Exhibit A

Conceptual Models of Stressors and Limiting Factors for San Joaquin River Chinook Salmon

Fisheries Management Plan:
A Framework for Adaptive Management in the San Joaquin River Restoration Program

SAN JOAQUIN RIVER
RESTORATION PROGRAM

November 2010

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Definitions

Alevin	The life stage of a salmonid between hatching from the egg and emergence from stream gravels as a fry. Alevins are characterized by the presence of a yolk sac, which provides nutrition while the alevin develops in the redd.
Apparent Velocity	The horizontal vector of interstitial flow that is a function of permeability and hydraulic gradient.
Conceptual Model	Conceptual models are verbal or graphic depictions of how scientists believe that ecological, hydrological, and managerial systems in the San Joaquin River Basin will function and respond to SJRRP actions. They will be used to help identify actions that should have a high likelihood of achieving SJRRP objectives and help identify key knowledge gaps and hypotheses that will be addressed by an adaptive management process. The conceptual models will also be used to help develop quantitative models that will facilitate the development of testable hypotheses.
D_{50}	The median diameter of gravel at a site (e.g., spawning bed).
Diel	A daily cycle, usually encompassing 1 day and 1 night.
Escapement	The number of adults that successfully “escape” the ocean fishery and return to freshwater habitats to spawn.
Fry	Fry are young salmonids that have absorbed their yolk sac and emerged from the redd. They typically use low velocity, shallow habitats near the river banks. In the Central Valley, fry are frequently defined as juveniles smaller than 50 millimeters in fork length.
Grilse	A precocious salmon or anadromous trout that has matured at a much smaller size and usually younger age (2-year-old) than that of the fully grown adult fish (3-year-old and older).
Limiting Factors	Stressors that significantly influence the abundance and productivity of Chinook salmon populations.

Parr	The life stage for salmon that is distinguished by its dark parr marks, and when the salmon is large enough to use mid-channel habitats. In the Central Valley, parr are defined as juveniles between 50 and 70 millimeters in fork length.
Permeability	The ease with which water passes through gravel, depending on the composition and degree of packing of the gravel and viscosity of the water.
Restoration Area	The San Joaquin River between Friant Dam and the Merced River confluence.
Redd	A nest prepared by a female salmon in the stream bed gravel where she deposits her eggs.
Restoration Flow Schedule	The schedule of flow releases from Friant Dam as prescribed in the Settlement.
Smolt	A young salmonid that is undergoing physiological and morphological changes for life in seawater. Subyearling smolts are generally between 70 and 120 millimeters in fork length, whereas yearling smolts are usually larger than 180 millimeters in fork length.
Stressors	Physical, chemical, or biological perturbations to a system that adversely affect ecosystem processes, habitats, and species. Examples include altered flows, blocked passage, blocked sediment recruitment, instream habitat alteration, invasive species, contaminants, and excessive salmon harvest.

Abbreviations and Acronyms

°C	degrees Celsius
°F	degrees Fahrenheit
μg/L	microgram per liter
AChE	acetylcholinesterase
BKD	bacterial kidney disease
CalEPA	California Environmental Protection Agency
CALFED	CALFED Bay-Delta Program
Central Valley Water Board	Central Valley Regional Water Quality Control Board
cfs	cubic feet per second
cm	centimeter
cm/hr	centimeter per hour
CVI	Central Valley Index
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWT	coded-wire-tag
D_{50}	median particle diameter for gravel
DDT	dichloro-diphenyl-trichloroethane
Delta	Sacramento-San Joaquin Delta
DFG	California Department of Fish and Game
DO	dissolved oxygen
DPR	California Department of Pesticide Regulation
DWR	Department of Water Resources
ENSO	El Niño Southern Oscillation
EPA	U.S. Environmental Protection Agency
ESU	Evolutionarily Significant Unit
FL	fork length
FMP	Fisheries Management Plan
FMWG	Fisheries Management Work Group
ft/hr	foot per hour
ft/s	foot per second
H_2S	hydrogen sulfide
IWM	instream woody material
MEI	Multivariate El Niño Southern Oscillation Index

mg/L	milligram per liter
MID	Modesto Irrigation District
mm	millimeter
NAWQA	National Water Quality Assessment Program
NH_3	ammonia
NMFS	National Marine Fisheries Service
NO_2	nitrogen dioxide
NO_3	nitrate
NPDES	National Pollutant Discharge Elimination System
OP	organophosphorus
PDO	Pacific Decadal Oscillation
PEIS/R	Program Environmental Impact Statement/Report
PKD	proliferative kidney disease
ppt	parts per thousand
RBDD	Red Bluff Diversion Dam
RM	river mile
Settlement	Stipulation of Settlement
SJRRP	San Joaquin River Restoration Program
SWP	State Water Project
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TID	Turlock Irrigation District
TKN	total Kjeldahl nitrogen
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAMP	Vernalis Adaptive Management Plan

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Chapter 1 Introduction

The Fisheries Management Work Group (FMWG) prepared this document for the San Joaquin River Restoration Program (SJRRP) to describe the life history requirements and the environmental factors that will most likely affect the abundance of San Joaquin River spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Restoration Area (San Joaquin River between Friant Dam and the Merced River confluence) (Figures 1-1 and 1-2), and downstream from the Restoration Area, including the lower San Joaquin River, Sacramento-San Joaquin Delta (Delta), San Francisco Estuary, and Pacific Ocean. Included are Chinook salmon conceptual models and supporting information intended to serve as key components of the Fisheries Management Plan (FMP) for the SJRRP. The models assume that all restoration actions prescribed in the Settlement will be implemented.

The conceptual models will be used to assist in guiding flow management, and identifying key habitat restoration needs. The models will also help identify key knowledge gaps to be addressed through a rigorous and comprehensive monitoring and adaptive management program. As part of the adaptive management process, monitoring data will be used to continually refine the conceptual models and management and restoration priorities. The conceptual models also assist in developing quantitative population models to refine the hypotheses to be tested under the Adaptive Management Approach defined in the FMP. As new information becomes available and restoration actions begin, the conceptual models will be revised accordingly.

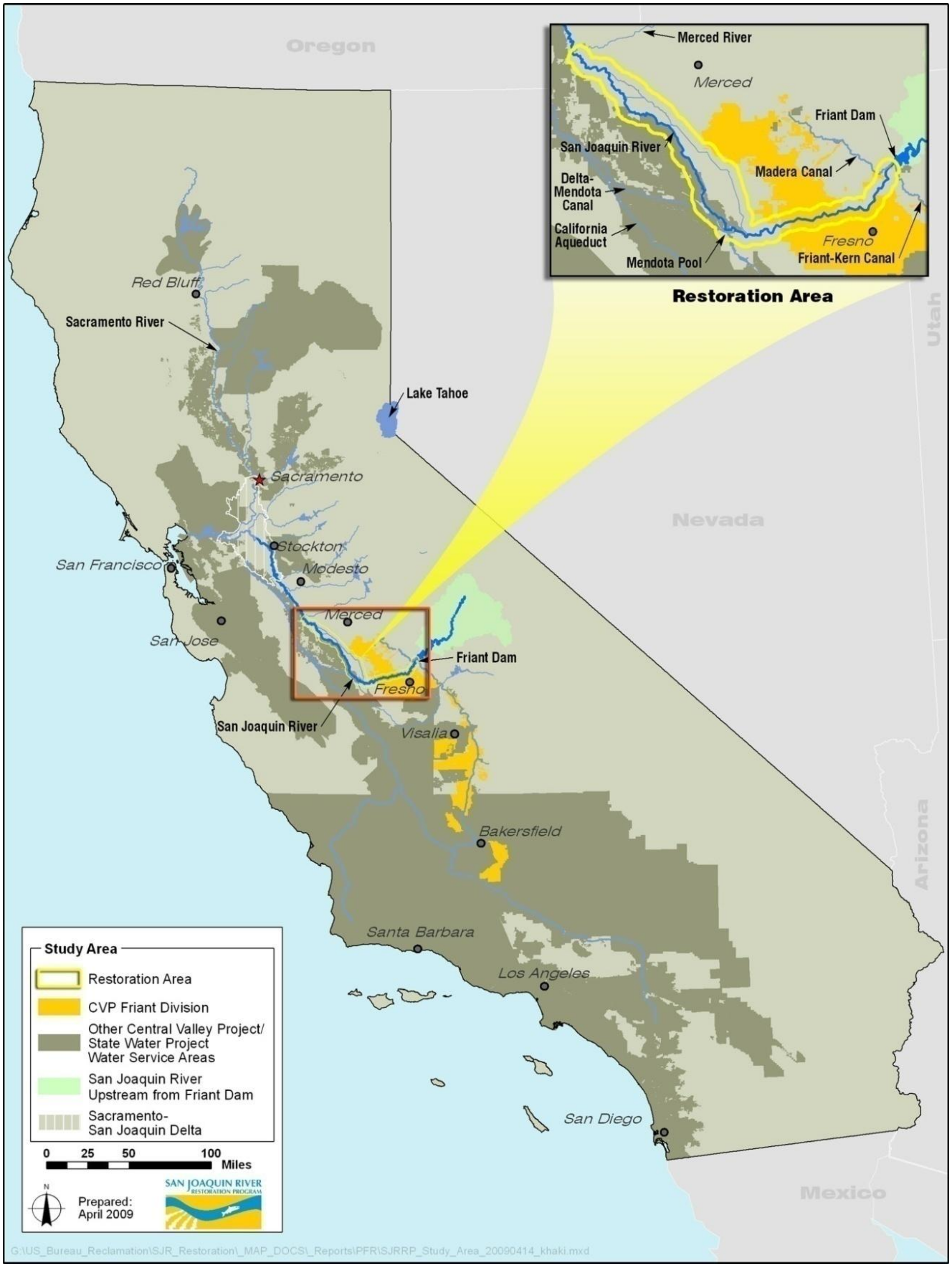

Figure 1-1.
San Joaquin River Restoration Program Study Area

Figure 1-2.
San Joaquin River Restoration Area and the Defined River Reaches

1.1 Document Organization

The information herein is the result of a thorough and in-depth review of background literature, reports, and existing models describing the life history and biology of Central Valley spring- and fall-run Chinook salmon. In addition, Central Valley late fall-run may be introduced through the SJRRP if their life history tactics prove to be more successful than fall-run Chinook salmon. The following components are described in detail:

- Historical population status of Chinook salmon in the San Joaquin River before and immediately after construction of Friant Dam (Chapter 2)
- Review of background literature on the basic life history and habitat requirements of Chinook salmon in the San Joaquin River Basin, including the Merced, Tuolumne, and Stanislaus rivers, the greater Central Valley, and other Pacific Coast river systems, where appropriate (Chapter 3)
- Discussion of stressors, including human activities and environmental conditions that affect Chinook salmon survival (Chapter 4)
- Conceptual models of the mechanisms likely to influence the abundance and recovery of spring- and fall-run Chinook salmon populations in the San Joaquin River (Chapter 5)
- Data needs (i.e., knowledge gaps) for spring- and fall-run Chinook salmon in the San Joaquin River Basin (Chapter 6)
- Sources used to prepare this document (Chapter 7)

1.2 Scope

The Restoration Goal is to "restore and maintain fish populations in 'good condition' in the mainstem of the San Joaquin River below Friant Dam to the confluence with the Merced River, including naturally producing and self-sustaining populations of salmon and other fish…" (Settlement). While many fish species will benefit from actions to meet the Restoration Goal, such as the incorporation of Restoration Flows, the emphasis of the Restoration Goal primarily is on spring-run Chinook salmon, and secondarily fall-run or late fall-run Chinook salmon. Therefore, the scope of this document is limited to spring-, fall-, and late fall-run Chinook salmon.

1.3 Coordination

This document and the conceptual models herein are based on existing salmonid models for the California Central Valley, scientific literature, and the opinions of experts working in the San Joaquin River Basin. It will be further developed through extensive coordination and collaboration with various salmonid experts, restoration ecologists, modelers, as well as groups working in the basin, and Work Groups of the SJRRP. The Chinook salmon conceptual models are intended to aid in the facilitation, negotiation, and coordination of quantitative Chinook salmon population models, monitoring metrics, potential adaptive management strategies, and various regulatory review processes.

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Chapter 2 Historical Population Dynamics in the San Joaquin River

Considerable historical documentation exists regarding the presence of Chinook salmon in the San Joaquin River and its tributaries, although the identification of race is often difficult to ascertain. The first documentation of Chinook salmon in the San Joaquin River comes from Spanish explorers and missionaries of Old California (Yoshiyama et al. 2001). Large schools of adult Chinook salmon were observed in the pools near Friant during May, June, and the first part of July by the U.S. Fish Commission (Yoshiyama et al. 2001). The anectdotal history of Native American inhabitants contains references to salmon being harvested seasonally upstream to Graveyard Meadows (Lee 1998). Salmon were also encountered in upper San Joaquin River tributaries such as the North San Joaquin River, Fine Gold Creek, Cottonwood Creek, and Whiskey Creek (Yoshiyama et al. 2001) and in valley floor tributaries such as the Chowchilla and Fresno rivers.

The California Fish and Game Commission noted dramatic salmon declines in the late 1800s (Yoshiyama et al. 2001). Gold mining, agricultural development, deforestation, and water development such as dam construction and flood conveyance activities adversely impacted salmon habitat. By the late 1800s and early 1900s, numerous impediments to anadromous fish passage were present in the San Joaquin River. These included Mendota Pool (River Mile (RM) 205) and Kerckhoff Dam (approximately RM 291) After Kerckhoff Dam was constructed in 1920, it permanently blocked spring-run Chinook salmon from spawning areas upstream and seasonally affected the flow in 14 miles of river with pools that provided over-summering habitat.

Clark (1929) reported that in the early 1900s there were primarily spring-run fish and relatively few fall-run. He said that the spring-run Chinook salmon was “very good” in 1916 and 1917, “fairly good” in 1920 and 1926, but in 1928, very few Chinook salmon were seen in the river. By the 1920s, reduced autumn flows in the mainstem San Joaquin River nearly eliminated the fall run, although a small run did persist.

2.1 Spring-Run Chinook Salmon

Spring-run Chinook salmon once occupied all major river systems in California where there was access to cool reaches that would support over-summering adults. Historically, spring-run Chinook salmon were widely distributed in streams of the Sacramento-San Joaquin River basins, spawning and rearing over extensive areas in the upper and middle reaches (elevations ranging 1,400 to 5,200 feet (450 to 1,600 meters)) of the San Joaquin, American, Yuba, Feather, Sacramento, McCloud, and Pit rivers (Myers et al. 1998). Only two evolutionarily significant units (ESU) of spring-run Chinook salmon remain in California: a Central Valley population and a Klamath-Trinity population

(Moyle et al. 1995). Spring-run Chinook salmon in the San Joaquin River were extirpated in the mid- to late 1940s following the construction of Friant Dam and diversion of water for agricultural purposes to the San Joaquin Valley.

After Friant Dam was constructed, numerous spring-run Chinook salmon returned to the river below the dam during the years when the river flowed below Sack Dam (Table 2-1) (DFG 1946, Warner 1991). Clark (1943) noted that Friant Dam first prevented upstream passage in 1942, although the dam did not begin storing water until February 21, 1944. Clark (1943) estimated that there were about 5,000 spring-run fish in a holding pool immediately below the dam in 1942, but no complete count was made that year. There was a “poor” run in 1944, when flows below Sack Dam were low and many fish were killed by “spearing” (DFG 1946). In 1945, daytime counts indicated that at least 56,000 spring-run fish passed through the Mendota Dam fish ladder or jumped over the dam (DFG 1946); it is likely that the Mendota Dam counts were low because many adults migrate at night. Flows below Sack Dam were low from spring 1948 through 1950 (Table 2-1) when only a portion of the runs were salvaged (Warner 1991). Escapement surveys were not conducted after 1950.

Table 2-1.
Spring-Run Chinook Salmon in the San Joaquin River from 1943 to 1950

Year	Number Counted	Counting Method	Flows at Sack Dam (cfs)
1943	35,000	Mendota Dam Ladder	4,086
1944	5,000	Mendota Dam Ladder	83
1945	More than 56,000	Mendota Dam Ladder	3,066
1946	30,000	Mendota Dam Ladder	1,138
1947	6,000	Mendota Dam Ladder	98
1948	More than 1,915	Hills Ferry Weir Trap	23
1950	36	Ladder from Salt Slough	3

Key:
cfs = cubic feet per second

2.2 Fall-Run/Late Fall-Run Chinook Salmon

The San Joaquin River likely supported relatively few fall-run Chinook salmon after diversions began at Sack Dam, some time between 1860 and 1880 (http://are.berkeley.edu/courses/EEP162/spring2007/documents/SJRcasehistory.pdf). Clark (1929) reported that there were few fall-run Chinook in the San Joaquin River since the early 1900s because of inadequate fall flows. During all but wet years, the river was nearly completely dewatered downstream from Sack Dam until late November (Hatton 1940, Clark 1943), by which time it was too late for most fall-run Chinook salmon to migrate upstream in the San Joaquin River Basin. However, Hatton (1940) reported that in some years, fall-run fish migrated through natural sloughs and irrigation canals to the San Joaquin River above the Mendota weir. No escapement surveys were made to document the abundance of fall-run fish in the San Joaquin River.

Since the 1950s, some San Joaquin River fall-run Chinook salmon have continued up the mainstem San Joaquin River into Salt and Mud sloughs, and their tributaries on the west side of the valley (DFG 2001). These sloughs conveyed poor quality water and had no suitable Chinook salmon spawning habitats (DFG 2001). In response to these events, the California Department of Fish and Game (DFG) has installed and operated a temporary fish barrier (Hills Ferry Barrier) just upstream from the confluence with the Merced River since 1992 (DFG 2001, 2005). Adult Chinook salmon were observed at the barrier and above the barrier between late October and mid-November in 2000 and 2004 (DFG 2001, 2005).

It is also likely a population of late fall-run Chinook salmon was present historically in the San Joaquin River basin although appreciable numbers are currently only present in the Sacramento River Basin (Williams 2006).

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Chapter 3 Life History Requirements

Central Valley Chinook salmon exhibit two general freshwater life-history-types, “stream-type” and “ocean-type” (Healey 1991). The evolution of stream-type and ocean-type life histories is an adaptation to the seasonal flow and temperature regimes in the rivers where Chinook salmon spawn and rear. Central Valley spring- and late fall-run Chinook salmon are generally classified as stream-type because the adults migrate into mid-elevation watersheds where they spend several months while they mature sexually, and because juveniles typically spend at least 1 year rearing in fresh water. However, in the Central Valley and Oregon, spring-run Chinook salmon juveniles often migrate to the ocean within a few months after emerging from the gravel in the redd. In Butte Creek, California, the contribution of the subyearling life stage to adult production is approximately four times that of the yearling life stage (Ward et al. 2002). In contrast, Central Valley fall-run Chinook salmon are considered ocean-type, because the adults spawn in the lower watersheds within a few weeks of entering fresh water, and juveniles typically migrate to the ocean within a few months.

Adult and juvenile Chinook salmon express temporal and spatial variations in life-history patterns allowing adaptations to diverse and variable riverine environments (Moyle 2002). Both adult and juvenile salmon exhibit variable life-history expressions on both a temporal and spatial scale. Sufficient life-history diversity must exist to sustain a population through environmental perturbations and to provide for evolutionary processes. Thus, it is important to preserve as much life-history diversity as possible to maintain healthy Chinook salmon populations (Williams 2006). To promote the long-term success of Chinook salmon populations, restoration should provide sufficient habitat for several life-history types of spring-run Chinook salmon in the Restoration Area.

