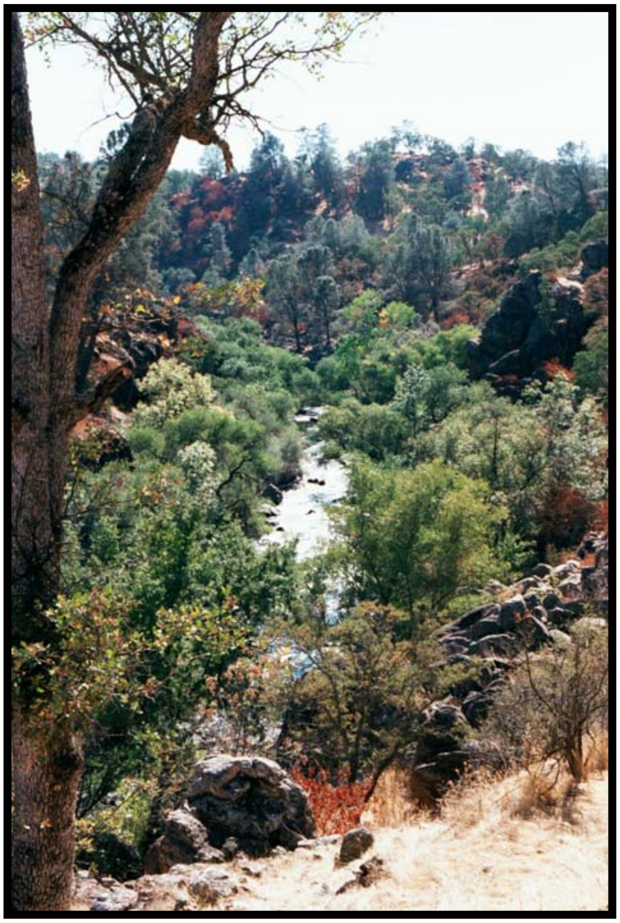

Lower Calaveras River Chinook Salmon and Steelhead Limiting Factors Analysis

First Year Report (Revised)

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1 PREFACE

The "Lower Calaveras River Chinook Salmon and Steelhead Limiting Factors Analysis" was developed as a CALFED proposal by Stillwater Sciences in partnership with the Anadromous Fish Restoration Program (AFRP), the Fishery Foundation of California (FFC), and Stockton East Water District (SEWD) to examine current conditions and fill existing information gaps to determine the potential of the Calaveras River system to support anadromous salmonid populations. The FFC, a local non-profit partner, submitted the proposal to CALFED, and the study was ultimately funded through AFRP.

This study is ongoing and has five primary objectives:

1. Establish stakeholder coordination;
2. Synthesize information on the life history and habitat conditions for anadromous salmonids;
3. Conduct reconnaissance-level field studies of salmonids and their spawning and rearing habitat;
4. Develop population modeling approaches to guide subsequent studies and restoration efforts for salmonids;
5. Identify actions to increase salmon and steelhead abundance.

The study is coordinated with and complements current research efforts by several groups to understand salmonid use of the Calaveras River below New Hogan Dam. These concurrent research efforts include the following:

1. SEWD is completing a second year of rotary screw trap monitoring of juvenile salmonid movements at the lower end of the spawning and rearing reaches of the Calaveras River. SEWD has also conducted temperature monitoring since 2000.
2. California Department of Water Resources (DWR) Fish Passage Improvement Program is scheduled to complete a two-year study of fish passage barriers in 2003. This study will result in recommendations for improving passage at structural barriers and perform general hydrologic analyses to address passage issues below Bellota Weir.
3. SEWD, with its consultant CH2MHill, is conducting a study of flow diversion infrastructure in reaches of the Calaveras River upstream of Bellota Weir.

This report is an intermediate product presenting a synthesis of work conducted in the initial phase of the Lower Calaveras River Chinook Salmon and Steelhead Limiting Factors Analysis and, where appropriate, incorporating information from other studies.

This report consists of the following sections:

1. Existing Information Review: Explains salmonid life history patterns and habitat use in the Calaveras River system based on previous work.
2. Conceptual Models: Develops models to serve as a theoretical framework for the limiting factors synthesis.
3. Focused Studies: Briefly describes field studies, reconnaissance efforts, and analyses in which basic data were gathered to understand factors related to the distribution and relative abundance of salmonids in the system at different points in their life cycle;

characterizes the distribution, quality and abundance of habitat within the system (appendices have been attached as appropriate).

4. Limiting Factors Synthesis: The results of focused studies and existing information review are evaluated in regard to the conceptual models of life history timing and habitat needs for steelhead and Chinook salmon.
5. Quantitative Modeling Approach: Modeling approaches are developed to structure future investigations of the status of fish populations in the system.

Future Studies: This document concludes with a discussion of future studies that will aid in understanding factors limiting anadromous salmonids in the Calaveras River system.

2 EXISTING INFORMATION REVIEW

The Calaveras River, a tributary to the San Joaquin River, is a relatively small, low elevation Central Valley drainage that receives runoff mainly from winter rainfall (CDFG 1993). Flow in the Calaveras River is regulated by New Hogan Dam, located approximately 38 miles upstream from the river's mouth at Stockton. New Hogan Reservoir has a storage capacity of 317,000 acre-feet at gross pool and is operated by the U.S. Army Corps of Engineers for flood control, water supply, and recreation. Rights to releases below New Hogan Dam are contracted for by the Stockton East Water District (SEWD) and the Calaveras County Water District through the Bureau of Reclamation.

The flow regime of the Calaveras River has been fundamentally altered since the 1930's, when regulation of the Calaveras River began, first through Hogan Dam and subsequently through New Hogan Dam. Historically, the river's hydrology was characterized by highly variable flows during winter months and rapid attenuation of flows in the summer. Under current flow management, the variability and magnitude of winter flows is strongly reduced, while the magnitude and consistency of summer flows has increased dramatically. Water supplies stored in New Hogan Reservoir are transferred, via the Calaveras River, to downstream locations as far as the town of Bellota (Figure 1), where SEWD operates a municipal water supply diversion. The effect has been to transform the lower river from a more Mediterranean system, with high intra-year variability, to one that behaves like a typical snowmelt system, with fall and winter precipitation stored and released gradually in the summer months.

Because of seasonal streamflow patterns and elevated stream temperatures it is thought that this river was historically marginal for salmon (Yoshiyama et al. 1996). Prior to flow regulation, Chinook salmon (*Oncorhynchus tshawytscha*) runs were known to have occurred on an "irregular basis" (CDFG 1993), although Clark (1929, as cited in Yoshiyama et al. 1996) reported that the Calaveras River was "dry most of the summer and fall" and so had no salmon. The historical occurrence of salmon in the Calaveras River may have been limited to exceptionally wet years (Yoshiyama et al. 1996). However, anecdotal evidence collected by Glenda Marsh (environmental scientist, CDWR, personal communication) suggests that salmon runs were observed in most decades during the last century.

While little is known of the historical anadromous runs in the Calaveras River, currently fall Chinook salmon and steelhead (*Oncorhynchus mykiss*) enter the Calaveras River when suitable fall streamflows occur. The Calaveras River also supports a popular resident rainbow trout fishery. In 1998, the Central Valley steelhead Evolutionarily Significant Unit (ESU) was listed as "threatened" under the federal Endangered Species Act (ESA) by NOAA Fisheries (NMFS 1998). In June 2000, critical habitat was designated for Central Valley steelhead that included Calaveras River; however, this designation was later rescinded and critical habitat designation for Central Valley steelhead is currently under review (NMFS 2003).

In recent decades the Calaveras River also supported an unusual winter Chinook salmon run which spawned in late-winter and spring, but it is unknown if that run existed before the dams were built on the river (Yoshiyama et al. 1996). This run, numbering from 100 to 1,000 fish annually, was documented for 7 years in the period between 1972 and 1984 (CDFG 1993) but was extirpated during the drought of 1988-1992, when summer instream flows were not sustained and the fish community shifted to a warm-water assemblage (USFWS 1993).

There is no evidence that winter run Chinook salmon naturally occurred in the San Joaquin basin prior to the development of hydroelectric and irrigation projects, and Yoshiyama et al. (1996) suggest that the existence of salmon in the Calaveras River during recent decades has been mainly the result of suitable conditions created by the dams. Hypolimnetic releases from New Hogan Dam and increased summer flows have probably reduced temperatures in the Calaveras River from historical levels. While bottom-draw dams are generally reliable sources of cool flow, due to the thermal stratification that occurs in a deep body of water, there are conditions under which the temperature of water released from New Hogan Dam may actually be quite high. Due to the fact that New Hogan Dam is only a short distance downstream of the old dam, there is a problem with an overdeveloped epilimnion between the two structures that results in occasional warm water releases into the system (USFWS 1993). However, during most years a large amount of cool tail-water habitat is potentially available for spawning and rearing Chinook salmon and steelhead in the reaches from New Hogan Dam approximately 15 mi (24 km) downstream to the diversion facilities at Bellota.

