. Proceedings of theme B, water for a changing global community, 27th Congress of the International Association for Hydraulic Research. American Society of Civil Engineers, New York.

Murray, C.B. and J.D. McPhail. 1988. Effect of incubation temperature on the development of five species of Pacific salmon (*Oncorhynchus*) embryos and alevins. Can. J. Zool. 66: 266-273.

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

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

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.

Pinder, L. J. and J. G. Eales. 1969. Seasonal Buoyancy Changes in Atlantic Salmon (Salmo Salar) Parr and Smolt. Journal of the Fisheries Research Board of Canada 26:2093-2100.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime: A paradigm for river conservation and restoration. BioScience. 47:769-784.

Saunders, R. L. 1965. Adjustment of Buoyancy in Young Atlantic Salmon and Brook Trout by Changes in Swimbladder Volume. Journal of the Fisheries Research Board of Canada 22:335-352.

Seesholtz, A., B. Cavallo, J. Kindopp, and R. Kurth. 2003. Juvenile Fishes of the Lower Feather River: Distribution, Emigration Patterns, and Association with Environmental Variables. Early Life History of Fishes in the San Francisco Estuary and Watershed: Symposium and Proceedings Volume. in press.

Snider B. and R.G. Titus. 1995. Lower American River Emigration Survey, November 1993-July 1994.

Snider, B., R. G. Titus, and B. A. Payne. 1997. Lower American River Emigration Survey, November 1994- September 1995.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Can. J. Fish. Aquat. Sci. 58:325-333.

Taylor, E.B. 1990. Phenotypic Correlates of Live-History Variation In Juvenile Chinook Salmon, Oncorhynchus Tshawtscha. Journal of Animal Ecology. 59:455-468.

Unwin, M.J. 1986. Stream residence time, size characteristics, and migration patterns of juvenile chinook salmon (*Oncorhynchus tshawytscha*) from a tributary of the Rakaia River, New Zealand. New Zealand Journal of Marine and Freshwater Research. 20:231-252.

Warner, G.H. 1955. Studies on the Downstream Migration of Young Chinook Salmon in the Feather River. California Department of Fish and Game.

Webber, P.K. 2002. Geochemical Markers in the Otoliths of Chinook Salmon in the Sacramento-San Joaquin River System, California. University of California, Berkely.

Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Environmental Factors Affecting Smoltification and Early Marine Survival of Anadromous Salmonids. Marine Fisheries Review 42:1-14.

Williams, J.G. 2001. Chinook Salmon in the Lower American River, California's Largest Urban Stream. Contributions to the Biology of Central Valley Salmonids. California Department of Fish and Game. Fish Bulletin 179, Volume 2.

Wooten, J.T., M.S. Parker, and M.E. Power. 1996. Effects of disturbance on River Food Webbs. Science 273:1558-1561.

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.

Zaugg, W. S. and H. H. Wagner. 1973. Gill ATPase Activity Related to Parr-Smolt Transformation and Migration in Steelhead Trout (Salmo Gairdneri): Influence of Photoperiod and Temperature. Comparative Biochemistry and Physiology 45B:955-965.