Whereas adult spring-run Chinook salmon returning to the San Joaquin River are expected to exhibit various life-history patterns on both temporal and spatial scales, the juvenile stage typically exhibits more life-history variability than adults. In addition, juvenile salmon have a stronger dependence on riverine habitat for successful survival than adults and many of the restoration actions required by the Settlement focus on the juvenile phase. Improving passage, migratory habitat, and holding habitat will be important to ensure long-term success for adult spring-run Chinook salmon. The following discussion focuses on the juvenile stage of spring-run Chinook salmon. It is expected that fall- and late-fall-run Chinook salmon juveniles will also benefit from the preservation of habitats that support multiple life-history types as well.

There is substantial variation between the stream-type and ocean-type life-history categories, particularly regarding spring-run Chinook salmon. Many subtypes of the ocean-type and stream-type migrant designations have been described (Gilbert 1912, Reimers 1973, Schluchter and Lichatowich 1977, Fraser et al. 1982). Specific patterns of juvenile migrants have been observed in Butte, Mill, and Deer creeks and are described in

Chapter 3. The Butte Creek population consists of fry migrants that primarily disperse downstream from mid-December through February, subyearling smolts that primarily migrate between late-March and mid-June, and yearlings that migrate from September through March (Hill and Webber 1999, Ward and McReynolds 2001, Ward et al. 2002). Juvenile emigration patterns in Mill and Deer creeks are very similar to patterns observed in Butte Creek, with the exception that Mill Creek and Deer Creek juveniles typically exhibit a later young-of-the-year migration and an earlier yearling migration (Lindley et al. 2004).

Before and shortly after Friant Dam was constructed, numerous spring-run Chinook salmon fry from the San Joaquin River entered the estuary. Before construction of Friant Dam, seasonal downstream migrations of juvenile Chinook salmon occurred following periods of high discharge (Hallock and Van Woert 1959). In 1944, peak migration at Mendota was between late January and June, peaking in February. At Mossdale, sampling indicated the greatest numbers emigrated during January and February (Hallock and Van Woert 1959). Juveniles captured at Mendota before 1949 were “for all practical purposes the progeny of spring-run Chinook salmon adults only, since very few fall-run fish spawned in the upper San Joaquin” (Hallock and Van Woert 1959). Based on this information, it is likely that fry-sized spring-run Chinook salmon from the San Joaquin River Basin historically used the lower San Joaquin River and the Delta for rearing.

The FMWG expects three general life-history types may be present in the San Joaquin River following restoration: 1) yearling, 2) fry migrant, and 3) transient fry migrant (Figure 3-1). There are many variations of these general life-history types, but these basic strategies are presented as a guideline. Similar to spring-run Chinook salmon observed in tributaries to the Sacramento River, the Fry Migrant category exhibits an early outmigration life history, using downstream rearing areas, such as Reaches 4 and 5. The Transient Fry Rearing life-history category would be expected to rear in upper reaches of the Restoration Area (i.e., Reach 2B), and migrate out of the Restoration Area in late spring. As found in the Sacramento River Basin, the Yearling life-history category of spring-run Chinook salmon expected in the San Joaquin River would use the upper reaches of the Restoration Area (Reach 1) for rearing and migrate downstream during fall or winter. The contribution of these life-history types to spring-run recruitment success is unknown.

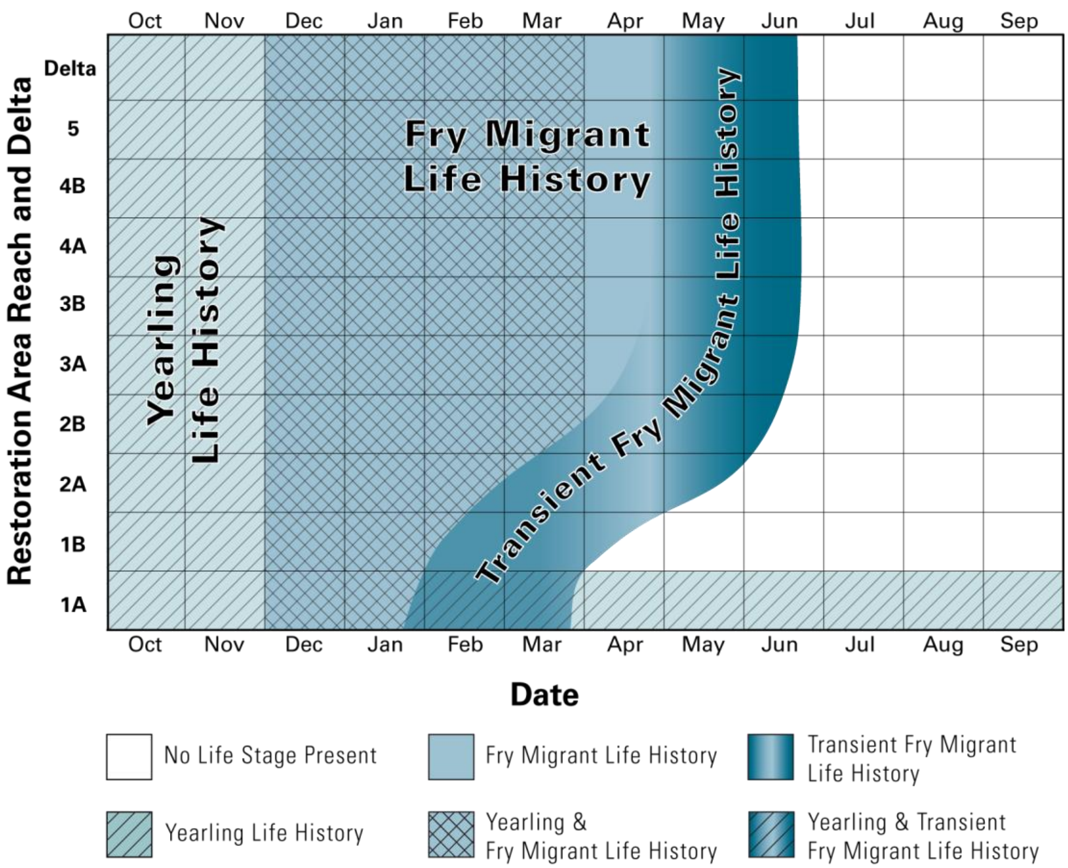


Figure 3-1.
General Representation of Three Life-History Types of Juvenile Spring-Run Hypothesized to Be Expressed in the Restoration Area and Delta Following Restoration Actions

The underlying biological basis for differences in juvenile life history appear to be both environmental and genetic (Randall et al. 1987). Distance of migration to the marine environment, stream stability, stream flow and temperature regimes, stream and estuary productivity, and general weather regimes have been implicated in the evolution and expression of specific emigration timing. Juvenile stream- and ocean-type Chinook salmon have adapted to different ecological niches. Ocean-type Chinook salmon tend to use estuaries and coastal areas more extensively for juvenile rearing. In general, the younger (smaller) juveniles are at the time of emigrating to the estuary, the longer they reside there (Kjelson et al. 1982, Levy and Northcote 1982, Healey 1991). Brackish water areas in estuaries also moderate physiological stress during parr-smolt transition. In the Sacramento River and coastal California rivers, subyearling emigration is related to the avoidance of high summer water temperatures (Calkins et al. 1940, Gard 1995). Ocean-type Chinook salmon may also use seasonal flood cycles as a cue to volitionally begin downstream migration (Healey 1991). Migratory behavior in ocean-type Chinook salmon juveniles is also positively correlated with water flow (Taylor 1990a).

Barriers to life-history expression include flow truncation or alteration, passage barriers, lack of appropriate habitat, water quality and temperature, ocean conditions, etc. Given the uncertainties with stock selection and adaptation to the San Joaquin River environment, we intend to manage and restore habitats to promote expression of several life-history variations exhibited in other spring-run populations.

A critical life-history requirement for all life-history stages of Chinook salmon is water temperature. Available literature frequently describes the suitability of water temperatures as optimal, suitable, not suitable, stressful, and lethal for fish. These definitions are not standardized to represent particular physiological responses and the definition of these frequently used terms often varies among authors. For these reasons, temperature requirements will be defined as either optimal, critical, or lethal. Optimal water temperatures are defined as those that provide for normal feeding activity, normal physiological response, and behavior void of thermal stress symptoms (McCullough 1999). Critical water temperatures are defined as causing some level of thermal stress. Thermal stress is defined as any water temperature that alters the biological functions of fish and decreases the probability of survival (McCullough 1999). Lethal levels are defined as resulting in substantial mortality. Water temperatures below optimal levels may also cause thermal stress or mortality, but the San Joaquin River system is not expected to experience thermally stressful low water temperatures, so those will not be addressed in this document.

Table 3-1 provides an overview of the water temperature objectives as identified by the FMWG for Chinook salmon. Optimal, critical, and lethal temperatures are cited. Optimal temperatures are defined using ecological and physiological optimum criteria. These criteria are threshold levels for long term population sustainability and signify optimum growth and survival under natural ecological conditions including the existence of predation pressure, competition, variability in food availability, etc. (EPA 2003). Because optimal temperatures represent a range, they are defined as “less than or equal to” the upper limit of the optimal range. Critical and lethal temperatures are cited from a number of independent studies evaluating thermal stress on salmonids in both laboratory and natural settings. Critical temperatures are expressed as a range of stress-inducing temperatures. The primary sources for water temperature criteria listed in Table 3-1 are the U.S. Environmental Protection Agency’s (EPA) Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality (EPA 2003), Rich (2007) Impacts of Water Temperature on Fall-Run Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*O. mykiss*) in the San Joaquin River System, and Pagliughi (2008), Lower Mokelumne River Reach Specific Thermal Tolerance Criteria by Life Stage for Fall-Run Chinook Salmon and Winter-Run Steelhead. All of these sources represent broad literature reviews of temperature thresholds and requirements for salmonids on the west coast.

Table 3-1.
Temperature Objectives for the Restoration of Central Valley Chinook Salmon

Monthly Water Temperature Objectives for the San Joaquin River Restoration Program												
Spring-Run and Fall-Run Chinook Salmon												
Life Stage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Adult Migration			Optimal: ≤ 59°F (15°C) Critical: 62.6 – 68°F (17 – 20°C) Lethal: >68°F (20°C)									
Adult Holding (Spring-Run Only)				Optimal: ≤55°F (13°C) Critical: 62.6 – 68°F (17 – 20°C) Lethal: >68°F (20°C)								
Spawning								Optimal: ≤ 57°F (13.9°C) Critical: 60 – 62.6°F (15.5 – 17°C) Lethal: 62.6°F or greater (17°C)				
Incubation and Emergence								Optimal: ≤55°F (13°C) Critical: 58 – 60°F (14.4 – 15.6°C) Lethal: >60°F (15.6°C)				
In-River Fry/Juvenile	Optimal: ≤60°F (15.6°C), young of year rearing; ≤62.6°F (18°C), late season rearing (primarily spring-run) Critical: 64.4 – 70°F (18-21.1°C) Lethal: >75 °F (23.9°C), prolonged exposure											
Floodplain Rearing*	Optimal: 55 – 68°F (13 – 20°C), unlimited food supply											
Outmigration	Optimal: ≤60°F (15.6°C) Critical: 64.4 – 70°F (18 – 21.1°C) Lethal: >75°F (23.9°C), prolonged exposure											

Sources: EPA 2003, Rich 2007, Pagliughi 2008, Gordus 2009.

Note:

* Floodplain rearing temperatures represent growth maximizing temperatures based on floodplain condition. No critical or lethal temperatures are cited assuming fish have volitional access and egress from floodplain habitat to avoid unsuitable conditions.

Shaded box indicates life stage is present

Key:

°F = degrees Fahrenheit

°C = degrees Celsius

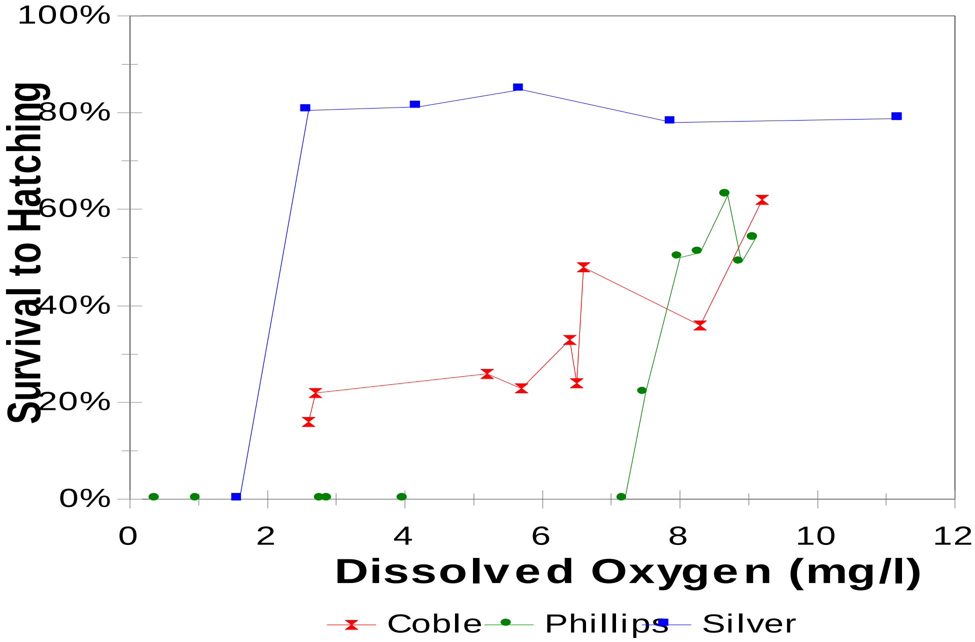
3.1 Egg Survival and Emergence

Salmon eggs incubate in nests called redds in gravel beds at depths of 12 to 18 inches under the surface of the bed until the alevins hatch in 40 to 50 days at a water temperature of 50 degrees Fahrenheit (°F) (10 degrees Celsius (°C)). Normal embryo development and emergence of the fry from the gravel require suitable water temperatures, high concentrations of dissolved oxygen (DO), sufficient intragravel flow to deliver oxygenated water and flush metabolic wastes from the egg pocket, and a minimal amount of fine sediments that would otherwise block their emergence. In the Sacramento River and its tributaries, the egg incubation period for spring-run Chinook salmon extends from August to March (Fisher 1994, Ward and McReynolds 2001), whereas the incubation period for fall-run Chinook salmon in the San Joaquin River Basin extends from late October through February. Late fall-run Chinook salmon eggs incubate through April to June.

This discussion focuses on factors that affect egg survival to the hatching stage and the factors that affect the ability of fry to emerge from the gravels. Gravel type, velocities, and specific spawning preferences of Chinook salmon are described in Section 3.5, Spawning.

3.1.1 Dissolved Oxygen and Turbidity

Numerous field and laboratory studies indicate that egg survival to hatching is greatly dependent on high concentrations of DO (Chapman 1988, Kondolf 2000). Excessive concentrations of substrate fines smaller than 1 millimeter (mm) in diameter are usually correlated with reduced DO (Chapman 1988, Kondolf 2000). There is a strong possibility that turbidity also affects egg survival as a result of clay-sized particles adhering to an egg's membrane (Stuart 1953), reducing the egg's ability to absorb DO. This effect provides a good explanation of why salmonid eggs survive at high rates under low DO concentrations under clean laboratory conditions but not under natural settings with higher turbidity levels. When steelhead eggs were incubated on clean, porous ceramic plates under highly controlled levels of DO and flow in a laboratory, survival was high (about 80 percent) at DO levels as low as 2.5 milligrams per liter (mg/L) (Silver et al. 1963) (Figure 3-2). In contrast, a field study by Coble (1961), during which steelhead eggs were placed in plastic mesh sacks with gravel, indicates that egg survival gradually declined as DO declined from 9.2 mg/L to 2.6 mg/L (Figure 3-2). Another field study by Phillips and Campbell (1962), during which eggs were placed in perforated metal boxes with glass beads, indicates that no eggs survived at DO levels at or below 7.2 mg/L (Figure 3-2).



Sources: Silver et al. 1963 Coble 1961, and, Phillips and Campbell 1962.

Figure 3-2.
Relationship Between Dissolved Oxygen Concentration and Survival to Hatching of Steelhead Trout Eggs During Laboratory and Field Studies

Studies with other salmonid species show similar results. Eggs of chum salmon (*O. keta;* Alderdice et al. 1958), Chinook salmon (Silver et al. 1963), and coho salmon (*O. kisutch;* Shumway et al. 1964) incubated under clean laboratory conditions hatched at high rates at DO concentrations as low as 2.0 to 2.5 mg/L. Chum salmon eggs that were deposited in natural redds in an experimental stream channel with washed gravels also exhibited relatively high survival rates (50 percent) at DO levels as low as 2.5 mg/L (Koski 1975). Conversely, the survival of coho salmon eggs incubated in natural streams either in natural redds (Koski 1966) or in experimental chambers (Phillips and Campbell 1962) were reduced at DO concentrations below 9.0 mg/L and 8.3 mg/L, respectively. Although the adhesion of fines to the egg's membranes was not evaluated in the field studies, it is the most likely explanation for why eggs require greater concentrations of DO in natural streams than in a laboratory or in washed gravel.

The DO requirement for Chinook salmon eggs has not been accurately determined under natural field conditions. Gangmark and Bakkala (1960) studied the hatching survival of Chinook salmon eggs in artificial redds in Mill Creek, Tehama County, relative to DO concentrations. Their results were questionable, however, because individual test results were not presented and the authors referred to their earlier studies for a description of the methods (Gangmark and Broad 1955). The egg-handling mortalities averaged 53 percent, possibly because the eggs were not allowed to water-harden before handling and because fungal infections caused by egg contact with the plastic mesh net bag resulted in mortality (Gangmark and Broad 1955). Furthermore, an evaluation of a portion of their raw data presented in Gangmark and Bakkala (1958) indicated that they obtained a poor relationship between survival and DO concentration, possibly due to variable rates in handling mortality among replicates. Without better direct evidence, it is assumed that Chinook salmon eggs have a relatively high DO requirement compared to coho and chum salmon and steelhead trout because Chinook salmon produce relatively large eggs. Large eggs generally require high DO concentrations because they have a relatively small surface-to-volume ratio (Beacham and Murray 1985).

In addition to the effects of low DO concentrations on survival of eggs to hatching, any reduction in DO below the saturation level results in slowly developing embryos that emerge at a small size and before the complete absorption of yolk (Phillips and Campbell 1962, Silver et al. 1963, Shumway et al. 1964, Mason 1969, Wells and McNeil 1970, Koski 1975). It is likely that small alevins are relatively weak and less able to emerge through sand layers covering the egg pocket than are large relatively healthy alevins incubated at high DO concentrations. Furthermore, Mason (1969) reported that small coho salmon fry subjected to low DO levels during incubation could not compete successfully with larger fry and emigrated from experimental channels. Chapman (1988) suggested that any reduction in DO levels from saturation probably reduces survival to emergence or postemergent survival.

3.1.2 Intragravel Flow

Intragravel flow is correlated with egg survival. Intragravel flow is measured as either permeability or apparent velocity during egg survival studies. Permeability is the ease with which water passes through gravel, and depends on the composition and degree of packing of the gravel and viscosity of the water (Pollard 1955). Apparent velocity is the horizontal vector of interstitial flow and is a function of permeability and hydraulic gradient (Pollard 1955, Freeze and Cherry 1979). It is measured as the rate of flow through a standpipe, which is called apparent yield, divided by the porosity of the surrounding gravel. The actual velocity of flow through interstitial spaces, which is called the true or pore velocity, is faster than the apparent velocity because flow travels around substrate particles whereas apparent velocity assumes that the flow path is linear. Laboratory studies, such as Silver et al. (1963), that incubate eggs without a gravel medium, measure true velocity, whereas all field studies measure apparent velocity with standpipes.