Currently, adult Chinook salmon and steelhead have two potential migration routes to access the Calaveras River upstream of Bellota Weir: 1) the Old Calaveras River channel downstream of the town of Bellota, and 2) Mormon Slough via the Stockton Diverting Canal (Figure 1). The majority of Chinook salmon and steelhead migrate through the Stockton Diverting Canal and Mormon Slough to access the mainstem Calaveras River, because this route typically receives higher flows than the Old Calaveras River channel. However, in many years, the timing and magnitude of stream flows below Bellota Weir are not sufficient to allow adult Chinook salmon and steelhead to migrate upstream into the high quality spawning and rearing habitat between Bellota and New Hogan Dam (USFWS 1993). Additionally, numerous in-channel structures, natural hydraulic barriers, and dry reaches along these migration routes create partial or complete migration barriers to Chinook salmon and steelhead. For example, several hundred fall Chinook salmon were observed during the fall of 1995 at Bellota Dam, where they were temporarily blocked (CDFG unpublished data, as cited in Yoshiyama et al. 1996).

3 CONCEPTUAL MODELS

Anadromous salmonids spend a considerable portion of their life cycle in fresh water; this period includes what are generally considered to be the vulnerable early life stages. During this time they are subject to a variety of physical and biological factors that may cause direct or indirect mortality, thereby limiting the size and health of the population. Because environmental requirements vary for each salmonid life stage, different factors are important during different life stages.

Life histories of anadromous salmonids can be categorized broadly as "ocean" or "stream" type strategies according to the relative proportion of their life cycle spent in marine or freshwater habitats (Healey 1991). Since European colonization, human activity in the western United States has generally altered freshwater systems in ways that favor ocean type over stream type life histories. Activities such as dam construction and other flow diversions tend to capture snowmelt runoff or block access to canyons with deep bedrock pools that provide thermal refuges to over-summering anadromous fish. The Calaveras River is unusual among Central Valley tributaries because the lowest large dam (New Hogan Dam) was built above significant canyon habitat, leaving large numbers of deep pools potentially available to over-summering fish.

The species of anadromous salmonids addressed in this report are steelhead and Chinook salmon. Chinook salmon are further divided into fall and spring runs, with the different habitat requirements of each run analyzed accordingly. We hypothesize that the habitat conditions in the Calaveras River are potentially sufficient to support self-sustaining populations of each of these three runs of anadromous fish.

Chinook salmon and steelhead differ in the timing and duration of specific life stages. These species also have different physiological tolerances and may differ in their use of space and food resources. In addition, life history variation within each species may result in spatial and temporal variation in habitat needs. However, despite these differences, these two species overlap considerably in time and space and therefore experience similar environmental conditions during portions of their freshwater life histories.

Limited specific historical information exists on the use of the Calaveras River by anadromous salmonids. However, based on what is known about the life history patterns of anadromous fish in the San Joaquin River and its major tributaries it is possible to develop detailed conceptual models of potential anadromous fish use of the Calaveras River. An appendix to this report provides detailed summaries on the use of the San Joaquin basin by Chinook salmon and steelhead (Appendix A). Sections 3.1, 3.2, and 3.3 describe conceptual models for freshwater stages of the salmonids considered in this synthesis.

3.1 Steelhead

Steelhead have an extremely plastic life history. Available information on Central Valley steelhead life histories suggests that adult immigration to freshwater begins in August, with a peak in migration activity typically occurring in September and October (Moyle 2002). Spawning occurs in the winter or spring, with surviving adults (sometimes known as "kelts") returning to the ocean from mid-April to mid-July. After a brief incubation period of approximately 30 days (depending on temperature), fry emerge in late spring and early summer and rear in the system for up to several years before emigrating to marine habitats as smolts. Smolt emigration may occur in any month of the year, but generally peaks during spring and, to a lesser extent, fall when flows were historically higher and water temperatures cooler, making conditions conducive to passage. In some cases, either due to genetic factors or a lack of conditions suitable for emigration, steelhead have been know to “residualize” in freshwater and mature without rearing in a marine environment (Zimmerman and Reeves 2000, Moyle 2002). Fish maturing in fresh water are commonly known as “rainbow trout.” The general life cycle of steelhead and rainbow trout is illustrated in Figure 2.

3.2 Fall Chinook Salmon

Fall Chinook salmon spend a smaller portion of their life cycle in freshwater relative to steelhead and spring Chinook salmon. Adult salmon ascend streams between mid-September and mid-December, establish territories, and spawn in suitable habitat soon after they arrive. Fry emerge from redds within 1 to 3 months of spawning, typically between December and February, depending on incubation temperature. Freshwater rearing typically lasts 1-5 months before juveniles begin to smolt and migrate to the ocean in April and May. In some cases, either due to late emergence or lack of passage in their first spring, juveniles will smolt the following fall or spring, when passage becomes possible. The general life cycle of Chinook salmon is illustrated in Figure 3.

3.3 Spring Chinook Salmon

Spring Chinook salmon spend considerably longer periods of time in the freshwater environment than their fall counterparts. Spring Chinook salmon adults typically enter freshwater in spring and early summer, when runoff is high, and seek out deep, cool water refuges to over-summer. Spawning occurs in early fall, with juveniles emerging through the winter and early spring. Juveniles rear in streams for 3-15 months and generally emigrate from freshwater in either the following spring or fall. The general life cycle of Chinook salmon is illustrated in Figure 3.

4 FOCUSED STUDIES

The first phase of the Lower Calaveras River Chinook Salmon and Steelhead Limiting Factors Analysis and the research efforts of other groups involved in the Calaveras River Fish Group have been devoted to a series of studies to understand basic spatial and temporal patterns of habitat availability and use by salmonids in the lower watershed. Habitat use patterns identified from these studies were then considered in combination with information from other systems and compared to the template of existing physical conditions in the Calaveras River to develop specific hypotheses to be tested in direct mechanistic studies during the second phase. For the purpose of some of the focused studies, the Calaveras River below New Hogan Dam was divided into subreaches: 1) New Hogan Reach, from New Hogan Dam downstream to Cosgrove Creek; 2) Canyon Reach, from Cosgrove Creek downstream to Jenny Lind; 3) Jenny Lind Reach, from Jenny Lind downstream to Bellota; 4) Bellota Reach, from Bellota downstream to the mouth of the Calaveras River.

4.1 Reconnaissance Surveys

Reconnaissance surveys were conducted during the winter of 2002 to assess conditions in the Calaveras River below New Hogan Dam. During these surveys, the quantity and quality of rearing habitat and the distribution and amount of spawning habitat (Figure 4) and deep pools (Figure 5) were estimated. In future phase two analyses, data collected on size and distribution of spawning and rearing habitat will be used to parameterize quantitative models to predict the carrying capacity of the system.

The reconnaissance surveys indicate that spawning habitat for Chinook salmon and steelhead is relatively common throughout the New Hogan and Jenny Lind reaches of the Calaveras River. Smaller spawning patches appropriate for steelhead, but too small for Chinook salmon, are common in the upper half of the Canyon reach.

The reconnaissance surveys also revealed the extensive nature of gold dredging activities in the basin and encroachment of the river channel by tailings piles, resulting in the confinement of the river channel. The increased shear stress on the streambed associated with river channel confinement may have resulted in mobilization of smaller spawning gravels and loss of spawning habitat.

There is also extensive evidence of vegetative encroachment within the channel, resulting in frequent occurrence of sites where gravel bars are colonized by vegetation. Vegetative encroachment is usually the result of decreased frequency and magnitude of storm flows common in regulated rivers and results in a net loss of potential spawning habitat.

The Canyon Reach had large, deep pools with high quality juvenile rearing habitat such as abundant summer feeding stations and good structure that also provided refuge for over-wintering juveniles. These pools may also be suitably large and deep enough to provide over-summering habitat for spring Chinook salmon.

4.2 Spawning Surveys

Spawning surveys were conducted from early January through late March 2002 to determine the temporal and spatial distribution of steelhead and resident rainbow trout spawning activity, as well as the size and potential superimposition of redds (Table 1). During this period new redds appeared frequently, with activity diminishing significantly towards the end of March. The area of each new redd was calculated from length and width measurements according to methods described in Keeley and Slaney (1996). The area of new redds varied substantially from approximately 1 to 7 ft^2 (0.09-0.65 m^2) (Figure 6). The Canyon Reach tended to have slightly larger redds then other reaches, although there were no statistical differences (α =.05) in redd size between reaches.

Table 1. Total available spawning habitat, average spawning patch size, and redd abundance in the Calaveras River by stream reach.

Reach	Number of Patches	Total Available Spawning Habitat (ft^2)	Average Spawning Patch Size (ft^2)	Number of Patches with Redds	Number of Redds*
Jenny Lind	43	696	175	14	28
Canyon (lower)	10	47	25	5	5
Canyon (upper)	16	55	26	7	12
New Hogan	17	**	**	9**	45

* Number of redds observed during first survey.
** Size of spawning patches was not recorded in New Hogan reach.

The size of adult female salmonids can be estimated from the size of their redds (Keeley and Slaney 1996). Redd size is related to spawning female length by the following equation:

$\text{Log}_{10}[\text{Redd Area } (m^2)] = 2.12 * \text{Log}_{10}[\text{Fish length (cm)}] - 3.39$

Based on the relationship developed in Keeley and Slaney (1996), redds observed in the Calaveras River were dug by females ranging from 5 to 12.5 in (13-32 cm) long. Median redd sizes of 2-3 ft^2 (0.19-0.28 m^2) correspond to fish lengths of approximately 7-9 in (18-22 cm). These size estimates suggest that most redds observed were constructed by resident rainbow trout, as steelhead redds would generally be expected to be much larger.

4.3 Migration Surveys

Migration surveys were conducted to determine the timing and preferred migration routes of adult and juvenile salmonids and to identify problem areas for fish passage across a range of flow conditions (Appendix B). This work was intended to serve as a general field validation of detailed engineering assessments developed by the California DWR Fish Passage Improvement Program for individual in-channel structures. These surveys also provide baseline information for future assessment of hydraulic barriers associated with channel morphology, such as critical riffles and dry reaches.

Adult salmonids were observed in the Diverting Canal and Mormon Slough. However, due to low numbers of returning adults and the highly sporadic nature of flows in lower parts of the system, it was not possible to determine with certainty the duration or peak of the spawning migration. Additionally, during the survey the only available upstream migration route was through the Diverting Canal and Mormon Slough, since contiguous surface flow was never observed within the Old Calaveras River Channel. Therefore, it is not known whether the Old Calaveras River Channel would represent a preferred route for salmonid migration if sufficient flow was available.

Gill netting and hook and line sampling conducted by the FFC indicates that smolts migrate downstream of Bellota Weir into Mormon Slough and the Old Calaveras River Channel at times when there is not continuous flow all the way to the San Joaquin River. A fish rescue operation in the summer of 2002 in the Old Calaveras Channel showed that fish move into the old channel and remain there despite potentially lethal conditions that occur later in the summer.

4.4 Snorkel Surveys

Snorkel surveys were conducted to determine the seasonal distribution and habitat use of juvenile steelhead and rainbow trout in the Calaveras River system (Appendix C). During snorkel surveys, fish were counted and assigned into length classes on a biweekly basis from mid-March to late-October 2002. Relative abundances of juvenile *O. mykiss* increased from April to October in all reaches sampled. Densities of 100-200 mm and 200-300 mm fish increased from very low numbers in all reaches (i.e., <1 fish/100 m^2) at the beginning of the survey period to much higher levels at the end of the season. End-of-season densities were highest in the Canyon Reach (approximately 9-13 fish/100 m^2), slightly lower in the Hogan Reach (approximately 7-11 fish/100 m^2), and lowest in the Jenny Lind Reach (approximately 2-4 fish/100 m^2). A similar pattern existed for juveniles <100 mm, and no pattern was evident for the largest size class of trout (>300 mm).

This pattern of gradual increase in the number of fish in larger size classes may reflect either growth of small fish and recruitment into larger size classes, or migration of larger fish into the areas where sampling was conducted. It is possible that the pattern observed may be the result of both processes acting concurrently.

Numbers of fish observed in the snorkel survey were consistently higher in the Canyon Reach compared with the Hogan and Jenny Lind reaches. This result is consistent with observations made during the reconnaissance survey of abundant, high quality rearing habitat in the Canyon Reach. A more detailed summary of snorkel survey findings is provided in Section 5: Limiting Factors Synthesis (a complete description of methods and results from the snorkel surveys is provided in Appendix C).

4.5 Permeability sampling

Gravel permeability studies were conducted in the Hogan and Jenny Lind reaches to determine the quality of spawning habitat. Because Chinook salmon may only rear for a short time in freshwater, we hypothesize that gravel quality is more likely to limit Chinook salmon than steelhead, which may be more limited by availability of rearing habitat. Therefore, we assessed gravel permeability in lower gradient reaches of the Calaveras River system that contain large riffles with gravel sizes that are typically favored by spawning Chinook salmon. Four riffles were sampled per reach. Across the top third of each riffle, three permeability sites were selected. Gravels were prepared by excavating and re-filling a hole to a depth of one foot. This preparation was made to winnow fines from the substrate and roughly approximate the effects of redd construction by a salmon. Gravel permeability was then measured according the protocol described by Barnard and McBain (1994).

Egg-to-fry survival rates were predicted from the permeability measurements using relationships determined for salmonids in experimental studies (McCuddin 1977; Tagart 1976) (Figure 7). Based on this analysis, the average predicted egg-to-fry survival rate was 31% for the two reaches studied. Survival rates in the area between Jenny Lind Bridge and Shelton Road (33%) were higher than those predicted for the area between Hogan Dam and the Canyon (29%), but this difference was not statistically significant (student's t-test, P=0.62).

4.6 Temperature Studies

Digital thermographs were deployed throughout the Calaveras River from spring 2002 through winter 2003 to develop a basic understanding of temperature patterns in the system and determine whether these patterns are consistent with the life history needs of steelhead and Chinook salmon.

During this study, temperatures between New Hogan Dam and the Bellota Weir remained well within the limits of acceptable conditions for Chinook salmon and steelhead (< 65° F). Detailed results from this study are included in Appendix D. These results agree with temperature monitoring studies conducted by S.P. Cramer on behalf of SEWD (see Section 4.8.2).

4.7 Hydrology

To determine how current flow operations of New Hogan Dam might interact with salmon life history needs in the Calaveras River, hydrologic data were obtained for 1964 through 2002 and plotted by individual water year to allow visual assessment of flow patterns and consideration of how these patterns could be expected to influence the ability of Chinook salmon and steelhead to use the system.

To define typical flow patterns, all water years between 1964 and 2002 were ranked according to total annual runoff. The median water year and the water years ranked immediately above and below the median were taken to represent normal flow patterns; the years selected in this manner were 1970, 1999 and 2000 (Figure 8).

The hydrographs for these water years indicate a consistent seasonal pattern in which the lowest flows occur during the fall months until storms and flood control releases result in distinct peak flows through the winter rainy season. Between peaks, winter base flow levels remain slightly higher than fall flows. Beginning in the spring, water supply releases from New Hogan Dam bring flows to a base level that is markedly higher than fall flows or flows between winter storm/flood-control peaks and these flows continue until fall, when flows return to low levels at the end of the irrigation season. Although the Calaveras River did not historically experience a snowmelt hydrograph, due the low elevation of the basin, current flow management practices have resulted in a prolonged elevated runoff period during the summer months that is similar to the hydrograph of snowmelt-dominated streams.

Because many of the structures and dry reaches that create passage problems are located downstream of Bellota Weir in Mormon Slough, and because much of the flow released at New Hogan Dam during periods outside the irrigation season is diverted into a municipal water supply system at Bellota, we evaluated the hydrographic patterns for the flow gage located below Bellota Weir. While this gage has only operated from 1997 to present, this period encompasses two of the water years (i.e., WY1999 and WY2000) identified in the previous analysis as “normal” water years since 1964 when New Hogan Dam began operation. The plots of the hydrographs for these years indicate that the pattern of flows entering Mormon Slough (Figure 9) roughly mirror those indicated by the gage at New Hogan Dam (Figure 8). However, during heavy winter storms contributions of runoff from the basin downstream of the dam may alter the hydrograph at Mormon Slough.

Following the end of the irrigation season, low fall flows below Bellota Weir, which frequently are set to zero by SEWD, limit upstream migration of adult salmonids through Mormon Slough (see Appendix B). However, information on the specific relationship between flows and the ability of fish to pass Mormon Slough needs to be established more formally through the ongoing assessment of structures by the Fish Passage Improvement Program and a future assessment of hydrologic and hydraulic constraints on passage in the Old Calaveras River and Mormon Slough.

California Department of Water Resources water year classifications for the San Joaquin Basin were reviewed to determine seasonal flow patterns in select water years classified as "wet" and "critically dry." The hydrograph selected for a "wet" year (WY 1983) showed that fall flows are interrupted earlier by storm peaks and flood control releases, while summer flows are roughly the same as during normal years (Figure 10). During a "critically dry" year (such as WY 1989), flows are dramatically lower than normal throughout the year, storm-related peaks are small, and summer base-flow is significantly lower than normal, punctuated by intermittent pulses of approximately normal flow (Figure 10).

4.8 Studies Being Conducted by Stockton East Water District

The Stockton East Water District (with the assistance of S.P. Cramer and Associates) has conducted a number of studies related to salmonid use of the Calaveras River. Rotary screw trap monitoring of smolt outmigration conducted in the spring of 2002 and 2003 and the continuous temperature monitoring conducted from 2001 to the present have provided information that is useful in this limiting factors synthesis.

4.8.1 SEWD Rotary Screw Trapping

The results of the rotary screw trap monitoring provide a valuable general indication of timing of juvenile and smolt movements in the system and an indication of size and general condition of fish captured. However, estimates of the number of fish emigrating are not possible at this time because the efficiency of the trap has not yet been determined for its current location and configuration.

To date, SEWD's monitoring efforts have captured large numbers of steelhead fry and smolts between January and May of 2002 and 2003 (S. P. Cramer, unpublished data). The size distribution of fish captured in 2002 was bi-modal, with a group of large fish clustered around 200 mm and another group of markedly smaller fish clustered around 50 mm. Our interpretation of these data is that they represent two age groups of *O. mykiss*, with the larger fish most likely being smolts or juveniles preparing to smolt and the smaller fish being young-of-the-year redistributing within the system.