The survival of steelhead and coho salmon egg to hatching in natural streams has been correlated with apparent velocity but not as strongly as with DO concentration, whereas there were no correlations with permeability (Coble 1961, Phillips and Campbell 1962). The size of coho salmon and steelhead embryos at hatching was reduced at low velocities, regardless of DO concentration in the laboratory (Shumway et al. 1964), whereas Chinook salmon and steelhead egg survival was not correlated with true velocity under the same laboratory conditions (Silver et al. 1963). Koski (1966) reported that survival to emergence of coho salmon eggs in natural redds was not correlated with a permeability index (milliliters per second). Sowden and Power (1985) reported that rainbow trout egg survival in a groundwater-fed stream was strongly correlated with DO and apparent velocity, but not with the percentage of fines less than 2 mm, the geometric-mean particle size, also called the fredle index.

Although egg survival and apparent velocity have been highly correlated in several studies, there is no consistent critical apparent velocity for egg survival, possibly because of the influence of different levels of DO and the adhesion of clay-sized particles to the egg's membrane among the studies. The results of five studies are listed below as evidence that the critical apparent velocity necessary for high rates of egg survival can vary from 0.65 foot per hour (ft/hr) (20 centimeters (cm) per hour (cm/hr)) to 50.9 ft/hr (1,550 cm/hr), depending on the DO concentration.

- Gangmark and Bakkala (1960) reported that the mean survival to hatching for newly fertilized Chinook salmon eggs planted in 220 artificial redds in Mill Creek, Tehama County, exceeded 87 percent where apparent velocity was at least 1.5 ft/hr and DO exceeded 5 mg/L. Mean survival was 67 percent at 14 sites where apparent velocity ranged between 0.5 and 1.0 ft/hr during the same study. However, the results of their study are questionable because individual test results were not presented and the methods were not described (see the above discussion on egg DO requirements).

- Coble (1961) reported that steelhead egg survival to hatching was high, 48 to 62 percent, at artificial redds with mean apparent velocities that exceeded 1.52 ft/hr (46.5 cm/hr) and mean DO levels greater than 6.4 mg/L.

- Phillips and Campbell (1962) reported that steelhead egg survival was high, 49 to 63 percent, in artificial redds with apparent velocities that exceeded 0.65 ft/hr (20 cm/hr) and mean DO levels that exceeded 8.3 mg/L.

- Reiser and White (1988) reported that Chinook salmon egg survival to hatching was highly correlated ($r = 0.797$) with apparent velocity and the percentage of two size classes of substrate fines during laboratory tests that maintained DO levels between 6.2 and 7.7 mg/L. These results suggest that at low DO levels tested, apparent velocity less than 50.9 ft/hr (1,550 cm/hr) resulted in reduced egg survival. They also reported that fines less than 0.84 mm in diameter affected survival to a much greater degree than did sediment between 0.84 and 4.6 mm in diameter, presumably due to greater influence of intragravel flow.

- Deverall et al. (1993) reported apparent velocities in natural Chinook salmon redds exceeded 16.4 ft/hr (500 cm/hr) at 45 of 49 redds in the Waitaki River, New Zealand, and that egg survival to hatching was between 75 and 98 percent at three redds where apparent velocity ranged between 6.56 ft/hr (200 cm/hr) and 9.84 ft/hr (300 cm/hr) and DO levels were near saturation.

3.1.3 Water Temperature

A review of numerous studies suggests that 42 to 55°F (5.5 to 13°C) is the optimum temperature range for incubating Chinook salmon (Donaldson 1955, Combs and Burrows 1957, Combs 1965, Eddy 1972, Bell 1973, Healey 1979, Reiser and Bjornn 1979, Garling and Masterson 1985). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards provides an optimum temperature threshold of less than 55°F (13°C) for incubation of salmonid eggs based on an extensive review referencing 41 sources that included five issue papers. The issue papers, in turn, referenced approximately 700 citations. As temperatures rise above this range the results can be increased incidence of disease, and mortality. Rich (2007) indicate, through a compilation of available studies that a range 58°F (14.4°C) to 60°F (15.6°C) contributes to increased mortality greater than 20 percent but less than 100 percent mortality. Seymour (1956) showed a rapid increase in Chinook salmon egg mortality as temperatures increased above 57°F (13.9°C), and 100 percent mortality in the yolk-sac stage when temperatures were increased to 60°F (15.6°C). Alderdice and Velsen (1978) estimated that the upper temperature limit for 50-percent mortality of Chinook salmon eggs was near 61°F (16°C); Healey (1979) found that water temperatures higher than 57°F (13.9°C) caused greater than 82-percent mortality of Chinook salmon eggs in the Sacramento River. These eggs appear to be no more tolerant of high water temperatures than the more Northern California races. Myrick and Cech (2001) likewise concluded that there appears to be very little variation in thermal tolerance of Chinook salmon eggs among geographic races.

Chinook salmon egg survival also declines at water temperatures below 42°F (5.6°C) and mortality is about 100 percent at a constant temperature of 35°F (1.7°C) (Leitritz 1959). Eggs can tolerate temperatures below 42°F (5.6°C) for about 6 days without mortality (Leitritz 1959). Gangmark and Bakkala (1958) reported water temperatures between 34 and 36.5°F (1.1 and 2.5°C) in January 1957 in artificial redds with planted eggs in Mill Creek, the North Fork of Mill Creek, and the Sacramento River. The duration of the cold temperatures was not reported but there was no indication that egg survival rates were affected. Cold water temperature tolerance limits are not specified in Table 3-1 due to the assumption that cold water impacts are not a limiting factor for Chinook salmon in the San Joaquin River.

3.1.4 Emergence

After hatching, alevins remain buried in the gravel for an additional period of development during which time nutrition is provided by absorption of the yolk sac. After yolk sac absorption by the alevins has been completed, fry begin the process of emerging from the gravel. In the Sacramento River Basin, spring-run Chinook salmon alevins remain in the gravel for 2 to 3 weeks after hatching and emerge from the gravels into the water column from November to March (Fisher 1994, Ward and McReynolds 2001). In the Tuolumne River, the period of fall-run Chinook salmon alevin development has been estimated to last between 35 and 55 days (mean 47 days) at 50 to 55°F (10 to 13°C), based on the timing from redd completion to peak emergence at five fall-run Chinook salmon redds monitored in fall 1988 (TID and MID 1992).

3.2 Juvenile Rearing and Migration

Upon emergence, Chinook salmon fry swim or are displaced downstream (Healey 1991). Active downstream movement of fry primarily occurs at night along the margins of the river. After this initial dispersal, fry may continue downstream to the estuary and rear, or may take up residence in the stream for a period of time from weeks to a year (Healey 1991). Although juvenile spring-run Chinook salmon are known to exhibit a stream-type life-history pattern wherein they remain in freshwater until the spring following their emergence from the gravel in the redd, they are also known to migrate from spawning areas in their first year. Populations in Oregon (Healey 1991) and California (e.g., Butte Creek) primarily migrate to the ocean as subyearling smolts within a few months after emergence. The duration of juvenile freshwater residency may be influenced by water temperature and river outflow. Nicholas and Hankin (1989) found that the duration of freshwater rearing in Oregon coastal streams is tied to water temperatures, with juvenile Chinook salmon remaining longer in rivers with cool water temperatures. Moyle (2002) suggests that the propensity for Chinook salmon fry and smolts to emigrate to the ocean increases as high flows cause reduced water temperatures and increased turbidity.

River-rearing Chinook salmon fry occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris or large substrate (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). Juvenile Chinook salmon often seek refuge in low velocity habitats where they can rest and feed on drifting invertebrates with minimum expenditure of energy. Because of the energetic demands of both retaining position within the water column and obtaining prey items, as well as the metabolic demands on ectotherms (organisms that regulate their body temperatures based on their surrounding environment) as water temperatures increase, feeding and growth in rivers depend on a number of factors working in concert. Energy required to maintain position within the water column is generally a function of body size (Chapman and Bjornn 1969, Everest and Chapman 1972). For example, small fish and newly emerged fry typically inhabit slower water habitats, often found at the margins of mainstem channels, backwaters, or side channels. Larger fish typically move into swifter flowing habitats, where larger prey are usually available (Lister and Genoe 1970). This shift is also energetically more economical, since larger fish would require more prey items, and capturing one prey item is energetically more efficient than capturing many.

Juvenile salmonids larger than 2 inches (50 mm) in length in the Sacramento-San Joaquin system also rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook salmon juveniles that reared on the Yolo Bypass than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. Sommer et al. (2001) found that drifting invertebrates, the primary prey of juvenile salmonids, were more abundant on the inundated Yolo Bypass floodplain than in the adjacent Sacramento River. Bioenergetic modeling suggested that increased prey availability on the Yolo Bypass floodplain was sufficient to offset increased metabolic demands from higher water temperatures (9°F (5°C)) higher than in the mainstem). Gladden and Smock (1990) estimated that annual invertebrate production on two Virginia floodplains exceeded river production by one to two orders of magnitude. In the Virginia study, annual production on the floodplain continuously inundated for 9 months was 3.5 times greater than on the floodplain inundated only occasionally during storms (Gladden and Smock 1990).

Sommer et al. (2001) suggested that the well-drained topography of the Yolo Bypass may help reduce stranding risks when floodwaters recede. Most floodplain stranding occurs in pits or behind structures (e.g., levees or berms) that impede drainage (Moyle et al. 2005). Additionally, research in the Cosumnes River (Moyle et al. 2005) and Tuolumne River

(Stillwater Sciences 2007) suggests that flow-through of water on inundated floodplains appeared to be more important for providing suitable habitat for Chinook salmon and other native fish species than the duration of inundation or other physical habitat characteristics. Thus, configuration of restored floodplains to promote active flow-through of river water (i.e., creation of conveyance floodplains) would likely maximize habitat value for juvenile Chinook salmon.

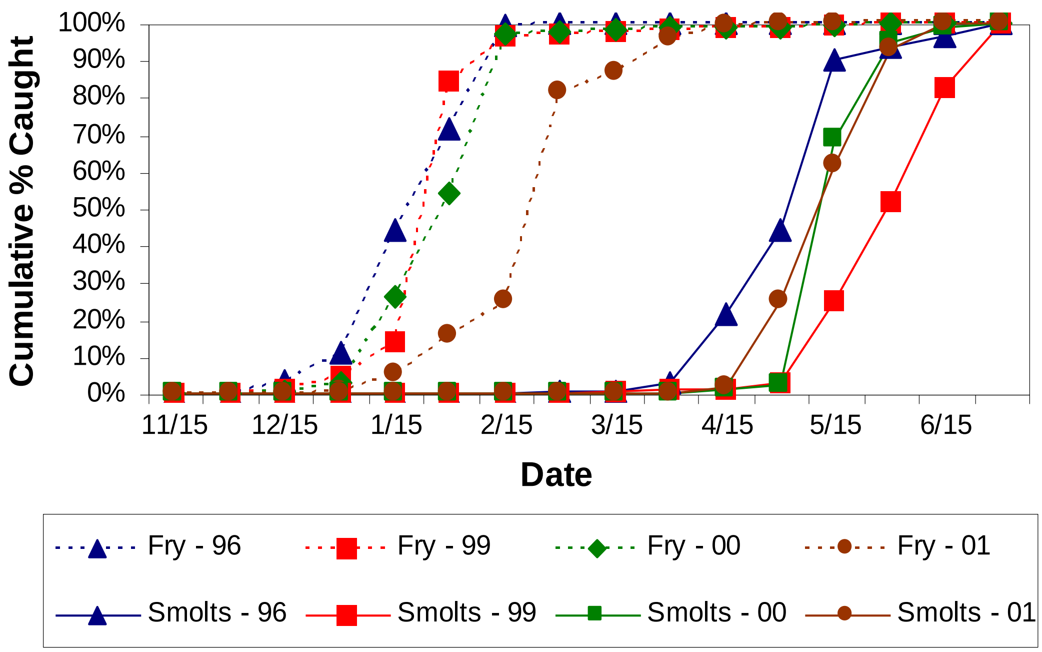
Considering the historical extent of floodplain inundation in the San Joaquin River Basin, and tule (*Scirpus acutus*) marsh habitat along the San Joaquin River before land development, it is possible that juvenile Chinook salmon and steelhead reared on inundated floodplains in the San Joaquin River in Reaches 2 through 5. These downstream reaches were inundated for a good portion of the year in normal and wetter years, providing suitable water temperatures for juvenile rearing from January to at least June or July in most years, and perhaps extending into August in wetter years. As snowmelt runoff declined, and ambient temperatures increased, water temperatures in slow-moving sloughs and off-channel areas probably increased rapidly. The extent to which juvenile salmonids would have used the extensive tule marshes and sloughs historically found in Reaches 2, through 5 is unknown.

The quality of juvenile rearing habitat is highly dependent on riparian vegetation. Riparian vegetation provides shading which may slightly affect river temperatures and provide cover; provides allochthonous organic matter that drives the Chinook salmon's food web; contributes woody debris for aquatic habitat complexity, bank stability through root systems, and filtration of sediments and nutrients in storm runoff (Helfield and Naiman 2001).

3.2.1 Migration Timing

Juvenile Chinook salmon in the Central Valley move downstream at all stages of their development: most as newly emerged fry dispersing to downstream rearing habitats and others that migrate toward the ocean as they undergo smoltification. Smoltification is the physiological process that increases salinity tolerance and preference, endocrine activity, and gill Na^+-K^+ ATPase activity. It usually begins in late March when the juveniles reach a fork length between 70 and 100 mm; however, a few fish delay smoltification until they are about 12 months old (yearlings) when they reach a fork length between 120 and 230 mm. Environmental factors, such as stream flow, water temperature, photoperiod, lunar phasing, and pollution can affect the onset of smoltification (Rich and Loudermilk 1991).

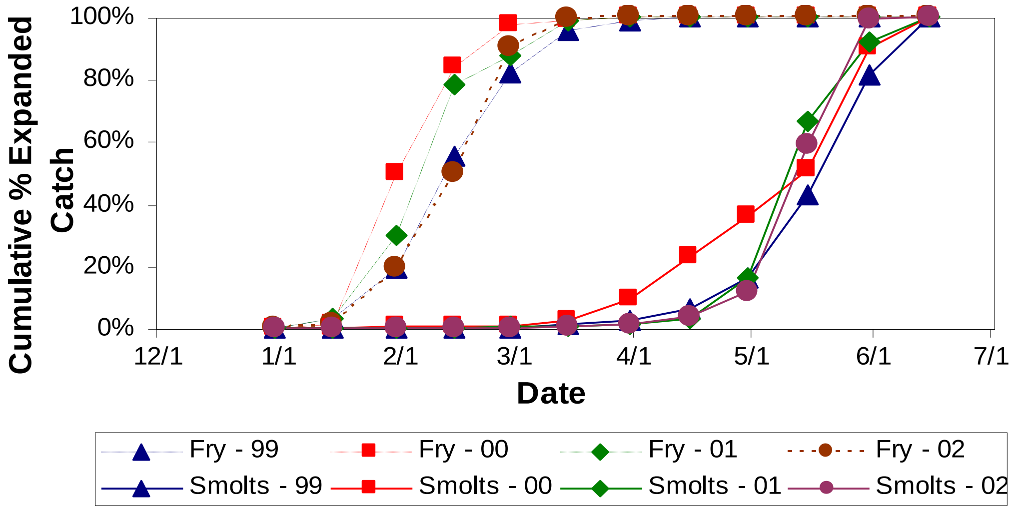
Rotary screw trap studies at the Parrott-Phelan Diversion Dam in Butte Creek probably provide the best available information on the migratory behavior of a natural spring-run Chinook salmon population in the Central Valley, because hatchery fish are not planted in Butte Creek and the fall-run Chinook salmon do not spawn above the study site. In Butte Creek, at least 95 percent of the juvenile spring-run Chinook salmon migrate as fry from the spawning areas upstream from Parrott-Phelan Diversion Dam into the Sutter Bypass where they rapidly grow (0.5 to 0.7 mm/day) to a subyearling smolt size (60- to 100-mm fork length (FL) (Ward et al. 2002). The Butte Creek fry primarily disperse downstream from mid-December through February (Figure 3-3) whereas the subyearling smolts primarily migrate between late-March and mid-June (Figure 3-3). Spring-run yearlings in Butte Creek migrate from September through March (Hill and Webber 1999, Ward and McReynolds 2001, Ward et al. 2002). Juvenile emigration patterns in Mill and Deer creeks are very similar to patterns observed in Butte Creek, with the exception that Mill Creek and Deer Creek juveniles typically exhibit a later young-of-the-year migration and an earlier yearling migration (Lindley et al. 2004).



Sources: Hill and Webber 1999, Ward and McReynolds 2001, Ward et al. 2002.
Notes:
1. The data are plotted in 2-week intervals relative to the last date of capture in each interval.
2. Fry less than or equal to 50-mm fork length.
3. Subyearling smolt greater than or equal to 70 mm fork length

Figure 3-3.
Cumulative Percent of Spring-Run Chinook Salmon Fry and Subyearling Smolt-Sized Fish Caught with Rotary Screw Trap at Parrott-Phelan Diversion Dam on Butte Creek, California, in 1996, 1999, 2000, and 2001

Fall-run Chinook salmon fry disperse downstream from early January through mid-March, whereas the smolts primarily migrate between late March and mid-June in the Stanislaus River (Figure 3-4), which is nearly identical to the timing of spring-run smolt outmigration in Butte Creek. Fall-run yearlings are caught during all months that the rotary screw traps are operating at Oakdale on the Stanislaus River; this occurs from December through June, regardless of flow (http://www.sanjoaquinbasin.com/fishbio-san-joaquin-basin-newsletter.html).



Source: http://www.sanjoaquinbasin.com/fishbio-san-joaquin-basin-newsletter.html.
Notes:
1. The data are plotted in 2-week intervals relative to the last date of capture in each interval.
2. Fry less than or equal to 50-mm fork length.
3. Smolt greater than or equal to 70-mm fork length.

Figure 3-4.
Cumulative Percent of Expanded Number of Fall-Run Chinook Salmon Fry and Smolt-Sized Fish Passing Rotary Screw Trap at Oakdale on the Stanislaus River, California, in 1999, 2000, 2001, and 2002

3.2.2 Delta and Estuary Rearing

In many systems, an important life-history strategy of juvenile salmonids is to take up residence in tidally functioning estuaries. While this is a common life-history strategy among Chinook salmon on the Pacific Coast, fry often appear most abundant 2 to 3 months earlier in the Delta than in other Pacific Coast estuaries, perhaps in response to the warmer temperatures in the Delta (Healey 1980, Kjelson et al. 1982). Juvenile Chinook salmon less than 70-mm FL are abundant in the Delta from February to April (MacFarlane and Norton 2002). Work in other West Coast estuaries indicates estuarine rearing by fry is important for Chinook salmon development (Levy and Northcote 1981). Fyke trapping and trawling studies conducted by the U.S. Fish and Wildlife Service (USFWS) in the Sacramento River and in the Delta suggest small juvenile Chinook salmon use the shoreline and larger juveniles typically use the center of the channel (USFWS 1994a). Other studies along the Pacific Coast also indicate a preference for nearshore areas by less mature juvenile Chinook salmon (Dauble et al. 1989, Healey 1991). The diet of fry and juvenile Chinook salmon in the San Francisco Estuary consists of dipterans, cladocerans, copepods, and amphipods (Kjelson et al. 1982). Thus, the nearshore habitats in the Delta and San Francisco Bay are probably valuable to juvenile Chinook salmon for rearing, whereas the main deepwater channels are used for migration.

Numerous spring-run Chinook salmon fry from the San Joaquin River entered the estuary before and shortly after Friant Dam was constructed. Before construction of Friant Dam, seasonal downstream migrations of juvenile Chinook salmon occurred following heavy outflow events (Hallock and Van Woert 1959). Peak migration at Mendota was between late January and June, peaking in February 1944. Additional sampling at Mossdale also found the greatest numbers emigrating during January and February (Hallock and Van Woert 1959). Juveniles captured at Mendota before 1949 were "for all practical purposes the progeny of spring-run Chinook salmon adults only, since very few fall-run fish spawned in the upper San Joaquin" (Hallock and Van Woert 1959). Based on this information, it is highly likely that fry-sized spring-run Chinook salmon from the San Joaquin River Basin historically reared in the lower San Joaquin River, Delta, and San Francisco Bay.