Initial scale analysis performed by S.P. Cramer (A. Fuller, personal communication, 29 July 2003) indicates that average fork lengths of age 2+ fish and 3+ fish are 201 mm and 232 mm, respectively. These provisional data suggest a positive growth increment of only 15% between the second and third years of rearing in the system, which may indicate bioenergetic limitations of the Calaveras River to produce larger *O. mykiss*. However, these data are potentially biased because they only include fish exhibiting a tendency to leave the Calaveras River. These data could be corroborated by sampling fish using less biased methods in other locations within the river.

4.8.2 SEWD Temperature Monitoring

Temperature monitoring was conducted by SEWD from spring through winter of 2000 to 2003 at seven sites extending from New Hogan Dam to Mormon Slough near the offices of SEWD. This monitoring indicates that, while temperatures increase continually with distance downstream from New Hogan Dam, temperatures observed upstream of Bellota Weir would not have been high enough to result in acute stress on salmonids. However, immediately below Bellota Weir temperatures in Mormon Slough exceeded stressful levels beginning in late spring and remain at potentially lethal levels (i.e., >70°F [>21°C]) until fall (S. P. Cramer, unpublished data).

5 LIMITING FACTORS SYNTHESIS

In conducting the limiting factors synthesis for this study we attempted to: (1) systematically review the life history requirements of each analysis species, (2) identify the full range of factors that might be operating to limit these populations in the Calaveras River, (3) screen these potential limiting factors using available information and reconnaissance observations to develop hypotheses about those factors thought to be of greatest importance in the watershed, and then (4) refine these hypotheses in view of the focused studies described above. Because of limitations in our understanding of current conditions and how limiting factors have operated in the watershed, there are various degrees of uncertainty associated with our identification and ranking of key limiting factors for both steelhead and Chinook salmon. Future studies, including a more quantitative population modeling approach exploring the relative importance of potential limiting factors, have been proposed to address what we feel are the most important uncertainties related to restoration and management of anadromous fish in the Calaveras River (see Section 8).

5.1 Identification and Screening of Potential Limiting Factors and Initial Hypotheses

In this section, we describe the range of potential limiting factors known to affect populations of steelhead and Chinook salmon. We then briefly discuss how existing information and reconnaissance survey results were used to develop hypotheses specific to the Calaveras River from the initial list of potential limiting factors and to prioritize focused studies testing those hypotheses.

Generally speaking, a wide range of factors may limit the size and growth potential of a population of organisms. While each of these factors may serve as the primary limiting factor under specific circumstances, our goal was to identify the factor or factors that appeared to be limiting salmonid populations under current conditions in the Calaveras River and its tributaries. The primary aim of this initial analysis was to use knowledge of various potential limiting factors combined with focused studies to identify key data gaps and uncertainties that need to be addressed in future studies. Additional analysis will more fully examine cause-and-effect relationships between management activities and their effects on the analysis species. This will yield a more quantitative understanding of the expected benefits of potential restoration and management strategies and actions that are available to promote self-sustaining populations of salmonids in the Calaveras River.

This study has focused on the freshwater phase of the salmonid life cycle. Factors affecting the amount and quality of available estuary rearing habitat may be important, and ocean harvest and others factors affecting growth and survival of salmon during the ocean phase of their life cycle may also be important limiting factors. However, these factors are beyond the scope of this study.

While performing the initial phase of this limiting factors analysis, we found it most useful to organize the analysis of potential limiting factors by life stages. The following section is organized based on life stages of salmonids described in Section 3. The results of focused studies and the review of existing information conducted to date are synthesized and analyzed for their implications on the potential for the lower Calaveras River to support the particular life stages of salmonids.

5.2 Adult Upstream Migration

5.2.1 Potential Limiting Factors

As adult salmonids migrate upstream to spawn, they frequently must overcome a variety of natural and anthropogenic obstacles before reaching suitable spawning areas. These include:

- *Attraction flows.* The initiation of upstream migration by adult salmonids generally requires an environmental cue in the form of an "attraction flow," which provides a chemical or other type of signal to the fish that upstream conditions are suitable for migration and spawning. Alterations in the timing, duration, or magnitude of attraction flows may disrupt successful spawning migration by anadromous salmonids.
- *Physical migration barriers.* Natural or man-made features such as dams, dewatered reaches, inadequate flows, "hanging" tributaries, natural falls, or culverts may compromise the success of spawning salmonids by preventing access to spawning habitat, or, in the case of partial barriers, by critically depleting the fish's energy reserves and delaying migration as it attempts to get past the obstacle.
- *Thermal migration barriers.* Upstream migration by adult salmonids may also be blocked or curtailed by environmental conditions, such as elevated water temperatures, that prevent fish from reaching spawning grounds. If water temperatures remain prohibitively high, spawning may not occur or may take place in suboptimal habitats.
- *Migration corridor hazards.* Other hazards that may be encountered by adult salmonids as they migrate upstream include poaching and false migration pathways presented by bypasses and diversions. These hazards can interfere with spawning migrations and limit the success of salmonid populations.

5.2.2 Relevant Studies

A number of efforts have been undertaken to gain a general understanding of migration issues affecting adult salmonids in the Calaveras River. Temperature monitoring was undertaken as part of this study (Section 4.6), as well as SEWD's monitoring program (Section 4.8.2). The temperature data collected is useful in determining whether temperature-related migration barriers exist for adult salmonids. To determine the potential impacts of physical migration barriers and migration corridor hazards, passage surveys (Section 4.3) and redd surveys (Section 4.2) were conducted in the present study, in conjunction with the modeling efforts of the Fish Passage Improvement Program.

While the impact of attraction flows on adult migration success is considered a potential limiting factor, it was determined that during the first phase of this study that documentation of a substantial adult migration would rule out the need to investigate attraction flows. The results of the first phase of studies indicate that such studies are necessary and that funding should be pursued for additional evaluations.

5.2.3 Conclusions about Adult Upstream Migration

The following conclusions have been reached regarding adult upstream migration:

- Limited upstream fish passage is the primary factor currently limiting steelhead and Chinook salmon populations in the Calaveras River.
- Flow regulation has resulted in a lack of attraction flows and prevalent dry reaches and structural barriers to passage during the fall and winter periods when Chinook salmon and steelhead would normally attempt to ascend the system.
- Environmental conditions such as high water temperatures and low dissolved oxygen below Bellota Weir may be a problem for migrating adult salmonids in the Calaveras River.
- Fish passage issues are relevant to both analysis species. However, the superior swimming and jumping ability of steelhead may allow them to ascend the system under conditions where Chinook salmon are not able to do so.

5.3 Adult Over-summering

5.3.1 Potential Limiting Factors

For adult spring Chinook salmon, the presence of deep, cool pools in which adults can over-summer before spawning is critical. Factors that may limit the over-summering success of spring Chinook salmon adults include:

- *Water Temperature:* Over-summering adults require low water temperatures in order to minimize physiological stress and maintain a low metabolic rate, not only to ensure survival, but also to ensure that energy reserves are adequate for reproduction in the fall.

- *Summer Holding Habitat:* Pools that are deep are critically important to over-summering by adult salmonids because these fish do not feed significantly during their holding period and rely primarily on stored energy reserves for their metabolic needs. By holding in cool, deep pools fish minimize predation risks, minimize energy expenditures, and conserve resources for spawning the following fall.

5.3.2 Relevant Surveys

Water temperature was monitored as part of this study and has also been conducted by SEWD (Sections 4.6 and 4.8.2). Reconnaissance surveys (Section 4.1) were conducted to determine the abundance of summer holding habitat, particularly of large deep pools.

5.3.3 Conclusions About Adult Oversummering

For spring Chinook salmon, the abundance of large, deep pools throughout the Canyon Reach combined with current water management that provides elevated summer flows likely result in adequate over-summering habitat.

5.4 Spawning and Incubation

5.4.1 Potential Limiting Factors

Environmental conditions play a crucial role in successful salmonid spawning, egg incubation, and survival to emergence. The range of environmental tolerance of salmonids during these life stages is narrow, and many factors may limit survival. These factors include:

- *Abundance of spawning gravel and redd superimposition.* Limited availability of spawning gravel is a problem faced by salmonids when access to spawning habitat has been blocked or suitable substrates have been dewatered or diminished. This problem can be further exacerbated in areas where limited spawning habitat availability results in competition for space and leads to redd superimposition.
- *Spawning gravel quality.* Suboptimal spawning gravel quality can limit spawning and incubation success by rendering gravel unusable by adult salmonids, creating unsuitable incubation conditions, and preventing fry from emerging after hatching.
- *Water quality and temperature.* During spawning, poor water quality or elevated water temperature may reduce the ability of adult salmonids to reach spawning grounds and successfully deposit eggs. Survival to emergence is dependent on successful incubation of eggs, which are especially vulnerable to low dissolved oxygen levels and high water temperature.
- *Substrate mobility/scouring.* Successful hatching and emergence require stable gravels in and around the egg pocket. Scouring of redd gravels can alter redd hydraulics and cause abrasion or displacement of eggs, resulting in reduced survival rates or direct egg mortality.
- *Redd dewatering.* Partial or complete dewatering of redds can result in low survival rates due to reduced delivery of water and oxygen and buildup of toxic metabolic byproducts, and may cause egg mortality due to desiccation.