3.2.3 Smoltification and Estuary Presence

Juvenile salmon undergo complex physiological changes, called smoltification, in preparation for their life in saltwater (summarized in Quinn 2005). These include changes in osmoregulation (salt balance), body shape and color, energy storage, and migratory behavior. A change in osmoregulation is critical because in the freshwater environment, juvenile salmon must keep from losing their essential electrolytes (salts that regulate body functions) and absorbing too much water. To do this, they minimize water intake, excrete dilute urine, and actively acquire salts with their gills. In saltwater, which is saltier than their body fluids, fish drink, but must excrete salts from their gills and produce concentrated urine. The smolting process is metabolically demanding and juveniles release hormones, including cortisol, that trigger the use of their energy reserves. Cortisol inhibits the immune system, making smolts more vulnerable to disease and other stress. The juveniles Chinook salmon also undergo morphological changes which camouflage them in streams to the blue-green backs, silver sides, and white bellies that are typical of pelagic marine fishes. The smolting process is triggered by a combination of conditions, including body size, rate of growth, increasing day length, and increasing water temperatures. There is a smoltification window during spring, after which slow-growing, small individuals lose their ability to smoltify.

As Chinook salmon begin smoltification, they tend to rear further downstream where ambient salinity is up to 1.5 to 2.5 parts per thousand (ppt) (Healy 1980, Levy and Northcote 1981). Smolts enter the San Francisco Estuary primarily in May and June (MacFarlane and Norton 2002) where they spend days to months completing the smoltification process in preparation for ocean entry and feeding (Independent Scientific Group 1996). Within the estuarine habitat, juvenile Chinook salmon movements are dictated by the tidal cycles, following the rising tide into shallow water habitats from the deeper main channels, and returning to the main channels when the tide recedes (Levy and Northcote 1981, Healey 1991). Kjelson et al. (1982) reported that juvenile Chinook salmon demonstrated a diel migration pattern, orienting themselves to nearshore cover and structure during the day, but moving into more open, offshore waters at night. The fish also distributed themselves vertically in relation to ambient light. During the night, juveniles were distributed randomly in the water column, but would school during the day into the upper 9.843 feet (3 meters) of the water column.

Decaying marsh vegetation forms the basis of the juvenile Chinook salmon's food web in the Columbia River (Bottom 2007). Juveniles, 40- to 60-mm fork length, primarily used shallow, nearshore, and wetland habitats. They fed on insects (adult dipterans), amphipods (*Corophium salmonis*, *C. spinicome)*, and water fleas (*Cladocera*) that were produced in wetland habitats. Juveniles spent an average of 73 days (10 to 219) in the Columbia River estuary growing an average of 0.5 mm per day in 2004 (Bottom 2007).

In the San Francisco Estuary, insects and crustaceans dominate the diet of juvenile Chinook salmon (Kjelson et al. 1982, MacFarlane and Norton 2002). Larval fish become increasingly important in the diet as juvenile Chinook salmon approach and enter the ocean (MacFarlane and Norton 2002). Juvenile Chinook salmon spent an average of about 40 days migrating through the Delta to the mouth of San Francisco Bay in spring 1997, but grew little in length or weight until they reached the Gulf of the Farallon Islands (MacFarlane and Norton 2002). After passing through Suisun Bay, juvenile Chinook primarily fed on the hemipteran *Hesperocorixa* sp., the calanoid copepod *Eucalanus californicus*, the mysid *Acanthomysis* sp., fish larvae, and other insects (MacFarlane and Norton 2002). In San Pablo Bay, marine crustaceans in the order Cumacea were the dominant prey of juvenile Chinook salmon. In the Central Bay, the juvenile Chinook salmon fed on insects, fish larvae, *Ampelisca abdita* (a gammaridean amphipod), and cumaceans (MacFarlane and Norton 2002). Based on the mainly ocean-type life history observed (i.e., fall-run Chinook salmon), MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon show relatively little estuarine dependence and may benefit from expedited ocean entry. It is possible that the absence of extensive marsh habitats outside Suisun and San Pablo bays, and the introduction of exotic species of zooplankton, limit important food resources in the San Francisco Estuary that are present in other Pacific Northwest estuaries (MacFarlane and Norton 2001).

3.2.4 Ocean Phase

All Chinook salmon use the ocean to achieve maximum growth, although this growth is a tradeoff with high mortality, and all races of Chinook salmon deal with this tradeoff differently (Pearcy 1992). Central Valley Chinook salmon typically spend between 2 and 4 years at sea (Mesick and Marston 2007a). Most mortality experienced by salmonids during the marine phase occurs soon after ocean entry (Pearcy 1992, Mantua et al. 1997). Typically, Chinook salmon time their ocean entry to minimize predation and maximize growth; however, Chinook salmon appear to use the "bet-hedging" strategy, adopting diverse ocean entry patterns that do not correspond to major ocean events (Pearcy 1992).

Because of the small size of juveniles entering the ocean, their movements are greatly influenced by currents during this time. Most head in a northerly direction along the coastal shelf during the first year of their life (Pearcy 1992). Williams (2006) notes that in the summer, juveniles are found in slow eddies at either side of the Golden Gate, but that their distribution shifts north beyond Point Reyes later in the fall. Knowledge of California salmon life in the ocean is extremely limited. MacFarlane and Norton (2002) were the first to describe their physiology and feeding behavior in coastal waters of central California. They compared the feeding rates and condition of fall-run Chinook salmon in the lower end of the Delta (Chipps Island), at the Golden Gate Bridge (representing the end of the San Francisco Bay), and in the Gulf of the Farallones. Results indicated that feeding and growth were reduced in the estuary, but increased rapidly in the coastal shelf in the Gulf of the Farallones (MacFarlane and Norton 2002). Fish larvae were the most important prey of juvenile Chinook salmon in the coastal waters of the Gulf of the Farallones (MacFarlane and Norton 2002). Euphausiids and decapod early life stages were also consumed in significant numbers.

Maturing Chinook salmon are abundant in coastal waters ranging from southeastern Alaska to California and their distribution appears to be related to their life-history type (stream-type or ocean-type), race, and physical factors such as currents and temperature (Healey 1991, Williams 2006). Unfortunately, little information exists on the geographic distribution of Chinook salmon in the sea. Williams (2006) reported coded-wire-tag (CWT) recoveries by fisheries management area from the Regional Mark Information System database. Results indicated that Central Valley Chinook salmon are primarily distributed between British Columbia and Monterey, California, with the highest percentages found off the coasts near San Francisco and Monterey.

Subadults feed on northern anchovy, juvenile rockfish, euphausiids, Pacific herring, osmerids, and crab megalopae along the Pacific Coast (Hunt et al. 1999). Northern anchovies and rockfish appear to be the most important prey items off the San Francisco coast (Hunt et al. 1999). It is likely that prey items change seasonally, and Chinook salmon take advantage of such changes with opportunistic feeding (Williams 2006).

3.3 Adult Migration

As Chinook salmon near sexual maturity, they attempt to return to their natal stream to spawn. Adults, particularly the stream-type fish that migrate long distances in the ocean to feed, use geomagnetic orientation in ocean and coastal waters to locate the mouth of their natal stream, where they switch to olfactory clues (Quinn 1990). The mechanism of compass orientation and the transition from compass orientation in coastal waters and estuaries to olfactory-based upriver homing appear to be very complicated and not well understood (Quinn 1990). Furthermore, ocean-type populations of Pacific salmon, such as the fall-run Chinook populations in the San Joaquin River tributaries, may not have a well-developed means of navigation by compass orientation since they do not migrate far from the coast to feed.

Adult Pacific salmon primarily rely on olfactory cues to guide the upstream migration to their natal stream, although other factors may be involved (Quinn 1990). It is generally believed that as juveniles rear and migrate downriver, they imprint on the olfactory cues at every major confluence and retrace the sequence as adults when they return to spawn (Harden-Jones 1968, Quinn et al. 1989, Quinn 1990). Few adult coho (Wisby and Hasler 1954) and Chinook salmon (Groves et al. 1968) that had their olfactory pits plugged (to prevent them from sensing waterborne odors) were able to home to their natal stream. Most (67 percent and 89 percent) of the control fish in those studies were able to home to their natal stream. Blinded fish were able to home more successfully than were fish with occluded olfactory pits. Experiments have also shown that juvenile coho salmon exposed to artificial waterborne odors while they were reared in hatcheries homed to waters that contained those artificial odors (Cooper et al. 1976, Johnsen and Hasler 1980, Brannon and Quinn 1990, Dittman et al. 1994, Dittman et al. 1996). Normal homing rates for Chinook salmon are not precisely known, but probably range between 84 percent and 99 percent, which are the homing rates calculated for hatchery-reared Chinook salmon in New Zealand (Unwin and Quinn 1993) and the Cowlitz River Hatchery, Washington (Quinn and Fresh 1984).

There is contradictory evidence that hereditary factors may also influence homing behavior. Bams (1976) and McIsaac and Quinn (1988) provided proof that a high proportion of displaced Chinook salmon offspring homed to their ancestral spawning area even though the juvenile fish were never exposed to their ancestral waters. However, Donaldson and Allen (1957) provided evidence that coho juveniles relocated to two different locations before smolting would home to their release sites and not to their original hatchery site. The scent from siblings (population-specific odors) did not affect adult coho salmon homing behavior in Lake Washington (Brannon and Quinn 1990), and no other mechanism to account for a hereditary factor has been discovered.

When adult Pacific salmon do not return to their natal stream, they appear to select a new river for spawning based on the magnitude of stream flow. Two field studies conducted by Quinn and Fresh (1984) in Washington and Unwin and Quinn (1993) in New Zealand determined that adult Chinook salmon strays selected rivers with the highest stream flow. An experimental study conducted by Wisby and Hasler (1954) also showed that when the scent of the fishes' natal river was not present, coho salmon moved into the arm of a forked channel with the greatest flow.

3.3.1 San Francisco Bay and Sacramento-San Joaquin Delta

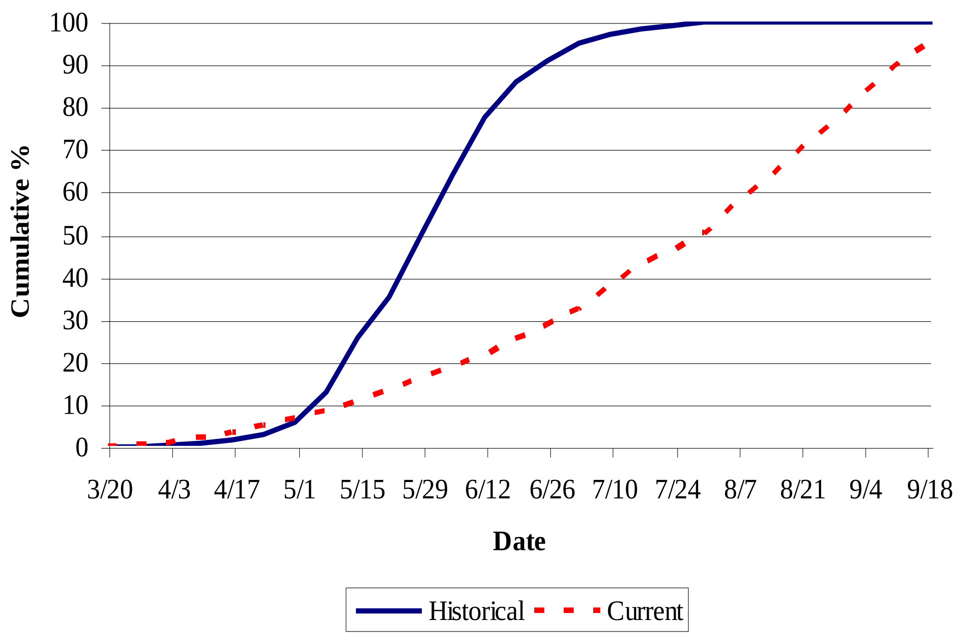
Chinook salmon runs are designated on the basis of adult migration timing as the fish enter San Francisco Bay; however, runs also differ in the degree of maturation at the time of river entry, thermal regime and flow characteristics of their spawning site, and the actual time of spawning (Myers et al. 1998). Spring-run Chinook salmon migrate upstream during the spring before they have fully reached sexual maturity, whereas fall-run Chinook salmon are sexually mature when they enter fresh water between June and December (Moyle 2002) and spawn shortly thereafter. Adult spring-run Chinook salmon begin entering San Francisco Bay in late January and early February (DFG 1998). Adult San Joaquin River Basin fall-run Chinook salmon have been collected in the Delta near Prisoners Point primarily during September and October (Hallock et al. 1970).

As adult Chinook salmon migrate through the Delta, they cease feeding (Higgs et al. 1995). Merkel (1957) found a high percentage of empty stomachs of salmon captured in North San Francisco Bay, particularly during the beginning of the spring-run Chinook salmon migration period (February and March). Merkel found no Chinook salmon in North San Francisco Bay with immature gonads, and presumed that samples from the San Francisco Bay were farther along in sexual maturity as opposed to offshore samples and as a result, the fish had ceased feeding, unlike the offshore samples (Merkel 1957). Recent study continues to verify the cessation of feeding on estuary entrance and gonadal development (DFG 1998).

Adult Chinook salmon inserted with sonic tags and tracked throughout the Delta and lower Sacramento and San Joaquin rivers were observed exhibiting substantial upstream and downstream movement in a random fashion while migrating upstream (CALFED 2001) several days at a time. Adult salmonids migrating upstream are assumed to make greater use of pool and mid-channel habitat than channel margins, particularly larger salmon such as Chinook salmon (Hughes 2004).

3.3.2 River

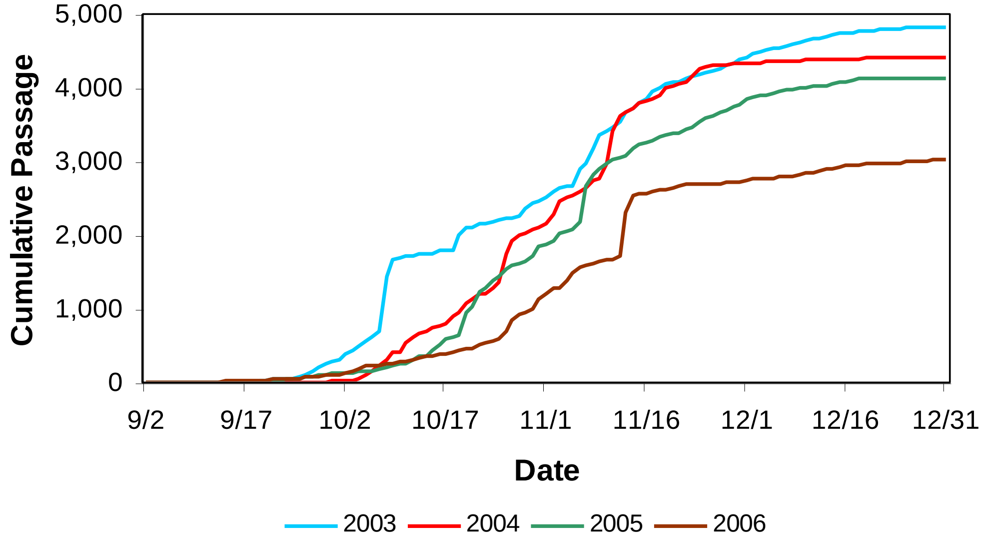
In the Sacramento River watershed (the closest population of spring-run Chinook salmon to the San Joaquin River), adult spring-run Chinook salmon historically returned to fresh water between late March and early July (Figure 3-5) (DFG 1998). The spring-run populations in Mill (Johnson et al. 2006) and Butte creeks (McReynolds 2005, personal communication) still exhibit this historical migration timing. However since 1970, most spring-run salmon in the Sacramento River upstream from the Red Bluff Diversion Dam (RBDD) migrate during the summer (Figure 3-5) (DFG 1998).



Source: DFG 1998.

Figure 3-5.
Timing of Adult Spring-Run Chinook Salmon Migrating Past Red Bluff Diversion Dam from 1970 to 1988 (Current) and Composite Data from Mill and Deer Creeks, Feather River, and Upper Sacramento River Before Construction of Shasta Dam (Historical)

Weir counts in the Stanislaus River suggest that adult fall-run Chinook salmon in the San Joaquin River Basin typically migrate into the upper rivers between late September and mid-November (Figure 3-6) (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007).



Sources: S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007.

Figure 3-6.
Cumulative Number of Adult Fall-Run Chinook Salmon Counted in Stanislaus River near Riverbank (RM 31.4) with a Weir and Vaki RiverWatcher Digital Infrared Recording System from 2003 to 2006

3.4 Adult Holding

When adult spring-run Chinook salmon begin their migration to their natal streams, they are sexually immature. After they arrive in their natal streams in the spring, they hold in deep pools through the summer, conserving energy until the fall when their gonads ripen and they spawn. In the Sacramento River system, adult spring-run Chinook salmon typically hold between April and July (Yoshiyama et al. 1998) or September (Vogel and Marine 1991) and then begin spawning in late August at the higher elevations, and in October at the lower elevations (DFG 1998). While holding during the summer, spring-run adults minimize their activity, which is thought to lower metabolic rates and therefore conserve energy for eventual reproductive activities (NRC 1992, as cited in Bell 1986).

Spring-run Chinook salmon adults generally require deep pools with relatively slow water velocities as holding habitat. Deep pools remain cooler during warm summer months, and provide refuge from avian and terrestrial predators. Instream cover (e.g., undercut banks, overhanging vegetation, boulders, large wood, and surface turbulence) also provides refuge from predation. For spring-run Chinook salmon in the

Sacramento River system, Marcotte (1984) reported that the suitability of holding pools declines at depths less than 8 feet. Airola and Marcotte (1985) found that spring-run Chinook salmon in Deer and Antelope creeks avoided pools less than about 6 feet deep. In the John Day River in Oregon, adults usually hold in pools deeper than 5 feet that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986). Marcotte (1984) reported that water velocities in holding pools used by spring-run Chinook in Deer and Antelope creeks ranged from 0.5 ft/s to 1.2 ft/s.

A temperature of 55°F (13°C) is considered optimal for adult holding salmonids according to the EPA (2003). Conclusions from Moyle et al. (1995) support this finding and reports water temperatures for adult Chinook salmon holding are optimal when less than 60.8ºF (16°C), and lethal when above 80.6°F (27°C) (Moyle et al. 1995). In Butte Creek, prespawn adult mortalities were minimal when average daily temperatures were less than 66.9°F (19.4°C) with only brief periods of high temperatures up to about 70°F (21°C) in July between 2001 and 2004 (Ward et al. 2006). According to Marine (1992) chronic exposures of 62.6 to 68°F (17°C to 20°C) is an incipient upper lethal water temperature limit for pre-spawning adult salmon (Marine 1992). Coutant (1970) as cited in Rich (2007) cites temperatures at 69.8 to 71.6°F (21 to 22°C) for a 1-week period as upper incipient lethal levels.

In the Stanislaus River, fall-run Chinook salmon probably do not hold for more than 1 or 2 weeks before spawning, based on the time between when they pass the Riverbank weir (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007) and the initiation of spawning (DFG 1991-2005).

3.5 Spawning

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries less than 10 feet wide (Vronskiy 1972) to large mainstem rivers (Healey 1991). The adults migrate upstream until they locate a bed of gravel where water temperatures and DO concentrations are suitable for egg incubation. Adult Chinook salmon typically spawn at the tails of pools (also referred to as heads of riffles), where the fish have access to both suitably sized gravel and refuge provided by the depth of the pool (Vronskiy 1972, Chapman 1943, Mesick 2001a). Pool tails may also provide optimum conditions for egg incubation, because surface water tends to downwell into the gravel at pool tails, thereby delivering high DO concentrations to incubating eggs, and transporting metabolic wastes from the egg pocket.