5.4.2 Relevant Studies

A number of focused studies were conducted to determine factors that could potentially impact spawning success of salmonids in the Calaveras River. As part of this study, reconnaissance surveys were conducted to estimate the abundance of gravel suitable for spawning of steelhead and Chinook salmon and determine the distribution of these patches of spawning gravel (Section 4.1). Reconnaissance surveys also indicated that redd scour due to substrate mobility was probably not a frequent problem. Based on the results of these surveys, low gradient riffle sites were identified for permeability studies to further examine spawning gravel quality (Section 4.5). Spawning surveys identified reaches preferred for spawning by adult salmonids and determined the frequency of current redd superimposition and redd dewatering (Section 4.2). Finally, temperature monitoring was conducted as part of this study (Section 4.6) and SEWD temperature data (Section 4.8.2) were reviewed to determine whether water temperature was appropriate for egg incubation.

Water quality was not specifically assessed as part of this study, because we are not aware of evidence that suggests that water quality (e.g. dissolved oxygen or chemical factors) might be a problem for egg development in the reaches where spawning takes place.

5.4.3 Conclusions About Spawning and Incubation

The following conclusions have been reached regarding spawning and incubation:

- Spawning habitat for Chinook salmon and steelhead is relatively common throughout the New Hogan and Jenny Lind reaches of the Calaveras River. Smaller spawning patches appropriate for steelhead, but too small for Chinook salmon, are common in the upper half of the Canyon reach. In other areas, confinement of the channel by dredger tailings or channel incision (particularly in the Mormon Slough Reach) may have resulted in increased shear stress, local scour of gravels, channel incision, and formation of long runs or pools that are unsuitable for spawning.

- Patches of spawning habitat in the lower watershed have probably been degraded by intrusion of fine sediment into spawning gravels, which has reduced permeability and would decrease survivorship of steelhead and Chinook salmon eggs and fry. Low permeability can result from the compaction of gravels and infiltration of fine sediments. Increased levels of fine sediments may result from increased delivery of sediment to the system or a lack of flow levels adequate to mobilize the streambed. Below New Hogan Dam, reduced gravel permeability is likely a by-product of declines in peak flow frequency and magnitude due to flow management practices in the system.

5.5 Juvenile Rearing

5.5.1 Potential Limiting Factors

Following emergence from the gravel, juvenile salmonids must begin feeding and competing for resources under varying environmental conditions. Factors that may limit survival of rearing juvenile salmonids may include:

- *Availability of summer rearing habitat.* During the summer when developing juveniles require opportunities to feed and grow and must also avoid predation, pools, substrate, interstices, and other complex habitats provide rearing salmonids with access to feeding stations and necessary refuges from predation. A lack of summer rearing habitat can reduce the success of juvenile salmonids through reduced food availability, increased competition for food and space, and increased predation.
- *Availability of over-wintering habitat.* Displacement or mortality caused by high winter flows frequently limits production of juvenile salmonids that do not have access to protected micro-sites associated with LWD, large substrates such as boulders, interstitial spaces, off-channel habitat, or other features that provide velocity refuges. Certain habitat elements, such as substrate interstices, may also increase winter survival by providing resting or hiding sites for fish when water temperatures are coldest.
- *Stranding by low flows.* Stranding can cause direct mortality of juvenile salmonids when low flows or rapidly receding water levels isolate fish in disconnected or dewatered habitats, subjecting them to predation, desiccation, or other hazards.
- *Predation.* Predation limits population success through direct mortality. Predation pressure on rearing salmonids may be increased by removal of instream and overhead cover, low flows, migration barriers, and changes in channel geometry that favor predatory fish.

- *Food availability.* An inadequate food supply can cause increased interspecific and intraspecific competition, and may lead to reduced fitness and, in some cases, mortality.
- *Interspecific interactions between native species.* Interspecific interactions between native species, which include competition for food and space, are usually related to reduced availability of food and suitable habitat. Juvenile salmonids may suffer reduced fitness and population success may be limited by these interactions.
- *Competition with introduced species.* Introduced species can compete for food and space with native salmonids, reducing access to these important resources and potentially limiting fitness and survival.
- *Water quality/ temperature.* The quality and temperature of stream water has a direct impact on the success of rearing juvenile salmonids. Prolonged periods of elevated water temperature, as well as acute or chronic water pollution, can lead to direct and indirect mortality of juvenile salmonids.

5.5.2 Relevant Studies

A number of focused studies were conducted to determine factors that could potentially impact rearing success of salmonids in the Calaveras River. Reconnaissance surveys were undertaken to develop a qualitative understanding of the availability of over-wintering and summer rearing habitat (Section 4.1). Snorkel surveys were conducted to develop a more refined understanding of juvenile movements and preferred summer rearing habitat (Section 4.4). An understanding of the summer distribution combined with information from the rotary screw trap work of SEWD (Section 4.8.1) provides valuable information on the time and relative magnitudes and physical condition of downstream movements by juveniles in the lower part of the system. Observations made during migration studies (Section 4.3) provided information on stranding potential for juvenile salmonids. The results of temperature monitoring were also used to determine whether physical conditions were appropriate for juvenile rearing (Sections 4.6 and 4.8.2).

5.5.3 Conclusions About Juvenile Rearing

The following conclusions have been reached regarding juvenile rearing:

- Flow management and channelization activities have dramatically altered the sloughs and wetlands below Bellota Weir. These activities have probably reduced suitability of the lowest river reaches for salmonid rearing. For example, dewatering of the Old Calaveras River channel and simplification and reduction of riparian cover on Mormon Slough has resulted in high temperatures that would not be expected to support significant numbers of rearing juveniles.
- Predation may impact juvenile salmonids if non-native predators have colonized the lower Calaveras River. Field reconnaissance surveys indicate the common occurrence of large run-pools between Jenny Lind Bridge and Shelton Road. These pools may support some warm-water predator species. Observations from aerial surveys indicate the presence of similar large run-pools between Shelton Road and Bellota Weir as well as large pools that appear to be captured gravel pits. Loss and degradation of wetland habitat at the confluence of the Calaveras and San Joaquin rivers and degradation of habitat quality in the delta may have further reduced the potential for rearing.

- In contrast to conditions in the lower reaches of the Calaveras River, a great deal of rearing habitat is present upstream of Bellota Weir. Upstream of Bellota Weir large numbers of steelhead smolts (>200 mm) captured in SEWD rotary screw trapping efforts indicate the system supports juvenile growth to relatively large sizes. Due to the fact that the selectivity of the rotary screw trapping has not yet been quantified using releases of known numbers of fish and size distributions of smolts, it is not possible to say with certainty the degree to which data collected reflect the characteristics of the overall population. However, while the exact abundance cannot be quantified, the data clearly show that the system is capable of producing large smolts in good condition, which would be expected to have a higher probability of survival to adulthood.
- Based on observations made during snorkel surveys, the Canyon Reach provides the majority of juvenile steelhead and rainbow trout production in the lower Calaveras River.
- Given the apparently robust population of *O. mykiss* and lack of observation of potentially antagonistic species during snorkel surveys, we hypothesize that interspecific interactions between native species and competition with introduced species is not a factor limiting steelhead populations.
- Besides water temperature, we are not aware of any evidence that water quality in the lower Calaveras River may negatively impact juvenile rearing.

5.6 Smolt Outmigration

5.6.1 Potential Limiting Factors

A variety of environmental factors may serve as outmigration cues to juvenile salmonids in streams. Outmigrating fish are subject to a range of conditions that influence their ability to successfully reach the ocean. These include:

- *Adequate flows for outmigration.* Juvenile salmonids undergo physiological changes and initiate outmigration when adequate river flows and temperatures occur, usually during spring. Reduced flow duration or magnitude during the outmigration period can render some portions of the river corridor impassible and may subject emigrating juveniles to increased predation, thereby reducing the chances of successful outmigration.
- *Water quality and temperature.* Water quality and temperature may be especially important to outmigrating salmonids during low-flow periods. Lethal or sublethal effects may result from pollutants or prolonged exposure to high water temperatures.
- *Predation.* Predation, especially by introduced warm-water, piscivorous fish, is believed to be a significant source of mortality of outmigrating salmonids in some rivers (Moyle 2002). Migrating juveniles may also be subject to predation by terrestrial or avian predators.
- *Diversion hazards.* Water diversions, such as canals, pumps, and bypasses, can act as “blind pathways,” preventing fish from reaching the ocean. They may also be directly lethal to fish or may expose them to high water temperatures, pollutants, predation, or desiccation.

5.6.2 Relevant Studies

Key to understanding the potential for the factors listed above to limit salmonids in the system is a clear understanding of the timing, routes, and magnitudes of fish outmigration movements. To this end, several efforts have contributed to an improved general understanding of salmonid outmigration in the Calaveras River. Rotary screw trapping by SEWD (Section 4.8.1) has provided valuable information on the timing and relative abundance of outmigrating fish. In addition, gill netting, fyke netting and hook and line sampling conducted as part of the migration study (Section 4.3) in the areas downstream of Bellota in the Old Calaveras River Channel and Mormon Slough have provided indications of the routes and fates of juveniles and smolts moving downstream of Bellota Weir. As we gain a better understanding of the outmigration patterns of fish using the system it will be possible to assess the necessary timing of adequate flows for outmigration.

In addition, the assessments in development by the CDWR Fish Passage Improvement Program, as well as the basic hydrographic analysis of the migration surveys (Section 4.3) will assist in determining the magnitude of adequate flows for outmigration. Temperature monitoring provided background on the timing of appropriate physical conditions for outmigration (Sections 4.6 and 4.8.2).

5.6.3 Conclusions About Outmigration

The following conclusions have been reached regarding outmigration:

- From late winter to the middle of April, flows sufficient to carry smolts from spawning and rearing areas to the San Joaquin River are relatively uncommon. Data from rotary screw trap monitoring at Shelton Road show that large numbers of smolt-sized *O. mykiss* attempt to outmigrate from January through June.
- After the middle of April, significant flows are released to convey water to irrigators who draw water from Mormon Slough (water is also occasionally released to water the Old Calaveras River Channel for groundwater recharge). Such flows probably stimulate smolts to begin migrating out of the reaches upstream of Bellota Weir.
- The number and condition of smolts captured at Shelton Road suggests that there are no substantial outmigration problems upstream of Shelton Road.
- The most significant potential impediments to outmigration appear to lie downstream of Bellota Weir in Mormon Slough and the Old Calaveras River Channel. Under current flow management practices, before the beginning of irrigation season, full connection of flows in Mormon Slough between Bellota Weir and the San Joaquin River occurs only when storm runoff below New Hogan Dam results in uncontrolled spill over the top of Bellota Weir. Diversion of flows away from the mouth of the Old Calaveras channel and development of extensive irrigation infrastructure in Mormon Slough channel has likely blocked smolt outmigration to large degree. In addition, flows in Mormon Slough generally are not sustained all the way to the San Joaquin River.
- Low velocity, deep habitats associated with irrigation infrastructure provide advantageous conditions for non-native piscivorous predators.
- Stranding of juveniles in both Mormon Slough and the Old Calaveras River channel is a potential problem, especially during the irrigation season. Outside of the irrigation season, the potential for stranding is increased in Mormon Slough when pulses from Cosgrove Creek provide enough streamflow to spill over Bellota Weir but not enough flow to reach the San Joaquin River.

6 OVERALL POTENTIAL FOR SALMONID PRODUCTION

The Calaveras River is unique among Central Valley tributaries because of its high summer flows, cool temperatures, abundance of high quality juvenile rearing habitat, and presence of deep pools that provide potentially excellent conditions for resident rainbow trout, steelhead, and spring and fall Chinook salmon above Bellota Weir.

Historically, San Joaquin tributaries supported large numbers of stream-type salmonids, such as spring Chinook salmon and steelhead. However, in many systems the steep, complex, canyon reaches which provide the structural complexity and deep pools required to sustain large stream-type salmonid populations have been blocked by large dams. Thus, many systems are dominated by flow regimes and habitat more suitable for ocean-type life histories (e.g., fall Chinook salmon), which have become the more predominant life history in the region. The Calaveras River represents a notable exception to this pattern and we hypothesize that it has the potential to serve as an important refuge for steelhead and spring Chinook salmon populations that exhibit stream-type life history strategies.

6.1 Summary of Steelhead Production Potential

Several factors point to the Calaveras River having excellent potential as a steelhead stream, perhaps none more compelling than the abundance of high quality rearing habitat that supports an excellent resident rainbow trout sport fishery. Due to the long duration of juvenile rearing in the steelhead life cycle, survival through this life stage is particularly important for maintaining a self-sustaining steelhead population. Conditions for juvenile steelhead rearing are potentially quite good in the Calaveras River. Relatively cool temperatures provide excellent conditions for salmonid growth. Complex structure in the stream channel provides refugia during high flow events, particularly in the winter. Flood control management at New Hogan Dam has probably also increased overwinter survival of juvenile steelhead.

The frequency of deep pools in the Calaveras River is probably similar to historical levels, especially in the canyon reaches of the river. However, the number of pools formed by logjams has probably been reduced due to large woody debris removal and reduced recruitment below New Hogan Dam.

During drought periods, flow management has resulted in significantly reduced and more seasonally variable flows in the Calaveras River. This precipitated a shift of the fish community toward a warm-water fishery during the drought of the late 80’s and early 90’s. This process was likely hastened both by the sensitivity of salmonids to elevated water temperatures, as well as the close proximity of warm-water fish populations in Mormon Slough and Cosgrove Creek. There is also a possibility that gravel pits between Bellota Weir and Jenny Lind Bridge are a source of warm-water fish species. However, recovery of the cold-water fishery following the 1988-1992 droughts provides compelling evidence that the cold water fishery rebounds quickly once appropriate conditions are reestablished.

6.2 Summary of Chinook Salmon Production Potential

While there is evidence that Chinook salmon return to the Calaveras River and ascend the Stockton Diverting Canal and Mormon Slough, during the past two years few if any fish that have successfully passed upstream of Bellota Weir. While potential Chinook salmon spawning habitat exists in the low gradient reaches between New Hogan Dam and the canyon and between the canyon and Bellota Weir, no evidence of Chinook salmon spawning was observed in these reaches during WY 2002.

The inability of adult Chinook salmon to migrate upstream and Chinook salmon smolts to migrate downstream clearly suggests that fish passage is the major limiting factor at this point in time. Problems with fish passage are due to reduced flows in the Calaveras River and structural migration barriers. By virtue of opening up habitat for spawning and rearing life stages, improved passage would be expected to result in an increase of the population of Chinook salmon using the Calaveras River.

If passage problems for Chinook salmon are resolved, and salmon are able to access reaches with spawning and rearing habitat above Bellota Weir, the quality of spawning habitat is still relatively poor. Additionally, reconnaissance surveys suggest that flow levels during the spawning period may be insufficient to make large amounts of spawning habitat accessible. However, further assessment of fry rearing potential is needed to determine if poor egg-to-fry survival alone would limit the reproductive success of salmon in the system.

Since no spawning has been observed, and only six Chinook salmon smolts have been observed upstream of Bellota in the period of this study (S.P. Cramer, unpublished data), there is limited information regarding Chinook salmon for this part of the system. However, the presence of juvenile steelhead and rainbow trout indicate that rearing conditions are suitable for salmonids, and that there is good potential for Chinook salmon smolt production.

7 MODELING APPROACH

Because of differences in life histories, different modeling approaches were applied to Chinook salmon and steelhead. This section describes species specific modeling approaches and the information needed to drive each model. Where data are available, preliminary modeling results of some life stages are presented.

7.1 Steelhead

7.1.1 Population Modeling

The salmonid population modeling approach used in this analysis is based on stock-production theory (Ricker 1976). Stock-production theory characterizes the number of individuals of one life stage at one time (the production) as a function of the number in the same cohort of an earlier life stage at an earlier time (the stock). This approach is particularly well suited to situations where physical habitat is believed to be limiting, and where population dynamics can be plausibly separated into density-independent and density-dependent components, such as productivity (the ratio of stock to production that would be expected if there were no limits on population density) and carrying capacity (the maximum number of individuals of a given life stage that the habitat can support for the duration of that life stage).

The population model uses the following relationships between a stock S and a production P. The parameter r can generally be interpreted as the intrinsic productivity (e.g., a density-independent survival rate, or in the case of reproduction, a fecundity). The parameter K is interpreted as the carrying capacity for the production stage. In practice, both of these can vary from year to year in response to varying environmental conditions. All of these relationships are asymptotic to the two lines $P = rS$ and $P = K$. There are three basic types of functional relationships that are used in this model:

Truncated Linear: $P = \max(rS, K)$

Modified Beverton-Holt: $P = \dfrac{rKS}{\left((rS)^{\gamma} + K^{\gamma}\right)^{1/\gamma}}$

Superimposition: $P = K\left(1 - \exp(-rS/K)\right)$

The truncated linear relationship is often used when no natural carrying capacity is evident; in this case K is set to some very large value, or simply omitted. The parameter γ of the modified Beverton-Holt relationship controls the "stiffness" of the relationship: $\gamma = 1$ is the usual Beverton-Holt relationship; larger values yield curves which make more abrupt transitions between the two asymptotes $P = rS$ and $P = K$. The superimposition relationship was derived from analytical models of habitat selection.

7.1.2 Model Parameterization

The steelhead population modeling approach involves three basic steps: (1) collecting habitat-specific information regarding habitat quality and quantity from suitable reaches within the area of interest; (2) assigning density-independent survival and habitat-specific carrying capacity values for each salmonid life stage; and (3) integrating these values into a system of equations to express the impact of current salmonid habitat conditions on potential steelhead production. These three steps are described in further detail below.