Gravel suitable for spawning consists of a mixture of particle sizes from sand (0.1 to 6.0 inches (0.25 to 15.24 cm)) diameter cobbles, with a median diameter (D_{50}) of 1 to 2 inches (2.54 to 5.08 cm). D_{50} values of gravel for spring-run Chinook have been found to range from 0.4 to 3.1 inches (10.8 to 78 mm) (Platts et al. 1979, Chambers et al. 1954, 1955, all as cited in Kondolf and Wolman 1993).

Chinook salmon are capable of spawning within a wide range of water depths and velocities (Healey 1991). The water depths most often recorded over Chinook salmon redds range from 0.4 to 6.5 feet and velocities from 0.5 feet per second (ft/s) to 3.3 ft/s, although criteria may vary between races and stream basins. For example, fall-run Chinook salmon, because of their larger size, are generally able to spawn in deeper water with higher velocities (Healey 1991) than spring-run Chinook salmon, which tend to dig comparatively smaller redds in finer gravels (Burner 1951). Similarly, 4- and 5-year-old fish are generally larger than the average 3-year-old fish, and can spawn in deeper, faster water with larger gravels and cobbles.

On arrival at the spawning grounds, adult female Chinook salmon dig pits in the gravel bed that are typically 12 inches deep and 12 inches in diameter. During spawning, the female deposits about 1,500 eggs in a pit and then covers them with gravel. Over a period of 1 to several days, the female gradually digs several egg pits in an upstream direction within a single redd (Burner 1951, Healey 1991). By disturbing the gravel that surrounds the egg pocket, the female loosens the bed material and cleans some of the fine sediment from the gravel, thereby improving interstitial water flow. Females can remove from 2 percent to 15 percent of fine sediment smaller than 0.04 inch (less than or equal to1 mm) during the redd-building process, depending on the initial proportion of fines in the gravel (Kondolf 2000). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Defense of a constructed redd helps to prevent subsequent spawners from constructing redds in the vicinity of an egg pocket, which can dislodge the eggs and increase egg mortality. Adult Chinook salmon females generally defend their redd until they die, usually within 1 to 2 weeks of spawning.

3.6 Adult Carcasses

There is substantial evidence that adult Pacific salmon carcasses provide significant benefits to stream and riparian ecosystems. In the past, the large numbers of salmon that returned to streams contributed large amounts of nutrients to the ecosystem (Pearsons et al. 2007, Bilby et al. 1998, Hocking and Reimchen 2002). The carcasses provide nutrients to numerous invertebrates, birds, and mammals, and nutrients from decaying salmon carcasses are incorporated into freshwater biota (Helfield and Naiman 2001, Bilby et al. 1998), including terrestrial invertebrates (Hocking and Reimchen 2002). Helfield and Naiman (2001) found that nitrogen from carcasses is incorporated into riparian vegetation. Merz and Moyle (2006) found marine-derived nitrogen incorporated into riparian vegetation and wine grapes. Merz and Moyle (2006) also compared relative nitrogen contribution rates between salmon-abundant and salmon-deprived rivers. The results indicated that salmon-abundant rivers had much more marine-supplied nitrogen than nonsalmonid-bearing rivers (Merz and Moyle 2006). This nutrient supply is a positive feedback loop in which nutrients from the ocean are incorporated into riparian growth that in turn provides ecosystem services by providing additional growth and development of the riparian system. Carcass nutrients are so important to salmonid stream ecosystems that resource managers spread ground hatchery salmon carcasses in Washington streams (Pearsons et al. 2007).

Chapter 4 Stressors

A number of documents have addressed the history of human activities, current environmental conditions, and factors contributing to the decline of Chinook salmon in the Central Valley. The San Joaquin River Restoration Study Background Report (McBain and Trush 2002) describes the changes in habitat and likely stressors that will affect Chinook salmon in the Restoration Area. The Final Restoration Plan adopted for the Anadromous Fish Restoration Program in 2001 (USFWS 2001) identifies many stressors that affect spring-run and fall-run Chinook salmon in the Central Valley. The Final Program Environmental Impact Statement/Report (PEIS/R) for the CALFED Bay-Delta Program (CALFED) (CALFED 2000) and the Final PEIS for the Central Valley Project Improvement Act (CVPIA) provide summaries of historical and recent environmental conditions for Chinook salmon and steelhead in the Central Valley. National Marine Fisheries Service (NMFS) prepared range-wide status reviews and recovery plans for West Coast Chinook salmon (Myers et al. 1998, NMFS 2009)). NMFS also assessed the factors for Chinook salmon decline in a supplemental document (NMFS 1996). The following summarizes the information from these documents as well as more recent research on Chinook salmon and their habitats in the Central Valley and other West Coast rivers.

Stressors are defined as physical, chemical, or biological perturbations to a system that adversely affects ecosystem processes, habitats, and species. Examples include altered flows, blocked passage, blocked sediment recruitment, instream habitat alteration, invasive species, contaminants, and excessive salmon harvest. Stressors that significantly influence the abundance and productivity of Chinook salmon populations are considered limiting factors for that particular population.

Stressors are discussed here according to each life history stage of Chinook salmon: (1) egg survival and emergence, (2) juvenile rearing, (3) smoltification and downstream migration, (4) ocean survival, (5) adult migration, (6) adult holding for spring-run Chinook salmon, and (7) spawning. In addition, the potential effects of releasing hatchery-reared juvenile Chinook salmon and climate change are discussed in terms of recovering naturally spawning populations. The following discussion generally pertains to both spring- and fall-run Chinook salmon, particularly for the juvenile stages, which typically use the same habitats at the same times. The discussion of stressors that affect adult stages will include issues specific for each run.

4.1 Egg Survival and Emergence

Stressors that may affect the survival of eggs and emergence of alevins in the San Joaquin River include high water temperatures, sedimentation (fines deposited in the substrate), turbidity (suspended clay-sized particles), and redd superimposition. Chinook salmon egg mortality rapidly increases as water temperatures exceed 57°F (13.9°C). High rates of sedimentation of the spawning gravels reduce intragravel flows and potentially entomb alevins. High levels of turbidity can coat the egg membrane with clay-sized particles that inhibit its ability to absorb oxygen or excrete metabolic wastes.

Other potential stressors for incubating eggs, such as predation, anglers walking on redds, and streambed scour, are not expected to be significant within the Restoration Area. Eggs incubating in natural gravels in the San Joaquin River Basin are probably protected from large invertebrate (e.g., crayfish) or fish (e.g., sculpin) predators because the interstitial spaces in the gravel are too small for predators to reach the egg pockets. Sculpin and crayfish are capable of penetrating deeply into streambeds to feed on salmon eggs and alevins but only where the gravel is coarse and free of fine sediments (McLarney 1964, Phillips and Claire 1966, Vyverberg 2004, pers. comm.). It is also unlikely that walking on redds would harm incubating eggs because the eggs are typically 12 inches below the surface of the gravel and natural gravel beds do not shift easily or otherwise move when walked upon. Montgomery et al. (1996) reported that the tops of chum salmon (*O. keta*) egg pockets were below the level of scour depth that occurred during frequent, bankfull flows in a small West Coast stream. It is likely that Chinook salmon bury their eggs at greater depths than chum salmon (DeVries 1997), therefore, streambed scour should be an unlikely source of mortality for incubating eggs in the Restoration Area.

4.1.1 Excessive Sedimentation and Turbidity

Koski (1966) reported that a majority of mortality in redds was caused by the inability of alevins to emerge due to excessive amounts of fine sediments in the redd. He found numerous dead coho salmon alevins that were completely buttoned-up but extremely emaciated at a depth of 8 inches. Beschta and Jackson (1979) showed that in a flume, fines 0.5 mm in diameter tend to form a barrier in the upper 10 cm of the gravel bed that “seals” against intrusion of fines into the egg pocket but also creates a barrier to emergence. This barrier has been described in salmon redds as a mixture of coarse sand and fines 6 to 12 inches above the egg pocket (Hawke 1978) that has a geometric mean diameter (d_g) lower than the substrate above and below the middle layer (Platts et al. 1979). Bams (1967) reported that when sockeye salmon alevins confronted a sand barrier, they “butted” upward to loosen sand grains and form an open passage to the substrate surface. Koski (1966) reported that the number of days for the first coho salmon alevins to emerge was unaffected by the amount of fines, but that the total duration of emergence for all alevins was longer in redds with high percentages of fines.

Quantification of alevin entombment relative to the amount of fines has been difficult. Researchers who evaluated emergence rates by capping natural redds with nets, such as Koski (1966, 1975), Tagart (1976), and Tulock Irrigation District (TID) and Merced Irrigation District (MID) (1991), cannot accurately estimate egg survival to emergence (Young et al. 1990) because they did not estimate egg viability, fertilization success, the loss of eggs during deposition in the egg pocket (Young et al. 1990), or escapement of fry that migrate under the trap’s netting (Garcia De Leaniz et al. 1993).

Laboratory studies suggest that alevin entombment occurs over a range of substrate particle sizes, including those less than or equal to 0.85 mm (Shelton and Pollock 1966), less than or equal to 3.3 mm (Koski 1966), less than or equal to 4.67 mm (Tapple and

Bjornn 1983), and less than or equal to 6.4 mm (McCuddin 1977). However, these studies tested the ability of large, healthy alevins to emerge under high concentrations of sand, which is an abnormal condition considering that high concentrations of sand typically result in low DO levels and small, weak alevins.

Flood events, and land disturbances resulting from logging, road construction, mining, urbanization, livestock grazing, agriculture, fire, and other uses may contribute sediment directly to streams or exacerbate sedimentation from natural erosive processes (California Advisory Committee on Salmon and Steelhead Trout 1988, NMFS 1996). High permeability measurements in Reach 1A approximately 5 years ago suggest that sedimentation has not been a problem (Stillwater Sciences 2003). Furthermore, turbidity levels are usually low in the San Joaquin River Basin until high rates of runoff occur in January or February, which is after a majority of the eggs have hatched.

4.1.2 Excessively High Water Temperatures

Target incubation temperatures for Chinook salmon are daily maximums of less than 55°F (13°C) (EPA 2003). Water released from Friant Dam should be less than 58°F (14°C) throughout the spawning period as long as the cold water pool in Millerton Lake is not exhausted. The HEC 5Q water temperature model developed for the Restoration Area (Deas and Smith 2008) suggests that implementing the Restoration Flow Schedule could result in maximum temperatures of the Friant release flows of under 62°F (16.7°C) in October or November (Figure 4-1). Using hydrologic and climatic conditions from 1980 to 2005, the temperature of the release flows would exceed 60°F during 20 years of the 26-year period (Figure 4-1). It is possible that these temperatures could result in Chinook salmon egg mortality rates of about 50 percent.

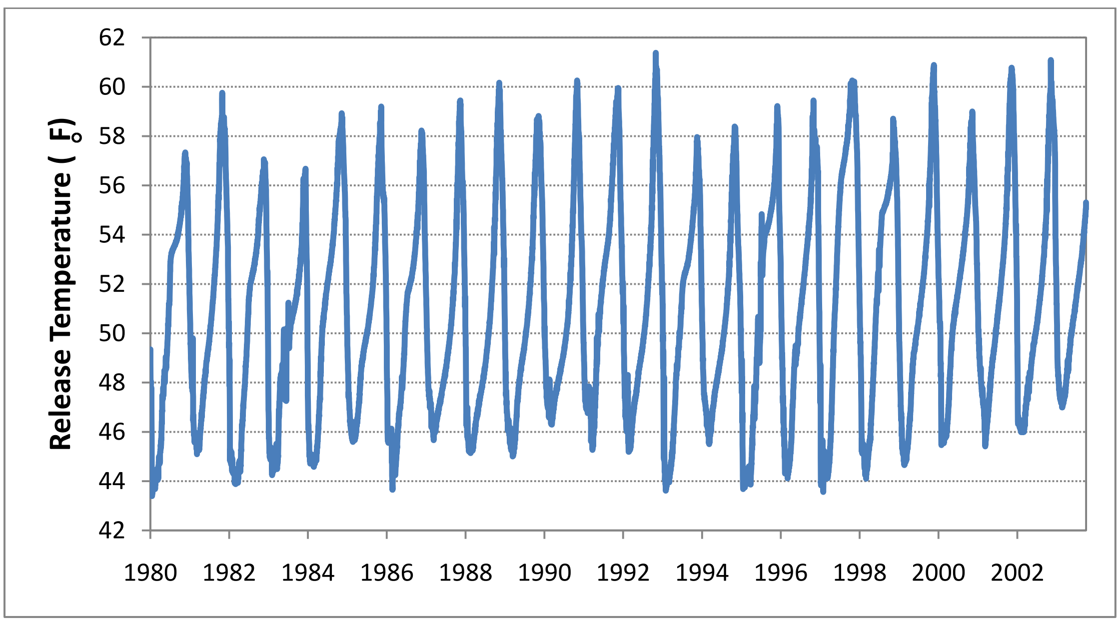


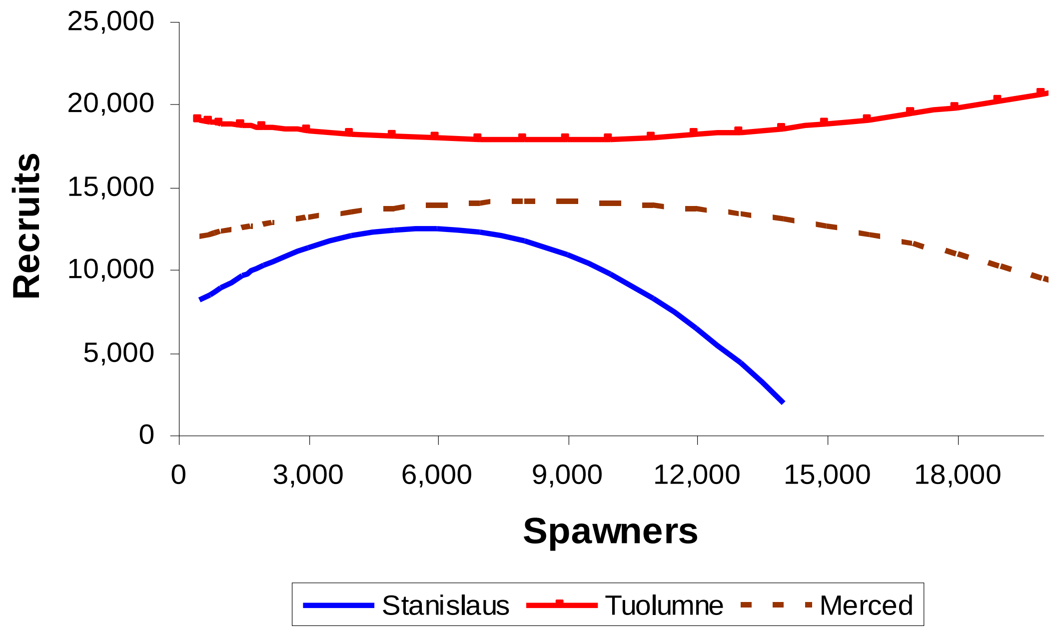
Figure 4-1.
Results of HEC 5Q Water Temperature Model Showing Predicted Water Temperatures of Releases from Friant Dam if Restoration Hydrograph Releases Were Made Under Hydrologic and Climatic Conditions from 1980 to 2004

4.1.3 Redd Superimposition

Redd superimposition occurs when spawning fish construct new redds on top of preexisting redds such that either the eggs in the preexisting redd are either destroyed (dug up) or buried under fines that prevent most of the fry from emerging. Redd superimposition has been reported for the Stanislaus River (Mesick 2001a), American River (Vyverberg 2004, pers. comm.), and the Tuolumne River (TID and MID 1991). Redd superimposition can occur at low escapements and in areas with ample high-quality spawning habitat (Mesick 2001a), presumably because spawners prefer to dig redds in the loose gravels provided by preexisting redds that are no longer guarded by the original female. Redd superimposition does not necessarily kill the eggs or entomb the alevins in the original egg pocket, because most superimposing redds are not constructed exactly on top of preexisting redds but rather several feet to the side as well as several feet upstream or downstream from the original redd. Entombment would only occur in superimposed redds constructed in spawning beds where the concentration of fines was relatively high.

Redd superimposition rates in the Stanislaus River were estimated during fall 2000 when escapement was relatively high by monitoring superimposition at 82 artificial redds that were constructed in late October before most of the fall-run fish had begun to spawn (Carl Mesick Consultants 2002). In this study, redd superimposition completely disturbed 15 percent of the artificial egg pocket areas (presumably with 100 percent egg mortality) and buried another 23 percent of the artificial egg pocket areas with gravel and fines that could entomb some or all of the alevins.

It is unlikely that redd superimposition limits adult recruitment in the Stanislaus, Tuolumne, and Merced rivers because many more fry are produced at high spawner densities than can be sustained by the quality of the rearing habitat. Spawner-recruitment relationships for the Tuolumne and Merced rivers are relative flat (Figure 4-2) (Mesick and Marston 2007b), which suggests that high densities of spawners do not reduce adult recruitment to a significant degree. Although a high density of adult spawners has reduced adult recruitment in the Stanislaus River (Figure 4-2), rotary screw trap evidence indicates that many more fry were produced than the number of smolt outmigrants from 1998 to 2004 when spawner abundance ranged between 2,400 and 11,650 fish (Mesick and Marston 2007b).



Source: Mesick and Marston 2007b.
Note:
A categorical variable called "Population Shift" was used for all three rivers to account for a shift in recruitment that occurred sometime between 1987 and 1994.
The relationships are based on regression models of recruits, quadratic spawner terms (a2 +a +c), and a mean Vernalis flow of 7,000 cubic feet per second from March 1 to June 15.

Figure 4-2.
Spawner-Recruit Relationships for Stanislaus, Tuolumne, and Merced Rivers

4.2 Juvenile Rearing and Migration

Likely stressors for juvenile Chinook salmon rearing in and migrating through the Restoration Area include inadequate food resources, high water temperatures, predation, entrainment at unscreened diversions, contaminated runoff from agriculture and housing development, and disease. These stressors are primarily influenced by flow diversions, agricultural practices, urban development, and gravel excavations.

Except during flood years, a relatively small number of Chinook salmon fry that migrate into the lower San Joaquin River (below the confluence with the Merced River) from the San Joaquin River tributaries and Delta are thought to survive. Ocean recovery rates of the fry obtained from the Coleman National Fish Hatchery and tagged with coded wire half tags indicate that fry survival was lower in the Central Delta near the mouth of the Mokelumne River than in the North Delta near Courtland, Ryde, or Isleton during dry years, although the difference was not statistically significant (Brandes and McLain 2001). However, during flooding in 1982 and 1983, tagged fry survived at similar rates in the Central Delta and South Delta in the Old River compared to the North Delta (Brandes and McLain 2001). The poor survival of juveniles rearing in the Delta in dry and normal water years may be caused by predation, entrainment at numerous small, unscreened diversions, unsuitable water quality, high water temperatures, inadequate food resources, and direct mortality at the Federal and State pumping facilities in the Delta. Entrainment at the Delta pumping facilities may be minimal during very wet years because tagged fry were collected at the pumping facilities only during the dry years whereas none were collected in wet years (Brandes and McLain 2001). Although the fry migration life stage does not appear to contribute as much to current production of the population in San Joaquin River tributaries and the Delta, it may be an important life stage in rivers with functional floodplain habitats in downstream reaches, such as Sutter Bypass on Butte Creek (Ward and McReynolds 2001, Ward et al. 2002) and possibly in restored floodplain and wetland habitats in the lower Restoration Area, where fry can rapidly grow to a smolt size because of warmer water temperatures and abundant food resources.

4.2.1 Food Resources

The survival of juvenile Chinook salmon to the adult stage partially depends on their ability to grow rapidly enough to begin their downstream migration as smolts early in the spring when their chances are highest to survive their migration through the Delta and estuary to the ocean. In addition, it is highly likely that large, healthy smolts will survive their migrations at higher rates than would smaller, poorly fed smolts.