7.1.2.1 Collecting Habitat-Specific Information

Reach-specific habitat information is necessary for this population modeling approach. Study reach lengths should be at least 20 channel widths long to capture the natural variability of the channel and help ensure that the study reaches are representative of conditions in the Calaveras River where juvenile steelhead have been observed rearing.

Reaches will be divided into four basic habitat types (pool, riffle, glide, and cascade) according to standard habitat mapping descriptions (Bisson et al. 1982, McCain et al. 1990). Mean length, width, and depth are estimated for each habitat unit, and maximum depth is measured within each unit. In addition to these habitat parameters, the area of potential spawning habitat (if present) is estimated. Spawning habitat area estimates are based on steelhead spawning habitat criteria reported in the literature, including a water depth of >24 cm (Smith 1973), flow velocities between 40 and 91 cm/s (Bovee 1978), and a particle size (D_{50}) of 10–46 mm (Kondolf and Wolman 1993).

7.1.2.2 Assigning Steelhead Life-history Parameters

Steelhead life history was separated into discrete stages having identifiable, and to some extent overlapping, habitat requirements. As discussed above, the population dynamics modeling approach that we propose requires two biological parameters for each stage: (1) a carrying capacity ("K"), which describes the ultimate limits imposed by crowding and competition; and (2) an intrinsic productivity ("r"), which describes the expected dynamics under conditions for which the effects of crowding and competition can be ignored. The type of stock production curve used to model each life history segment is provided in Table 2. Tables 2 and 3 summarize the "K" and "r" parameters, where available, to be used in the analysis, and the derivations of these values. Table 4 provides supplemental information on substrate embeddedness and steelhead density relationships. Output from the population model is an estimate of the number of individuals of each life stage the habitat is expected to produce under current habitat conditions.

Table 2. Structure and parameters for modeling of Calaveras River steelhead population dynamics.

Life history segment	Stock-production relationship	r (fish/fish)	K (fish)
Spawning and superimposition (spawner to effective eggs)	Superimposition	2,751.5[a]	spawning habitat area × 0.2 redds/ft² × 5,503 eggs/redd [b]
Egg and alevin rearing (effective egg to spring fry)	Truncated Linear	0.31 [b]	(NA)
Early fry rearing (spring fry to 0+ summer)	Modified Beverton-Holt ($\gamma = 2$)	1	See Table 4
Summer rearing, first year (0+ summer to 0+ fall)	Truncated Linear	1	See Table 4
Winter rearing, first year (0+ fall to 1+ spring)	Modified Beverton-Holt ($\gamma = 2$)	1	See Table 4
Summer rearing, second year (1+ spring to 1+ fall)	Modified Beverton-Holt ($\gamma = 2$)	1	See Table 4
Winter rearing, second year (1+ fall to 2+ smolt)	Modified Beverton-Holt ($\gamma = 2$)	1	See Table 4
Outmigration, ocean life, and return (2+ smolt to spawner)	Truncated Linear	0.05[c]	(NA)

a. 0.5 females/total spawners × 5,503 eggs/female (estimated from Shapovalov and Taft 1954)
b. Inferred from permeability samples (See Section 4.5)
c. Shapovalov and Taft (1954)

Table 3. Derivations of carrying capacities for use in the steelhead population model.

Life history segment	Habitat type	Fish density (fish/ft²)	K (fish)
Early fry rearing	Pool	0.1095[a]	Fish density × total area by habitat type
	Riffle	0.1433[b]	
	Run	0.1437[c]	
Winter rearing, first year	All	(NA)[d]	Fish density × area of cobble/boulder substrate in all habitat units[e]
Summer rearing, second year	Pool[f]	0.007525[g]	Fish density × total area by habitat type
	Run[f]	0.004738[h]	
Winter rearing, second year	All	(NA)[d]	Fish density × area of cobble/boulder substrate in all habitat units[e]

a. 1.179 fish/m² (Connors 1996) × 0.3048² m²/ft²
b. 1.543 fish/m² (Connors 1996) × 0.3048² m²/ft²
c. 1.547 fish/m² (Connors 1996) × 0.3048² m²/ft²
d. Fish density to be estimated from substrate embeddedness (See Table 4)
e. Area of cobble/boulder substrate in all habitat units. The total area of cobble/boulder substrate winter habitat is divided between age 0+ and age 1+ steelhead using the following scaling factor: 85/165 = (age 0+ fork length) / (age 1+ fork length). This ratio of average age 0+ to age 1+ fish length is used as a scaling factor to approximate the degree to which fewer larger fish can fit in a given habitat area.
f. Includes only habitat units with summer maximum depth of at least 2 ft
g. 0.081 fish/m² (Connors 1996) × 0.3048² m²/ft²
h. 0.051 fish/m² (Connors 1996) × 0.3048² m²/ft²
i. Fish density to be estimated from substrate embeddedness (See Table 4)

Table 4. Winter 0+ juvenile steelhead density (fish/ft²) in an artificial stream channel with different levels of coarse substrate embeddedness (Redwood Sciences Laboratory and Stillwater Sciences 2004, unpublished data).

Embeddedness	Steelhead Density (fish/ft²)
0%	0.65
10%	0.33[a]
20%	0.16[a]
≥30%	0

[a] interpolated (not observed)

The population dynamics modeling approach that we propose requires two kinds of biological parameters: (1) carrying capacity for each life stage (which describes the ultimate limits imposed by crowding and competition); and (2) quantities such as fecundity and density-independent survival rates (which describe the population dynamics under conditions for which the effects of crowding and competition can be ignored). These may be called density-dependent and density-independent factors, respectively. The specific parameters for each life stage are developed from site specific habitat characteristics and, where appropriate, values reported in the literature.

7.1.2.3 Carrying Capacity Estimate

Carrying capacity is a measure of the maximum number of individuals the available habitat can support in the absence of any constraints imposed by population dynamics (survival-mortality) for the different life history stages of steelhead. Carrying capacity is calculated separately for each life history stage. To calculate total habitat carrying capacity for a specific life stage, the total area of each habitat type (see Section 7.1.2.1) is multiplied by the maximum density for a specific life stage to yield carrying capacity for that habitat type. These carrying capacities are then summed for all habitat types.

This assessment relies on fundamental concepts in population dynamics, particularly stock-production analysis. We feel that an expanded population dynamics modeling study could be a useful tool for evaluating potential benefits of alternative restoration strategies (e.g., what would be achieved by reducing fine sediment loading to improve spawning gravel permeability versus adding boulders or LWD to create more pool habitat or spawning gravel patches). We recommend that future studies include quantitative habitat surveys and steelhead population modeling.

7.2 Chinook Salmon

Because Chinook salmon typically rear for only a short time in freshwater, preliminary modeling approaches focused on development calendars for fry emergence and juvenile growth to smolt size rather than estimates of carrying capacity. This modeling approach will help guide recommendations on the timing of flow releases to facilitate Chinook salmon outmigration, presuming that adult salmon can access areas with spawning habitat.

7.2.1 Fry emergence

Accurate prediction of Chinook salmon hatching and emergence time is an important management tool for assessing production potential (Rombough 1985). For example, if emergence occurs too late in the winter, juveniles may not be able to grow to smolt size before river temperatures become stressful or lethal, or lower river reaches become dry. Rates of development to hatching and emergence for Chinook salmon are largely determined by water temperature and egg weight (Rombough 1985, Beacham and Murray 1990).

7.2.1.1 Model Parameterization

Estimated development rates of Chinook salmon eggs were modeled using water temperature and egg size to assess emergence timing during typical water years. Water temperature data from an average water year (WY 2000) were input into a temperature model to predict the approximate dates of hatching and fry emergence. Incubation temperatures were used from two reaches below

New Hogan Dam with potential Chinook salmon spawning habitat (New Hogan and Jenny Lind). A "development index" was set to 0 on the day of fertilization. For each day post-fertilization, the index was incremented by:

$$\exp(-6.350057 - 0.000899695\ W + 0.9322219 \ln T)$$

where T is the mean temperature (ºC) on that day, and W is the initial egg weight (mg). Emergence is predicted to occur when the index reaches 1.0. This model was obtained by fitting data reproduced in Beachamm and Murray (1990). Initial egg weight was set at 246 mg, based on Chinook salmon egg sizes obtained from CDFG's Merced River Hatchery. Development time to emergence was predicted for a time series of spring and fall Chinook salmon spawning dates from 1 September to 30 December. This period corresponds with the typical spawning period of spring and fall Chinook salmon, but it is likely broader than the period when Chinook salmon can access the Calaveras River. Flashboards associated with diversion structures prevent fish passage until their removal between 15 October and 30 October.

7.2.2 Juvenile Rearing

The onset of smoltification and outmigration depends on several factors, but perhaps the most important is the attainment of appropriate minimum body size (Bradford and Higgins 2001, Folmar and Dickhoff 1980).