Food resources in the Restoration Area may be adversely affected by a combination of factors:

- Reduced flows or dikes that substantially reduce the contribution of organic matter and prey-sized invertebrates from inundated floodplains
- Sedimentation and gravel extraction that affects the production of in-river, prey-sized invertebrates
- Lack of nutrients provided by low numbers of adult Chinook salmon carcasses
- Reduced native riparian and wetland vegetation that is the primary basis of the aquatic food web
- Lack of organic matter and prey-sized invertebrates from upstream reservoirs
- Pesticides and other contaminants that reduce the abundance of food organisms
- Competition for food with native and introduced species

Floodplain Inundation and River Connectivity

Most of the energy that drives aquatic food webs in rivers is derived from terrestrial sources (Allan 1995), and aquatic productivity is related to flood magnitude and the area inundated in some rivers (Large and Petts 1996). Flooding, particularly the rising limb of the hydrograph (i.e., period of increasing flow), typically results in high concentrations of both dissolved and particulate organic matter being released into the river (Allan 1995). High flows that inundate floodplains also provide food for juvenile fish that rear in floodplain habitats. Research in other river systems has shown that production of invertebrates, the most important prey resource for many fishes, on inundated floodplains can far exceed river production. Sommer et al. (2001) found that drift invertebrates, the primary prey of juvenile salmonids, were more abundant on the inundated Yolo Bypass floodplain than in the adjacent Sacramento River. As a result, feeding success, growth, and survival, of juvenile Chinook salmon were higher in the Yolo Bypass, the primary floodplain of the lower Sacramento River, than in the adjacent mainstem channel in 1998 and 1999 (Sommer et al. 2001). Gladden and Smock (1990) estimated that annual invertebrate production on two Virginia floodplains exceeded river production by one to two orders of magnitude.

Floodplain habitats tend to produce small invertebrates with short life cycles such as chironomids and cladocerans (McBain and Trush 2002). However, the duration and frequency of floodplain inundation can be an important determinant of invertebrate production and community structure. In the Virginia floodplains, annual production on the floodplain continuously inundated for 9 months was 3.5 times greater than on the floodplain inundated only occasionally during storms (Gladden and Smock 1990). On Cosumnes River floodplains, Grosholz and Gallo (2006) found that the invertebrate community structure was regulated by the timing and duration of inundation of the floodplain. Planktonic crustaceans emerged first, followed by insect macroinvertebrates. Importantly, juvenile fish diets tracked the species composition of the emerging invertebrate community subsequent to inundation of the floodplain.

Lateral connectivity of river channels to adjacent floodplains has been shown to be an important control on the timing, composition, and total invertebrate biomass in a river. In the Rhone River Basin, Castella et al. (1991) showed, using a series of connectivity indices, that invertebrate diversity and biomass in the river can be linked to the connectivity of the river to its floodplain. The mainstem San Joaquin River is bordered by San Joaquin River Flood Control District levees and individual landowner levees (McBain and Trush 2002) resulting in a separation of much of the river from its historic floodplain.

Invertebrate colonization of a rewatered river channel or newly inundated floodplain is regulated by three primary mechanisms: proximity to a source of colonists, the *in situ* invertebrate "seedbank" in the substrate, and the timing and duration of inundation. In Alabama's Sipsey River, Tronstad et al. (2005) showed that invertebrate species composition and the timing of recolonization is controlled by the frequency of inundation of invertebrate "seedbanks" in floodplain soils: recently inundated soils had faster rates of emergence and greater species diversity than soils with a longer interval between periods of inundation. This disparity suggests that invertebrate production in newly rewatered reaches and adjacent floodplains of the San Joaquin River may be directly related to the length of time since they were last wetted. Constructed floodplains, for example, may take considerably longer to become productive than bypass channels that receive flood flows during periodic storm events. The invertebrate community in the upper Sacramento River recovered to a composition similar to undisturbed sections of the river within 1.5 years after sterilization by a chemical spill (Boullion 2006 as cited in Cantara Trustee Council 2007). The source of invertebrates from immediately upstream areas likely contributed to the rapid recolonization of the upper Sacramento River, and a similar situation can be expected when Restoration Flows are released into the formerly dewatered reaches of the San Joaquin River in the Restoration Area.

The physical habitat structure of the rewatered habitat also plays a role in the rate, composition, and maintenance of invertebrate communities. Hilborn (1975) demonstrated that habitat heterogeneity is a fundamental control on ecosystem community structure. A simple sand-bedded channel with no riparian habitat (i.e., homogeneous habitat) will typically have lower invertebrate diversity than a comparable channel that is more complex and includes substrate size variability and developed riparian vegetation. Fundamentally, channel heterogeneity equates to more niches for more types of invertebrates. For example, Benke (2001) found that invertebrate diversity and biomass in Georgia rivers was higher in a system with a well developed floodplain and abundant instream woody material (IWM) in the river, than in an otherwise similar system with lower habitat diversity. In the Restoration Area, channels and floodplains with existing habitat complexity (e.g., riparian vegetation, IWM) are likely to support higher invertebrate production and diversity than homogeneous channels or newly constructed floodplains.

Indirect Effects of Pesticides and Other Contaminants

It is likely that contaminants usually do not kill juvenile salmonids directly, but instead substantially reduce their food resources or increase their susceptibility to disease or pathogens. However, the observed concentrations of organophosphate pesticides in water samples collected in the San Joaquin River at Vernalis and most other locations in the Delta in January through April in 2001 and 2002 shortly after rainfall events, when contaminant levels are highest (Werner et al. 2003), were seldom toxic to two cladocerans (*Ceriodaphnia dubia*, and *Simocephalus vetelus*), a chironomid larvae (*Chironomus tentans*), and an amphipod (*Gammarus daiberi*). Results of surveys conducted between 1992 and 2000 suggest that the amounts of organophosphate pesticides applied as dormant sprays in the San Joaquin River Basin have steadily decreased over the past decade, although they still exceed criterion maximum concentration levels established by DFG (Orlando et al. 2003). Since 1993, there has been a shift in insecticides in the Central Valley from organophates to permethrin and finally to new compounds of pyrethroids, which are nearly 20 times more toxic to aquatic invertebrates and fish than permethrin (Amweg et al. 2005). Fresno, Madera, and Stanislaus are three of four counties with the greatest pyrethroid use in the San Joaquin River watershed. Pyrethroids are the likely cause of frequent sediment toxicity in the westside subbasin of the San Joaquin River Basin. The sediment has been categorized as highly toxic based on *H. azteca* mortality. *Hyalella azteca* is an epibenthic freshwater amphipod that shows sensitivity to toxic compounds adsorbed to the sediment, including herbicides and pyrethroid pesticides. A *H. azteca* 10-d survival and growth toxicity test is used to assess toxicity from pyrethroids and other compounds adsorbed to the sediment. Two examples of commonly used pyrethroids that are found in sediments are bifenthrin (Type I pyrethroid) and esfenvalerate (Type II pyrethroid).

Bed sediments of the San Joaquin River had trace amounts of bifenthrin during the irrigation season (Domagalski et al. 2009). Bifenthrin was one of the most commonly detected pyrethroids in bed sediments. Bifenthrin is one of the pyrethroids of greatest toxicological concern in urban runoff (Holmes et al. 2008) because of its residential use (Weston et al. 2005). In the San Joaquin River, one sample on the downstream edge of Stockton was toxic to *Hyalella*, probably because of bifenthrin (Weston and Lydy 2009).

East-side tributaries and the San Joaquin River had very little mortality from sediment toxicity. However, small west side creeks have most frequent occurrence and highest toxicity of bed sediments.

Unfortunately, there are not enough field monitoring data on the spatial and temporal occurrences of pyrethroids for making risk assessments to date (Oros and Werner 2005).

Sedimentation and Gravel Extraction

Sedimentation, which is the deposition of fine sand (less than or equal to 0.2 mm), and gravel extraction, which created ditches and ponds in the riverbed and floodplain, have probably reduced the availability of food resources for juvenile Chinook salmon and steelhead in the Restoration Area. Waters (1995) suggested that a change from gravel and cobble riffles to deposits of silt and sand results not only in a decrease in abundance of invertebrates that are important prey, but also results in a change in invertebrate species from those inhabiting the interstitial spaces of large particles to small, burrowing forms less available to fish. However, captured mine pits in the San Joaquin River Basin typically store large volumes of organic matter and contain dense growths of aquatic vegetation. There is an abundant “hatch” of adult aquatic insects from these ponds, and it is possible that these ponds provide more food than is produced in the main channels.

Nutrients from Adult Salmon Carcasses

After spawning, adult Chinook salmon carcasses remain in the stream corridor to decompose, and are an important food and nutrient source within a watershed (Cederholm et al. 1999). Decomposing salmon carcasses are recognized as a source of marine-derived nutrients that play an important role in the ecology of Pacific Northwest streams (Gresh et al. 2000). On the Olympic Peninsula in Washington, 22 different animal species were observed feeding on salmon carcasses (Cederholm et al. 1999). Carcass nutrients can affect the productivity of algal and macroinvertebrate communities that are food sources for juvenile salmonids. Decomposing salmon carcasses have also been shown to be vital to the growth of juvenile salmonids (Bilby et al. 1998; Bilby et al. 1996, as cited in Gresh et al. 2000).

The relatively low abundance of Chinook salmon and steelhead has significantly reduced this important nutrient source in the Central Valley, and throughout the Pacific Northwest. Gresh et al. (2000) estimated that the annual biomass of salmon entering Pacific Northwest streams (California, Oregon, Washington, Idaho) was historically on the order of 352 million pounds, and has been reduced to only approximately 26 million pounds, a reduction of more than 93 percent. Channelization and removal of IWM can also decrease the retention of salmon carcasses and reduce nutrient input.

Riparian Vegetation

Historically, canopy species within the riparian corridor in the upper reaches of the Restoration Area (Reaches 1 and 2A) consisted of a patchy band of cottonwoods, willows, and valley oaks on floodplain and terrace surfaces between the confining bluffs. In the downstream reaches (downstream from Mendota), there were large flood basins (low-lying areas adjacent to the river channel) dominated by tule marsh on both sides of the river, often many miles wide. Riparian canopy species (cottonwood, willow, valley oak) were limited to relatively narrow bands (typically less than 1,000 feet wide based on 1914 maps) of mineral soil berms deposited along channels that dissected the vast tule marsh.

Conversion of native vegetation types to agriculture, aggregate mining, and urban development has strongly impacted the San Joaquin River's wetlands and riparian habitat. As of 1998, approximately 25,380 and 6,030 acres of riparian and wetland habitats have been converted to agricultural and urban uses, respectively (McBain and Trush 2002). Approximately 4,610 and 1,920 acres of riparian forest and riparian scrub, respectively, were present in 1998 (McBain and Trush 2002).

The San Joaquin riparian corridor, like most California landscapes, is host to many nonnative invasive plant species. In 2000, the California Department of Water Resources (DWR) mapped vegetation along the San Joaquin River from Friant Dam to the confluence with the Merced River (DWR 2002). DWR identified 127 nonnative plant species – 50 percent of all plant species identified. The primary nonnative invasive species identified by DWR include tree-of-heaven, giant reed, pampas grass, eucalyptus, edible fig, white mulberry, Lombardy poplar, castor bean, Himalayan blackberry, scarlet wisteria, and tamarisk (DWR 2002). The DWR effort also recorded parrot's feather, a highly invasive aquatic plant. Nonnative invasive plant species cover 99 acres along the river corridor in nearly monospecific stands, and occur as a component of most, if not all, native vegetation types (McBain and Trush 2002). These plant species are particularly abundant in Reach 1, where high levels of disturbance may have aided their spread, as suggested by their distribution in and around aggregate mining pits (McBain and Trush 2002).

Exotic plant species can alter the structure and dynamics of natural ecosystems. Nonnative plant species can impact native wildlife by displacing native vegetation that is used for nesting or as a food source. Once established, nonnative plant species can alter nutrient cycling, energy fixing, food web interactions, and fire and other disturbance regimes, to the extent that the native landscape is changed. Habitat fragmentation contributes to the spread of nonnative species by increasing edge habitat, which provides greater opportunities for invasion by exotic species (Cox 1999). Ecosystem alterations resulting from nonnative plant species invasions can be exacerbated by activities such as overgrazing and vegetation clearing that create favorable conditions for further nonnative plant establishment (Cox 1999, Randall and Hoshovsky 2000). Alteration of historical flooding regimes by flow regulation further promotes invasions by nonnative species by eliminating processes necessary for recruiting and maintaining native plant species (Cox 1999).

Reservoir Productivity

The San Joaquin River Basin upstream from Millerton Lake consists of granitic soils with low mineral nutrient content (Reclamation 2006). Partly as a result, Millerton Lake is low in total dissolved solids (TDS) and has low levels of chemical nutrients (Dale Mitchell, 2006, pers. comm.). Little information is available regarding the plankton communities of Millerton Lake, but there is evidence that plankton production varies considerably on a seasonal basis. Cladocerans in the genus *Leptodora* (water fleas) have been observed to be abundant in Millerton Lake during summer months, with population crashes commonly occurring in September (Dale Mitchell 2006, pers. comm.). Threadfin shad in Millerton Lake are known to feed extensively on *Leptodora*, indicating that this organism may be seasonally available as a food source for fishes in the San Joaquin River downstream from Friant Dam.

Competition with Native and Introduced Species

Some nonnative fish species have habitat requirements that overlap with those of native species. These species may be more aggressive and territorial than native species, resulting in the exclusion of native species from their optimal habitats. Many of the nonnative species, such as green sunfish, also tolerate extremely high water temperatures and appear better able to persist in water with low DO, high turbidity, and contaminants than native fishes.

The arrival of the Asiatic clams (*Corbicula fluminea* and *Corbula amurensis*) in the San Francisco Estuary disrupted the normal benthic community structure and depressed phytoplankton levels in the estuary due to the highly efficient filter feeding of these clams (Cohen and Moyle 2004). The decline in the levels of phytoplankton reduces the population levels of zooplankton that feed on them, and hence reduces the forage base available to salmonids transiting the Delta and San Francisco Estuary. This lack of forage base can adversely impact the health and physiological condition of these salmonids as they migrate through the Delta to the Pacific Ocean.

Introductions of exotic zooplankton species have supplanted other zooplankton species that provided important food resources for fish in the upper San Francisco Estuary (Hennessy and Hieb 2007). In 1993, *Limnoithona tetraspina*, an introduced cyclopoid copepod, mostly replaced the historically common and larger *L. sinensis*. The introduced copepod (*Pseudodiaptomus forbesi*) along with the Asiatic clam contributed to the decline of the calanoid copepod (*Eurytemora affinis*) beginning in the late 1980s. *E. affinis* was an important food resource for juvenile fish. The introduced calanoid copepod (*Sinocalanus doerrii*) was first recorded in spring 1979. In contrast, the native cladocerans (*Bosmina*, *Daphnia*, and *Diaphanosoma*) and the native rotifer (*Synchaeta bicornis*) have gradually declined since the early 1970s. It is likely that relatively small exotic species, such as *L. tetraspina*, are not as important in the juvenile salmonid forage base as were the displaced native species.

4.2.2 Disease

USFWS conducted a survey of the health and physiological condition of juvenile fall-run Chinook salmon in the San Joaquin River and its primary tributaries, the Stanislaus, Tuolumne, and Merced rivers, during spring 2000 and 2001 (Nichols and Foott 2002). *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease (BKD), was detected in naturally produced juveniles caught in rotary screw traps from the Stanislaus and Tuolumne rivers and juveniles caught with a Kodiak trawl at Mossdale in the San Joaquin River. No gross clinical signs of BKD were seen in any of the fish examined. However, these low-level infections might remain active after the fish enters the ocean where the clinical symptoms might develop.

Proliferative kidney disease (PKD) was detected in both natural and hatchery juveniles from the Merced and mainstem San Joaquin rivers in 2000 and 2001 (Nichols and Foott 2002) and in natural juveniles from the Merced River in 2002 (Nichols 2002). The myxozoan parasite *Tetracapsula bryosalmonae,* which causes PKD, was detected in the kidney samples of only 2 percent of the juvenile Merced River fish in April 2000, but in 90 percent of the April 2001 samples, 100 percent of the May 2001 samples, and 51 percent of the April 2002 samples. Heavy infections were observed in 22 percent of the samples in 2002 (Nichols 2002). These data suggest that the incidence of pathogen infection is low in above-normal water years such as 2000 compared to dry water years such as 2001 and 2002. PKD has been described at the Merced River Fish Hatchery since the 1980s and in California since at least 1966. It compromises the fish’s performance in swimming, salt water entry, and disease resistance (Nichols and Foott 2002). Nichols and Foott (2002) suggested that PKD could be a significant contributor to mortality in natural fish.

Columnaris disease, caused by the bacterium *Flexibacter columnaris*, was observed in juvenile Chinook salmon caught in rotary screw traps in the Stanislaus River in spring 2007. The disease can rapidly increase in the population as water temperatures reach a mean daily temperature of 68 to 69.8°F (20 to 21°C). Along with the protozoan *Ichthyophthirius multifillis* (also referred to as Ich), columnaris was a leading cause of adult salmon mortality in the lower Klamath River in 2002.

There were no signs of infection from pathogenic species of bacteria, including *Aeromonas salmonicida*, *Yersinia ruckeri,* and *Edwardsiella tarda*, in the San Joaquin River Basin during spring 2001 (Nichols and Foott 2002). Although *Myxobolus cerebralis*, the causative agent of whirling disease, was not detected in a pooled sample of 194 fish, the parasite has been detected in rainbow trout from the Stanislaus River. Tests were not conducted for *Flavobacterium columnare*.

The pathogen *Ceratomyxa* is present in the Central Valley and studies indicate that it causes a high mortality rate of Chinook smolts migrating through the lower Willamette River, Oregon (Steve Cramer 2001, pers. comm.). This disease relies on tubifix worms for an intermediate host and the worms flourish in organic sediments. It is likely that the worms multiply and the disease spreads in years when organic sediments are not flushed by high flows. There are indications that mortality of smolts due to this disease increases in drought years and decreases in wet years. *Ceratomyxa* disease is a particular concern for the San Joaquin River because there is a tubifex worm farm located in Reach 1A, at RM 261 (Jones and Stokes 2002a). It is also possible that organic sediments accumulate and produce tubifex worms in captured mine pits.

4.2.3 Predation

Fish species in the Restoration Area that will probably prey on juvenile Chinook salmon include largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), Sacramento pikeminnow (*Ptychocheilus grandis*), green sunfish (*Lepomis cyanellus*), warmouth (*L. gulosus*), black crappie (*Pomoxis nigromaculatus*), and striped bass (McBain and Trush 2002). DFG (2007a) electrofishing surveys of the Restoration Area in 2004 and 2005 indicated that largemouth and spotted bass (*M. punctulatus*) were prevalent as far upstream as Reach 1B and were very common in the lower reaches of the river. Largemouth bass are adapted to low flow and high water temperature habitats and typically inhabit captured mine pits in the San Joaquin River Basin. Smallmouth bass are adapted to riverine habitats but are also relatively inactive when water temperatures are low. Large salmonids, such as rainbow trout at least 140-mm FL, would also be expected to prey on juvenile Chinook salmon. Although planted catchable-sized rainbow trout might prey on juvenile Chinook salmon, it is DFG policy not to plant hatchery trout in rivers that contain anadromous fish populations, such as Chinook salmon.

Juvenile salmonids are also susceptible to avian predators. Species including California gulls, ring-billed gulls, Caspian terns, double-crested cormorants, and American white pelicans have been documented to prey on outmigrating steelhead and salmon as they pass through dams on the Columbia and Snake rivers (Bayer 2003). Fish-eating birds that occur in the California Central Valley include great blue herons (*Ardea herodias*), gulls (*Larus spp*.), osprey (*Pandion haliaetus*), common mergansers (*Mergus merganser*), American white pelicans (*Pelecanus erythrorhynchos*), double-crested cormorants (*Phalacrocorax spp*.), Caspian terns (*Sterna caspia*), belted kingfishers (*Ceryle alcyon*), black-crowned night herons (*Nycticorax nycticorax*), Forster’s terns (*Sterna forsteri*), hooded mergansers (*Lophodytes cucullatus*), and bald eagles (*Haliaeetus leucocephalus*) (Stephenson and Fast 2005). These birds have high metabolic rates and require large quantities of food relative to their body size.

Predation in Central Valley Rivers

High predation rates are known to occur below small dams, such as RBDD and Sack Dam in the Restoration Area. As juvenile salmon pass over small dams, the fish are subject to conditions that may disorient them, making them highly susceptible to predation by other fish or birds. In addition, deep pool habitats tend to form immediately downstream from the dams where Sacramento pikeminnow (*Ptychocheilus grandis*), striped bass, and other predators congregate. Tucker et al. (1998) showed high rates of predation by Sacramento pikeminnow and striped bass on juvenile salmon below the RBDD.

EA Engineering, Science and Technology (TID and MID 1992), conducted river-wide electrofishing surveys in the Tuolumne River in spring 1989 and 1990, and found that few largemouth and smallmouth bass contained naturally produced juvenile Chinook salmon in their stomachs, whereas bass had numerous hatchery-reared juvenile Chinook salmon in their stomachs shortly after the fish were released for a survival study (Table 4-1). It is likely that there were numerous naturally produced juvenile Chinook salmon during both years because there was a moderate number of spawners present during both years: 5,779 and 1,275 present in fall 1988 and 1989, respectively (http://dnn.calfish.org/IndependentDatasets/CDFGFisheriesBranch/tabid/157/Default.aspx). The spring 1990 studies should have been particularly effective for evaluating predation because the electrofishing was conducted at night, shortly after the bass would have been feeding and their stomachs would still have contained undigested juvenile Chinook salmon. In addition, the study was conducted during a drought, when predation rates would be expected to be highest due to low flows and high water temperatures. These results suggest that bass prey on few naturally produced juveniles because they primarily migrate at night when predation rates are lowest, whereas hatchery fish typically migrate during the day (Roper and Scarnecchia 1996) and they are thought to be naïve at avoiding predators.

Table 4-1.
Predation Studies in Lower Tuolumne River in 1989 and 1990

Sampling Dates	La Grange Flows (cfs)	Percent Largemouth Bass with Juvenile Salmon in Stomachs	Percent Smallmouth Bass with Juvenile Salmon in Stomachs	Origin of Juvenile Salmon
4/19 to 5/17, 1989	40 to 121	3.6 (2 out of 56)	8.6 (5 out of 58)	Naturally Produced
1/29 to 3/27, 1990	142 to 174	2.1 (2 out of 97)	3.1 (1 out of 32)	Naturally Produced
4/25 to 4/28, 1990	187 to 207	2.6 (2 out of 76)	6.3 (1 out of 16)	Naturally Produced
5/2 to 5/4, 1990	299 to 572	26 (40 out of 152)	33.3 (6 out of 18)	CWT Hatchery

Source: TID and MID 1992.
Key:
cfs = cubic feet per second
CWT = coded wire tag

Striped bass, which primarily migrate into the San Joaquin River tributaries during the late-winter and spring (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007), were the primary predators of juvenile fall-run Chinook salmon fitted with radio tags in a Stanislaus River study (Demko et al. 1998). Although more than 90 percent of the radio-tagged fish appear to have been eaten by predators, there is uncertainty as to whether gastrically implanting the radio tags, which had 12-inch-long external whip antennas, impaired the ability of the juvenile salmon to avoid predators.

Adult Sacramento pikeminnow, which form large schools in ditch-like channels 3 to 8 feet deep, are very abundant in the San Joaquin River Basin and prey on Chinook salmon fry. Although none of the electrofishing studies conducted in the Tuolumne and Stanislaus rivers identified pikeminnow as predators of juvenile Chinook salmon, it is relatively difficult to capture schooling Sacramento pikeminnow with electrofishing gear, and they have complex stomachs that may be difficult to sample using flushing techniques.

Predation in the Delta

Striped bass, Sacramento pikeminnow, and largemouth bass are predators of juvenile Chinook salmon in some Delta habitats. Pickard et al. (1982) reported that juvenile salmon predation was high for both Sacramento pikeminnow and striped bass in the Sacramento River Delta between 1976 and 1978. Gill nets were set in Horseshoe Bend and near Hood to collect predators between February 1976 and February 1978. The results suggest that 150- to 1,050-mm FL striped bass and 300- to 700-mm FL Sacramento pikeminnow primarily fed on fry and relatively few smolts. Feeding rates for pikeminnow and striped bass were highest in winter (December through February), when 77.7 percent had fish in their stomachs, and low during spring (March through May), when only 23.3 percent had fish in their stomachs. However, stomach evacuation rates would be expected to be higher during the spring; therefore, an in-depth analysis is needed to determine the relative predation rates for fry and smolts. Relatively few steelhead, white catfish (*Ictalurus catus*), channel catfish (*I. punctatus*), and black crappie (*Pomoxis nigromaculatus*) were caught in the gill nets at Horseshoe Bend.

In contrast, Nobriga et al. (2003) used seines and experimental gill nets to sample age-0 and age-1 striped bass and largemouth bass in 3- to 13-foot-deep water in the Yolo Bypass, lower Sacramento River, and in the Central Delta from March through June 2001. They reported that only 1 juvenile Chinook salmon was found in the stomach of 1 of 81 striped bass and another juvenile Chinook salmon was found in the stomach of 1 of 63 largemouth bass. These predators were primarily feeding on yellowfin goby (*Acanthogobius flavimanus*), gammarid amphipods, *Corophium*, and/or aquatic insects.

Densities of black bass and striped bass are about 3 times higher in the central Delta downstream from Rough and Ready Island near Stockton and in the Mokelumne River (eastern Delta) than in the northern or southern areas of the Delta based on a DFG resident fish study conducted from 1980 to 1983 (Table 4-2), (Urquhart KAF 1987). DFG introduced Florida largemouth bass into the Delta in the early 1980s and again in 1989, and catch rates of black bass have increased since 1993 (Lee 2000). Although predation of juvenile Chinook salmon in the Delta has not been quantified, predation would contribute to the low survival rates of juvenile Chinook salmon migrating between Dos Reis and Jersey Point and to Sacramento River juveniles migrating into the Mokelumne River through the Delta Cross Channel.

Table 4-2.
Densities and Mean Fork Length of Largemouth Bass, Smallmouth Bass, and Striped Bass per Kilometer Collected in DFG Electrofishing Surveys in Sacramento-San Joaquin Delta, 1980 to 1983

Location	Largemouth Bass 208 mm FL	Smallmouth Bass 225 mm FL	Striped Bass 140 mm FL
Central Delta	12.81	0.02	0.03
Eastern Delta	12.92	0.20	0.19
Southern Delta	4.42	0.36	0.03
Northern Delta	3.83	0.78	0.03
Western Delta	5.97	0.08	0.00

Note:
The sampling sites in each region of the Delta are shown in Figure 1 of Schaffter (2000).
Key:
DFG = California Department of Fish and Game
FL = fork length
mm = millimeter

4.2.4 Water Quality

Water quality in the valley floor of the San Joaquin River Basin has been impaired as a result of contamination from a variety of sources, including (1) aquatic and terrestrial herbicide application, (2) urban and agricultural pesticide application, (3) trace elements from industrial and agricultural activities as well as those naturally present in soils, and

(4) effluent from wastewater treatment plants and livestock operations, particularly dairy farms. Point sources of pollution originate from single identifiable sources, whereas nonpoint sources that originate from many different sources. Examples of nonpoint sources are agricultural runoff (e.g., excess fertilizers, herbicides, and pesticides) and urban stormwater containing oil, grease, heavy metals, polycyclic aromatic hydrocarbons, and other organics (Central Valley Water Board 1998). Impervious surfaces (e.g., concrete) tend to reduce water infiltration and increase stormwater runoff (NMFS 1996).

In general, water contamination or degradation may cause chronic or sublethal effects that compromise the physical health of aquatic organisms and reduce their survival over an extended period of time beyond initial exposure. For example, a study conducted in Puget Sound, Washington (Arkoosh et al. 1998), indicates that emigrating juvenile Chinook salmon exposed to contaminants, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls suffered increased susceptibility to the common marine pathogen (*Vibrio anguillarium*). Similarly, a laboratory study suggests that sublethal concentrations of pollutants can be acting synergistically with endemic pathogens of juvenile Chinook salmon, thus compromising survivorship through immunologic or physiologic disruption (Clifford et al. 2005). Although less common, high concentrations of particular contaminants (e.g., ammonia, hydrogen sulfide, herbicides, pesticides) may lead to acute toxicity and death after only short exposure times.

Recent studies suggest that chronic or sublethal effects of contaminants may be subtle and difficult to detect. For example, early experimental studies indicated that hatchery-reared juvenile Chinook salmon exposed to undiluted agricultural subsurface drainwater from the west side of the San Joaquin River had greater than 75 percent mortality, whereas there were no chronic detrimental effects on the growth and survival of the study fish exposed to agricultural return flows that were diluted by greater than or equal to 50 percent (Saiki et al. 1992). However, recent studies suggest that juvenile fall-run Chinook salmon died in the laboratory after eating selenium-contaminated invertebrates and prey fish over a 90-day period that were collected from the San Joaquin River Basin (Beckon 2007). These two sets of studies suggest that bioassays of fathead minnows in water samples from the San Joaquin, Merced, Tuolumne, and Stanislaus rivers that showed little evidence of toxicity (Brown 1996) may not have detected chronic or sublethal effects that may affect Chinook salmon.

Herbicides

Chemicals containing ingredients such as diquat dibromide, free and complexed copper (e.g., copper ethylenediamine), fluridone, glyphosate, dimethylamine salt of 2, 4-dichlorophenoxyacetic acid, and alkylphenolethoxylates are applied to control aquatic weeds such as *Egeria densa* and water hyacinth (*Eichhornia crassipes*) in the Delta (DFG 2004). The primary impacts of diquat dibromide and fluridone are sublethal to juvenile Chinook salmon causing of narcosis rheotropism, chemical interaction, and immunotoxicity (NMFS 2006a). Exposure of juvenile Chinook salmon to these herbicides can increase their vulnerability to predation from both piscine and avian predators as well as reduce valuable invertebrate prey items (NMFS 2006a). In addition, the application of herbicides may result in low DO concentrations as the plants decompose (NMFS 2006a, 2006b).

Pesticides/Insecticides/Fungicides

Recent studies have indicated a serious potential risk of pesticides/insecticides/fungicides to exposed early life stages of Chinook salmon and aquatic invertebrates in the Central Valley (Viant et al. 2006). A large number of pesticides/insecticides/fungicides have been detected by water quality sampling programs in the San Joaquin River Basin, including aldrin, carbaryl, chlorpyrifos, diazinon, dieldrin, diuron, heptachlor, lindane, malathion, metribuzin, and trifluralin (Domagalski et al. 2000). Most problems occur in the lower Restoration Area (Reaches 3 through 5) where water quality is influenced by water imported from the Delta and by agricultural drainage, particularly from Mud and Salt sloughs. Reaches 1 and 2 have generally good water quality (Brown 1997). Domagalski's study (et al. 2000) and other multiyear studies (Brown 1997, Panshin et al. 1998) assessed a wide array of contaminants. More than half of the surface water samples from certain agricultural drainages in the Central Valley contain seven or more pesticides/insecticides/fungicides (Panshin et al. 1998). These pesticide mixtures include organophosphates and carbamates that are likely to have additive effects on the neurobehavior of salmon exposed in contaminated watersheds (Scholz et al. 2006). The growing number of chemical pesticides/insecticides/fungicides found in the San Joaquin Valley is too large to encompass in this review. Furthermore, accurately quantifying risks of individual pesticides/insecticides/fungicides or synergistic effects of multiple pesticides/insecticides/fungicides is not easily validated; most studies rely on comparing contaminant levels (from biota or the environment) to literature values, regional or national statistics, or suitable reference sites.

USGS NAWQA Toxicity Monitoring. The San Joaquin-Tulare study unit was among the first basins chosen for the U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA), and has recently focused considerable attention on pesticide contamination in the San Joaquin River Basin (Dubrovsky et al. 1998, Panshin et al. 1998, Kratzer and Shelton 1998, Brown and May 2000). Generally, toxicity within the San Joaquin River has been attributed to pesticides/insecticides/fungicides from agricultural nonpoint sources, substantiated by the lack of detection of pesticide compounds in reference sites on the upper Kings River and Tuolumne River, situated above agricultural influences (Dubrovsky et al. 1998). In the NAWQA studies, available drinking water standards were not exceeded at San Joaquin River monitoring sites, but the concentrations of several pesticides/insecticides/fungicides exceeded the criteria for the protection of aquatic life. As mentioned previously, regional or national contamination levels are used to interpret San Joaquin River study results. Gilliom and Clifton (1990, from Brown 1998) reported that the San Joaquin River had some of the highest concentrations of organochlorine residues in bed sediments among the major rivers of the United States. Although the organochlorine pesticide DDT (dichloro-diphenyl-trichloroethane) was banned in the United States in 1973, DDT concentrations have continued to be detected in biota of the San Joaquin Valley streams at lower levels (Goodbred et al. 1997, Dubrovsky et al. 1998) as contaminated soils are transported to streams and sediment is resuspended from riverbeds.

Concentrations of organophosphate pesticides (i.e., diazinon and chlorpyrifos) in runoff are high, and highly variable during winter storms (Kratzer and Shelton 1998). In winter, dormant-spray pesticides, including diazinon and chlorpyrifos are applied to fruit orchards and alfalfa fields in the San Joaquin River Basin and Delta islands (Kuilvila 1995, 2000). These pesticides are delivered to local watercourses and the Delta by overland runoff. Diazinon is the common name of an organophosphorus (OP) pesticide used to control pest insects in soil, on ornamental plants, and on fruit and vegetable field crops. Chlorpyrifos is also an OP pesticide and is used to kill insect pests by disrupting their nervous system. OP pesticides were originally developed for their water solubility and ease of application. After they have been applied, they may be present in the soil, surface waters, and on the surface of the plants that are sprayed, and may be washed into surface waters by rain.

Reaches 1 and 2 of the San Joaquin River have not been identified as problem areas by the NAWQA studies, but pesticides have been detected in groundwater samples from domestic water supply wells. However, concentrations of pesticides in groundwater supplies generally have not increased in the last decade (Dubrovsky et al. 1998). The extremely low levels of pesticides and herbicides, and ephemeral nature of their presence in surface waters, prompted the creation of the California Department of Pesticide Regulation (DPR) within the California Environmental Protection Agency (CalEPA), which tracks pesticide use. Data are available at the following Web site: http://www.cdpr.ca.gov/dprdatabase.htm.

Basin Plan Objectives and Central Valley Water Board Monitoring. For most pesticides, numerical water quality objectives have not been adopted, but a number of narrative water quality objectives (e.g., no adverse effects) for pesticides and toxicity are listed in the Basin Plan (Central Valley Water Board 1998). The EPA criteria and other guidelines are also extremely limited, since numerical targets based on the anti-degradation policy would not allow pesticide concentrations to exceed natural "background" levels (i.e., nondetectable levels or "zero"). For the San Joaquin River system, including the five reaches of this study area, the California State Water Quality Control Board (SWRCB) has set a goal of "zero toxicity" in surface water. This goal is intended to protect the beneficial uses of recreation, warm freshwater habitat, cold freshwater habitat, and municipal and domestic supply from potential pesticide impacts.

The most recent 303(d) list of impaired waterbodies presented by the Central Valley Region Water Quality Control Board (Central Valley Water Board) identifies Reaches 3, 4, and 5 of the San Joaquin River study area, Mud Slough, and Salt Slough as impaired due to pesticides and "unknown toxicity." In addition to the Central Valley Water Board, USGS, and DPR are conducting cooperative synoptic and/or in-season sampling for pesticides, herbicides, and insecticides. The following stations are part of the ongoing studies: San Joaquin River at Vernalis (USGS 11303500), Maze (USGS 11290500), Patterson (USGS 11274570), Crows Landing (USGS 11274550), and Stevinson (USGS 11260815), Bear Creek at Bert Crane Road. (Central Valley Water Board MER007), Salt Slough at Lander/Hwy 165 (USGS 11261100), Mud Slough (USGS11262900), and Los Banos Creek at Hwy 140 (Central Valley Water Board MER554). Results of these sampling efforts will help characterize the distribution of pesticides and other toxins within these impaired waterbodies. Annual reports discussing the results for DPR-funded studies can be found at http://www.cdpr.ca.gov/docs/empm/pubs/memos.htm.

Because of their importance as a marker of pesticide-use practices, DDT and two OP pesticides, diazinon and chlorpyrifos are focused on in this document. These compounds, and simazine and metolachlor, were some of the most frequently detected compounds in the NAWQA program studies (Dubrovsky et al. 1998). In addition to the well-known effects of DDT on egg shell thinning and deformities in birds, OP pesticides can affect survival or cause chronic physiological effects on exposed fish via acetylcholinesterase (AChE) enzyme inhibition and induction of heat shock proteins in response to stress. Juvenile Chinook salmon may be more vulnerable to predation and grow less as a result of only brief exposures to AChE-inhibiting pesticides (Eder et al. 2007, Scholz et al. 2000). Recently, there has been a general movement towards the use of pyrethroids instead of OP pesticides in agriculture. High doses of pyrethroid compounds, such as esfenvalerate can be acutely toxic to juvenile Chinook salmon (Wheelock et al. 2005). The ecological effects of increased use of pyrethroids on aquatic ecosystems and Chinook salmon populations are in need of further research (Phillips 2006). Despite the fact that pyrethroids are now one of the most important insecticides and increasingly applied in the Central Valley, primarily for agriculture and urban purposes, only a limited number of studies and monitoring efforts are focusing on occurrence and toxicity (Oros and Werner 2005). There are not enough field monitoring data to date on the spatial and temporal occurrences of pyrethroids for making risk assessments (Oros and Werner 2005).

Trace Elements

Selenium and mercury are two environmental contaminants of primary concern in aquatic environments, and the San Joaquin River is not an exception. Selenium and mercury are trace elements that can be harmful to aquatic life because they undergo biomagnification after being converted to organic forms in reducing (i.e., low oxygen) conditions by methylating bacteria. As a result of this conversion to an organo-metallic compound, methylated selenium and mercury are preferentially absorbed into fatty tissues and can biomagnify through the food chain despite low ambient concentrations. Central Valley Water Board water quality objectives for selenium are currently being exceeded for Mud Slough and downstream reaches. While the reported background concentrations for selenium for the San Joaquin River above Salt and Mud sloughs are about 0.5 micrograms per liter (µg/L), selected sites along the river have selenium concentrations from 1 to 5 µg/L (Central Valley Water Board 2001). The input of selenium from the Grasslands area into the San Joaquin River represents a major risk for larval fish, including Chinook salmon (Beckon 2007).