Food availability and water temperature directly influence fish growth. On maximum daily rations, growth rate increases to a certain optimal temperature and then declines with further increases in temperature. Rations reduced from maximum levels also result in reduced growth rates, so declines in juvenile salmonid growth are a function of both temperature and food availability. Brett et al. (1982) found the highest growth rates under maximum daily ration occur at 64.4–71.8°F (18–22°C), with declines in growth rates at higher temperatures and much reduced growth at 75.6°F (24.8°C). Rich (1987) showed only slightly reduced growth rates at 66 and 70°F (19 and 21°C) for American River juvenile Chinook salmon under constant exposure for 45 days, with the highest growth rates occurring at from 56–60°F (13–15°C).

7.2.2.1 Model Parameterization

Growth rates for juvenile Chinook salmon were modeled using estimates of food consumption and observed water temperature to assess rearing conditions during typical water years and determine when juveniles could attain a minimum size for outmigration. Juvenile growth was estimated using models developed by Stauffer (1973) which predict specific daily growth rates as a function of food availability, and water temperature. Water temperatures (WY 2000) from reaches with potential juvenile Chinook salmon rearing habitat (New Hogan and Jenny Lind) were input into the model. Ration levels in these models were calibrated for use in Central Valley streams using juvenile Chinook salmon size-at-age data from the Tuolumne River (TID/MID 2001). Because maximum food availability rations (Rmax) are typically only achieved in a laboratory, rations used in the model were set at a fraction of Rmax. Based on growth rates observed for juvenile Tuolumne River Chinook salmon, ration level was initially estimated at 0.7*Rmax (TID/MID 2001), although it is not known whether macroinvertebrate production is similar in the Calaveras River.

Fry were assumed to be 30 mm at emergence, and 80 mm at smoltification based on juvenile Chinook salmon sizes observed in other San Joaquin tributaries (TID/MID 2001). Juvenile growth rates were predicted for a time series of spring and fall Chinook salmon emergence dates from 1 October to 30 December. Spawning was assumed to occur in New Hogan and Jenny Lind reaches. After emergence, some juveniles were assumed to redistribute downstream and rear into lower portions of the Jenny Lind Reach. The preliminary model does not include energetic costs for migration between spawning and rearing reaches, although this can be incorporated in future modeling efforts.

7.2.3 Preliminary Chinook Salmon Development Calendars

Chinook salmon development calendars for the Calaveras River below New Hogan Dam are presented in Figures 11, 12, and 13. Generally, because of colder water temperatures later in the winter, for a given reach, the later spawning is initiated the longer the time to emergence. However, increases in water temperature beginning in early February (Figure 14) caused development rates to increase noticeably. Depending on the date of fertilization, eggs from some later spawning fish may have faster development rates than those spawned earlier. Therefore, because development rates are very responsive to site specific temperatures, emergence dates may vary depending on both the date and location of spawning.

Although stream temperatures are generally progressively warmer downstream from New Hogan Dam, there are periods during the winter when temperatures in the New Hogan Reach are actually warmer than downstream reaches (Figure 14). These temperature patterns tend to minimize differences in egg development time between reaches. Table 5 presents predicted time to emergence are presented by the range of development days, begin and end dates of emergence, and peak emergence based on typical peak spawning dates for spring and fall Chinook salmon. In the New Hogan Reach, predicted time to emergence ranged from 71 days for eggs fertilized on 1 September to 88 days for eggs fertilized on 31 December. In the Jenny Lind reach, time to emergence ranged from 66 to 83 days for eggs fertilized on those same dates. In both reaches, all fish are predicted to emerge before 30 March. Fry emergence period is predicted to extend from 9 November to 29 March, with peaks in emergence from 24 to 29 November and from 23 January to 7 February, corresponding to typical spawning peaks for spring and fall Chinook salmon in the Central Valley.

Table 5. Predicted time to emergence for Chinook salmon eggs in New Hogan and upper Jenny Lind reaches of the Calaveras River.

Reach	Range (days)	Begin	End	Spring Run Peak	Fall Run Peak
New Hogan	71-88	Nov 9	Mar 29	Nov 24 - Nov 29	Jan 23 - Feb 7
Jenny Lind (upper)	66-83	Nov 4	Mar 27	Nov 24 - Nov 29	Feb 7 - Feb 17

The site specific temperature patterns described above also tend to minimize differences in predicted time to emigration between reaches. Table 6 presents predicted time to emigration for juvenile Chinook salmon by range of development days, begin and end dates of emigration, and peak emigration based on typical peak spawning dates for spring and fall Chinook salmon. Few longitudinal patterns in development rates could be identified, except that in downstream reaches the emigration period tended to contract, with beginning dates shifting later and ending dates shifting earlier in the year (Table 6). In the New Hogan Reach, the predicted time to emigration ranged from 100 days for fish that emerge on 9 November to 105 days for fish that emerge on 29 March. The emigration calendar extended from 18 February to 8 July, with peaks in emigration occurring from 10 to 20 March, and 20 to 30 May, corresponding to the timing of typical spawning peaks for spring and fall Chinook salmon in the Central Valley. In the upper Jenny Lind Reach, the predicted time to emigration ranged from 120 days for fish that emerge on 4 November to 110 days for fish that emerge on 24 March. The emigration calendar extends from 28 February to the 28 June, with peaks in emigration expected to occur from 20 to 30 March and 10 to 20 May. In the lower Jenny Lind Reach, the predicted time to emigration ranged from 115 days for fish that emerged in other reaches on 9 November to 105 days for fish that emerged on 24 March. The emigration calendar extended from 5 March to 23 June, with peaks in emigration expected to occur from 16 to 21 March and 1 to 10 May.

Table 6. Predicted time to emigration for juvenile Chinook salmon in New Hogan and Jenny Lind reaches of the Calaveras River.

Reach	Range (days)	Begin	End	Spring Run Peak	Fall Run Peak
New Hogan	100-105	Feb 18	July 8	Mar 10 - Mar 20	May 20 - May 30
Jenny Lind (upper)	110-120	Feb 28	June 28	Mar 20 - Mar 30	May 10 - May 20
Jenny Lind (lower)	105-115	Mar 5	June 23	Mar 16 - Mar 21	May 1 - May10

8 FUTURE STUDIES

To continue the progress toward understanding the factors and processes controlling salmonid abundance in the Calaveras River watershed, we have identified the following priorities for future study. The limited historical information on anadromous salmonids in the Calaveras River suggests that steelhead and Chinook salmon used the river opportunistically in years with sufficient streamflow. Regulation of the lower Calaveras River through New Hogan Dam may have increased the consistency of conditions suitable for steelhead and Chinook salmon spawning and rearing. However, many fish passage problems associated with municipal and agricultural diversions from Bellota Weir downstream to the river's mouth limit access to suitable fish habitat. Therefore, future studies should focus on quantifying both the potential carrying capacity of the lower Calaveras River and the magnitude and timing of flow releases necessary to facilitate anadromous fish migrations.

To this end, we recommend modeling steelhead carrying capacity of the lower Calaveras River using the methods described in Section 7.1. Reach-specific habitat information necessary for this population modeling approach should be collected in representative sample sites within all reaches identified as containing habitat for steelhead. As described in Section 7.1.2.3, sensitivity analyses should be conducted for various steelhead life stages to test hypotheses about factors limiting steelhead populations.

Because salmonid development through early life stages is very sensitive to stream temperature we suggest that an analysis of factors affecting stream temperatures below New Hogan Dam be completed. This analysis can be used to develop a spatially explicit flow-dependent model of stream temperatures below New Hogan Dam. This study will help identify stream reaches where water temperatures reach levels potentially stressful or lethal to salmonids. As part of this model development, we suggest analyzing the sensitivity of stream temperatures to model variables. This approach would help facilitate an adaptive management approach to managing stream temperatures in the lower Calaveras River. The temperature model would also help refine the Chinook salmon development calendars modeled in Section 7.2, and help predict the timing of flow releases necessary to facilitate emigration of Chinook salmon.

Further refinement to the Chinook salmon early life stage development model can be achieved by obtaining measurements of food availability in the lower Calaveras River. We recommend measuring invertebrate production in the lower Calaveras River to test assumptions of food availability used in models of juvenile salmon growth.

We also recommend studies to assess migration success of both juvenile and adult salmonids. Despite what appear to be large numbers of smolt sized *O. mykiss* being captured at Shelton Road (Section 4.8.1), few adults return to spawn in the Calaveras River. Modeling efforts by the CDWR Fish Passage Improvement Program, to be completed 2003, will determine flows required for passage of structural barriers. We further recommend studies to quantify flows required for passage at natural hydraulic and hydrologic barriers in order to provide a hydrologic model of the system to aid flow management. Upon the implementation of management actions determined by these studies and installation of passage facilities by SEWD at Bellota Weir to provide passage to reaches upstream of Bellota Weir, we suggest the following:

1) continuing rotary screw trap monitoring of outmigrating smolts with the addition of mark/recapture studies used to quantify capture efficiencies;

2) scale analysis from returning steelhead and Chinook salmon adults to identify successful life history strategies;
3) radio tagging adult steelhead and Chinook salmon to determine fish migration timing, straying and failure rates, and preferred spawning locations.

We hypothesize that with sufficient passage for upstream and downstream migration, the Calaveras River may produce self-sustaining steelhead and Chinook salmon populations and could play an important part in regional efforts to manage populations of steelhead and Chinook salmon.

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