Effluent from Wastewater Treatment Plants and Livestock Operations

Free ammonia (NH_3), other nitrogen species (nitrates, nitrites, organic nitrogen), pH, chlorine, and DO are a concern in the Delta, particularly near the outflow from sewage treatment plants and dairy farms. One of the most significant water-quality problems in the Delta is the low DO problem in the Stockton Deepwater Ship Channel. The first 7 miles of the Stockton Deepwater Ship Channel west of the Port of Stockton experiences DO concentrations below the Central Valley Water Board DO water quality standards (SJRDOTWG 2007). The low DO problem is due to poor water circulation, flow, the deepness of the channel, and the oxygen demand exerted by wastewater discharge from the Stockton Regional Wastewater Control facility and the decomposition of algal biomass produced upstream. In response to nutrients discharged by irrigated agriculture and dairy operations in the San Joaquin River Basin, high concentrations of planktonic algae grow within 8 to 10 feet of the water's surface upstream from the ship channel and then settle below the sunlight zone and die when the water flows into the 35-foot-deep ship channel (Lee and Jones-Lee 2003). Minimum DO concentrations measured in the San Joaquin River ship channel at the DWR Rough and Ready Island station during April and May typically range between about 3 mg/L during low flows (e.g., 1987) and 7 mg/L during flood conditions (e.g., 1998). DO levels below 3.3 mg/L are considered lethal for salmon whereas levels below 5.0 mg/L may reduce growth rates of juvenile salmon (Spence et al. 1996). Nitrification of even low levels of ammonia as well as decomposition of algal detritus and residual wastewater use large amounts of DO. Other factors that affect DO concentrations in the ship channel include water temperature, atmospheric aeration, and sediment oxygen demand (Jones and Stokes 2002b).

Observed Salmon Mortalities During the 2007 VAMP Studies. It is possible that impaired water quality in the San Joaquin River near Stockton was responsible for the mortality of about 20 percent of tagged juvenile fall-run Chinook salmon during the May 2007 Vernalis Adaptive Management Plan (VAMP) studies. A total of 152 out of about 780 juvenile Chinook salmon that had surgically inserted acoustic tags and were released in the mainstem San Joaquin River stopped their migrations and presumably died adjacent to a railroad bridge and the Stockton Regional Wastewater Control Facility outfall (Natural Resource Scientists 2007). Initially, 116 dead fish were observed on May 17 and 18 (Natural Resource Scientists 2007), whereas another 36 dead fish were located after May 20, 2007. The cause of the mortality remains uncertain because few of the dead fish were recovered, no bioassay studies were conducted in the river near the wastewater facility, and there were no water quality monitoring stations where the dead fish were found. Because of the high concentration of fish tags at this location, either unusually high predator activity or some toxicity event was hypothesized to have resulted in the localized fish mortality.

Potential water quality constituents that may be associated with fish toxicity or mortality of the VAMP study fish in May 2007 include NH_3, hydrogen sulfide (H_2S), and low levels of OP pesticides (e.g., chlorpyrifos and diazinon). Monitoring of the wastewater control facility's effluent indicated that pH, DO, turbidity, chlorine, and ammonia were within compliance conditions of the facility's permits shortly after the fish had been released (Patricia Leary 2007, pers. com). Monitoring in the river approximately 0.5 mile upstream and downstream from the site also suggest that pH (7.75 to 8.25) and DO (greater than 9 mg/L) levels would not account for the mortality (Mueller-Solger 2007). However, although unionized ammonia levels in the river were less than 0.02 mg/L, well below the EPA (1999) critical levels for salmon (e.g., 0.21 mg/L NH_3 at 68°F, and a pH of 8), final effluent grab samples collected by Central Valley Water Board staff at the Stockton Regional Wastewater Control Facility contained total ammonia and total Kjeldahl nitrogen (TKN) at levels of 4.4 mg/L and 6.2 mg/L, respectively. Since average daily pH at the Port of Stockton approaches levels (pH 8 or above) that produce acute and chronic ammonia toxicity, and algal photosynthesis in the lower San Joaquin likely produces diel pH swings due to scavenging of carbon dioxide and alkalinity, it is possible that ammonia toxicity to fish occurs at some time of day for several months from spring through fall of each year.

4.2.5 Entrainment

In 2001, DFG inventoried 95 riparian diversions in the Restoration Area between RM 209 and 267 that were mostly unscreened pumps (McBain and Trush 2002). The estimated maximum diversion capacity ranged between less than 1 cubic feet per second (cfs) to 63 cfs. Three of these diversions are weir structures just downstream from Friant Dam. The Big Willow Unit Diversion (RM 261.3) is a cobble-type weir that diverts a small amount of water to the Fish Hatchery. The Rank Island Unit is a cobble weir located at RM 260, and diverts approximately 5 cfs to property on the north side of the river. The Milburn Unit Diversion is a small concrete-rubble weir located at RM 247.2. A small pump is located just upstream. In addition, Herren and Kawasaki (2001) found 298 and 2,209 diversions in the San Joaquin River Basin and Delta respectively. More than 95 percent of these diversions were unscreened, and the impacts of these diversions on juvenile Chinook salmon are unknown. No studies have been conducted to determine the entrainment rates at the pumps and weirs in the Restoration Area or downstream in the Delta.

Below the Restoration Area

The irrigation season in the San Joaquin River between Stockton and the Merced River between 1946 and 2002 has been principally between March and October, with some water diverted in February and November (Hallock and VanWoert 1959, Quinn and Tulloch 2002). DFG estimated that an average of 127,000 acre-feet of water was diverted annually from all diversions in this reach from 1946 to 1955 (Hallock and VanWoert 1959). Quinn and Tulloch (2002) estimated that from 1999 to 2001, annual pumping rates increased to an average of about 154,500 acre-feet at the four largest diversions, which include the Banta-Carbona Irrigation District, West Stanislaus Irrigation District, Patterson Water Company, and El Solyo Water Company.

During 1955, nets were fished in the Banta-Carbona Irrigation District pumps (RM 67.5), El Solyo pumps (RM 82.0), and Patterson Water Company pumps (RM 104.4) (Hallock and Van Woert 1959). The highest entrainment rates were measured at the Banta-Carbona site in 1955 at about 12 fish per hour. In summer 2002, screens were installed at Banta-Carbona that appear to be effective at protecting juvenile salmon. In comparison, the Patterson Water Company pumps entrained about 1.6 juvenile Chinook salmon per hour and the El Solyo pumps entrained about 5.2 Chinook salmon per hour in 1955. There are no screens at the West Stanislaus Irrigation District, Patterson Water Company, or El Solyo Water Company pumps, although screens are proposed for the Patterson pumps.

Entrainment of juvenile Chinook salmon at the Federal (Central Valley Project (CVP)) and State (State Water Project (SWP)) pumping facilities in the Delta is not directly measured but instead estimated as a function of the expanded number of fish salvaged, fish size, and water velocity through the louvers (Foss 2003). For a 2,000-cfs export flow, the efficiency of the louvers for fish larger than 100 mm in length is estimated to be

70 percent and 68 percent at the CVP facilities and SWP facilities, respectively. Louver efficiencies are about 6 percent higher for Chinook salmon up to 100 mm in length compared to larger fish. The number of fish salvaged at the louvers is estimated with samples taken at least every 2 hours while water is pumped (Foss 2003). When tagged juvenile fall-run Chinook salmon were released in the San Joaquin River near Mossdale in spring 1992 and 1993, means of 3.3 percent and 0.3 percent were salvaged at the CVP and SWP facilities, without and with a barrier at the Head of the Old River, respectively (Table 4-3).

Most juvenile mortality at the Delta pumping facilities is probably due to predation in Clifton Court Forebay and the canals leading to the pumps by nonnative predators such as striped bass, largemouth bass, and sunfishes (i.e., Centrarchidae). It is assumed that prelouver predation losses are 15 percent from the trash racks to the louvers at the CVP facilities and 75 percent in Clifton Court Forebay which leads to the SWP facilities (Foss 2003). Some of the acoustically tagged juvenile fall-run Chinook salmon released for the spring 2007 VAMP studies were preyed on by large fish congregated near the trash racks at the CVP pumping facilities (Vogel 2008).

Table 4-3.
Number of Tagged Fall-Run Chinook Salmon Smolts from the Feather River Hatchery Released in San Joaquin River at Mossdale in 1992 and 1993, and Salvage Rates

Release Date	Vernalis Flow (cfs)	CVP and SWP Export Rates (cfs)	HORB Installed	Number Released	Expanded Salvage		Percent Salvaged	
					CVP	SWP	CVP	SWP
04-May-93	4,730	1,494	No	51,937	931	102	1.79%	0.20%
12-May-93	3,770	1,585	No	52,616	1,332	113	2.53%	0.21%
07-Apr-92	1,620	5,682	No	107,103	5,380	71	5.02%	0.07%
13-Apr-92	1,530	1,185	No	103,712	3,385	106	3.26%	0.10%
24-Apr-92	1,070	1,009	Yes	104,739	28	28	0.03%	0.03%
04-May-92	1,480	2,777	Yes	99,717	28	8	0.03%	0.01%
12-May-92	1,020	1,757	Yes	105,385	0	6	0.00%	0.01%

Source: USFWS 2000a.
Key:
cfs = cubic feet per second
CVP = Central Valley Project
HORB = Head of the Old River Barrier
SWP = State Water Project

4.2.6 Degraded In-River Physical Habitat

In Pacific Northwest and California streams, habitat simplification has led to a decrease in the diversity of anadromous salmonid species habitat (NMFS 1996). Habitat simplification may result from blocked gravel recruitment by upstream dams as well as various land-use activities, including gravel extraction, bank revetment, timber harvest, grazing, urbanization, and agriculture.

Gravel Recruitment Blocked by Dams and Levees

Friant Dam eliminated sediment supply from the upper watershed, and combined with the modified flow regime and land use downstream from Friant Dam, varying degrees of sediment budget imbalance have occurred in the river downstream. The current paradigm of dam impacts to sediment supply downstream from the dams is that periodic high flow releases from the dam transport sediment stored in the stream bed, and because the sediment supply from the upper watershed is blocked, channel degradation occurs downstream from the dam as alluvial features (bars and riffles) slowly diminish (Collier et al. 1996). Instream gravel mining has exacerbated this sediment deficit in the Restoration Area (McBain and Trush 2002). Local imbalances in sediment supply and transport have caused primarily incision and channel widening with some local aggradation (sedimentation) in the Restoration Area (Cain 1997). Loss of alluvial features in the Restoration Area has contributed to the reduction in frequency of floodplain inundation, which has probably caused a substantial reduction in potential food resources and refuge from predators for juvenile salmonids in the Restoration Area. In addition, channel incision reduces the availability of alternating bars and riffles that juvenile Chinook salmon use for feeding and predator avoidance during low flow periods.

Lack of Large Woody Debris

Large quantities of downed trees are a functionally important component of many streams (NMFS 1996). IWM influences channel morphology by affecting longitudinal profile, pool formation, channel pattern and position, and channel geometry. Downstream transport rates of sediment and organic matter are controlled in part by storage of this material behind IWM. IWM affects the formation and distribution of habitat units, provides cover and complexity, and acts as a substrate for biological activity (NMFS 1996). Wood enters streams inhabited by salmonids either directly from adjacent riparian zones or from riparian zones in adjacent nonfish-bearing tributaries. Removal of riparian vegetation and IWM from the streambank results in the loss of a primary source of overhead and instream cover for juvenile salmonids. The removal of riparian vegetation and IWM and the replacement of natural bank substrates with rock revetment can adversely affect important ecosystem functions. Living space and food for terrestrial and aquatic invertebrates is lost, eliminating an important food source for juvenile salmonids. Loss of riparian vegetation and soft substrates reduces inputs of organic material to the stream ecosystem in the form of leaves, detritus, and woody debris, which can affect biological production at all trophic levels. The magnitude of these effects depends on the degree to which riparian vegetation and natural substrates are preserved or recovered during the life of the project.

Dikes, Levees, and Bank Revetment

The construction of levees and dikes to convert land for agricultural production tends to channelize riverine habitats and reduces channel migration and avulsion (McBain and Trush 2002). Reduced channel migration has eliminated off-channel habitats, reduced complex side channels, and reduced instream habitat complexity that all serve to provide suitable conditions for juvenile salmonids over a wide range of flow. Agricultural conversion has also directly reduced the amount of floodplains, and levees and dikes have further isolated historic floodplains from the channel. It is likely that the loss of floodplain habitats has substantially reduced food resources and refuge from predators for juvenile salmonids.

Angular rock (riprap) is used to armor the streambanks from erosive forces in the Restoration Area and throughout the Central Valley. Simple slopes protected with rock revetment generally create nearshore hydraulic conditions characterized by greater depths and faster, more homogeneous water velocities than occur along natural banks (USFWS 2000b, Garland et al. 2002). Higher water velocities typically inhibit deposition and retention of sediment and woody debris. These changes generally reduce the range of habitat conditions typically found along natural shorelines, especially by eliminating the shallow, slow-velocity river margins used by juvenile fish as refuge and escape from fast currents, deep water, and predators (USFWS 2000b).

The use of rock armoring also limits recruitment of IWM and greatly reduces, if not eliminates, the retention of IWM once it enters the river channel. Riprapping creates a relatively clean, smooth surface that diminishes the ability of IWM to become securely snagged and anchored by sediment. IWM tends to become only temporarily snagged along riprap, and generally moves downstream with subsequent high flows. Habitat value and ecological functioning aspects are thus greatly reduced, because wood needs to remain in place to generate maximum values to fish and wildlife (USFWS 2000b). Recruitment of IWM is limited to any eventual, long-term tree mortality and any abrasion and breakage that may occur during high flows (USFWS 2000b). Juvenile salmonids are likely being impacted by reductions, fragmentation, and general lack of connectedness of remaining nearshore refuge areas.

A separate but connected bypass system, consisting of the Chowchilla Bypass Channel, Eastside Bypass Channel, and Mariposa Bypass Channel, was constructed to divert and carry flood flows from the San Joaquin River and eastside tributaries upstream from the Merced River. These bypasses lack floodplain access, habitat structure, nearshore habitat and riparian habitat required by Chinook salmon.

Urbanization

CALFED (2000) estimated that wetted perimeter reductions in the Delta have decreased from between 25 and 45 percent since 1906. Historically, the San Francisco Estuary included more than 242,000 acres of tidally influenced bay-land habitats, and tidal marsh and tidal flats accounted for 98 percent of bay-land habitats. Today, only 70,000 acres of tidally influenced habitat remain (CALFED 2000). While historical uses of riparian areas (e.g., wood cutting, clearing for agricultural uses) have substantially decreased, urbanization still poses a serious threat to remaining riparian areas. Riversides are desirable places to locate homes, businesses, and industry.

4.2.7 High Water Temperatures

Release temperatures from Friant Dam currently range from 48°F to 58°F (8.9°C to 14.4°C) and water temperatures are expected to be suitable for juvenile rearing except in the downstream reaches (Reaches 2B to 5) as air temperatures increase.

Unsuitably high water temperatures and exaggerated fluctuations in water temperature result from a combination of factors, including seasonally high air temperatures (May and June), low flow releases, groundwater pumping that eliminated the inflow of cool groundwater throughout the Restoration Area, removal of large woody riparian forests that provided shade, warm agricultural runoff, and warm flood flows from the Kings River through the James Bypass. It is also possible that high flow releases during summer and fall could exhaust the cold water pool in Millerton Lake and thereby cause release temperatures to substantially increase above 58°F (14.4°C).

Many of these impacts will directly affect the juvenile life stages of Chinook salmon in the river. Juveniles start to experience stress from increased water temperature in the 64.4 to 70°F (18 to 21.1°C) (Rich 2007, Pagliughi 2008). Although floodplain rearing temperatures can exceed these temperatures and benefit fish growth in the presence of adequate food supply (Jeffres et al. 2008). Prolonged exposure to temperatures above 75°F (23.9°C) can lead to nearly 100 percent mortality (Hanson 1997, Rich 1987, Zedonis and Newcomb 1997, as cited in Pagliughi 2008).

Delta Conditions

Currently, there are no flow or water temperature standards to maintain suitable habitat for juvenile Chinook salmon in the lower San Joaquin River. Water temperatures in the San Joaquin River near Vernalis (DWR gage data) were usually below 65°F (18.3°C) from mid-April to mid-May when Vernalis flows were at least 3,500 cfs. Springtime water temperatures at Vernalis exceeded 65°F (18.3°C) during drought years (e.g., 1977 and 1987 to 1992) and when high flows entered the San Joaquin River from the James Bypass upstream from Newman during spring 1986. By the end of May, water temperatures typically ranged between 65°F and 70°F (18°C and 21°C) and regardless of flow.

4.2.8 Harvest of Yearling-Sized Juveniles

Following reintroduction of spring-run Chinook salmon into the San Joaquin River, yearling Chinook salmon may be present in portions of the Restoration Area throughout the year. Yearling spring-run Chinook salmon (those adopting a stream-type life history strategy) typically range in length from about 80 to 150 mm (3 to 6 inches), depending on growth rate and freshwater residence time (Moyle 2002). Sport anglers may catch yearling Chinook salmon while fishing for trout or other game fish, likely resulting in injury or mortality due to hooking and handling. State fishing regulations specify bag limits for trout and Chinook salmon in the San Joaquin River, but size restrictions are not designated (DFG 2007b).

4.3 Ocean Phase

The survival of smolts entering the ocean during June and July is probably the most critical phase for salmon in the ocean (Pearcy 1992, Mantua et al. 1997, Quinn 2005). Marking studies suggest that about 59 to 77 percent of juvenile pink salmon (*O. gorbuscha*) died in their first 40 days at sea off the coast of British Columbia, whereas 78 to 95 percent of those that survived their first 40 days died over the next 410 days at sea (Parker 1968). Another marking study with chum salmon off the coast of Washington indicated that juvenile mortality averaged 31 to 46 percent per day during the first few days (Bax 1983).

The survival of smolts entering the ocean is highly correlated with ocean productivity as affected by freshwater outflow from the estuary. This, in turn, affects the availability of food resources at the interface between freshwater and saltwater, as well as coastal upwelling, ocean currents and El Niño events (Casillas 2007).

4.3.1 Inadequate Juvenile Food Availability

Long-term records indicate that there are 15- to 25-year cycles of warm and cool periods that strongly correlate with marine ecosystem productivity (Mantua et al. 1997; Hollowed et al. 2001). Cool productive cycles prevailed from 1947 through 1976, and a new cycle began in 1998, whereas warm unproductive cycles dominated from 1925 through 1946, and from 1977 through 1997 (Mantua et al. 1997; Mantua and Hare 2002). The coastal warming that occurred in the mid-1970s is believed to have caused increased stratification in the California Current; a sharper thermocline with less upwelling of nutrient-rich water; a reduction in the duration of upwelling; and a reduction in nutrients and/or zooplankton abundance carried by the California Current (Francis et al. 1998). In addition, the abundance of coastal euphausiids (*Thysanoessa spinifera*) declined whereas oceanic euphausiids (*T. pacifica*) increased (Francis et al. 1998). Such changes are thought to affect salmon early in their marine life history (Hare and Francis 1995), and coastal invertebrate species are important prey for ocean-type juveniles, such as Central Valley fall-run Chinook salmon.

The interface between the plume of freshwater outflow from the Columbia River and saltwater in the ocean is a highly productive area that is important to the survival of juvenile Chinook salmon and other salmonid species migrating into the ocean (Casillas 2007). Large freshwater plumes that extend well offshore 7 to 10 days after juvenile salmonids enter the ocean are highly correlated with higher numbers of returning adults 2 years later (Casillas 2007). The density of food organisms, particularly crustacean larvae, is unusually high at the freshwater-saltwater interface. It is likely that freshwater outflow from the San Francisco Estuary between May and July is also important to the survival of juvenile San Joaquin River Chinook salmon. The May through July period is probably important because that is when juvenile Chinook salmon entered the Gulf of the Farallones during spring 1997 (MacFarlane and Norton 2002). In the Gulf of the Farallones, the size of the plume would be controlled by inflow to the Delta from the Sacramento and San Joaquin river basins as well as Delta exports, which can be as high as 35 percent of Delta inflow from February through June, and 65 percent of Delta inflow from July through January (SWRCB 1995, California Regional Water Quality Control Board 2007).

Indicators of Ocean Productivity

Coastal waters off the Pacific Northwest are influenced by atmospheric conditions in the North Pacific Ocean, but also in equatorial waters, especially during El Niño events. Strong El Niño events result in the transport of warm equatorial waters northward along the coasts of Central America, Mexico, and California, and into the coastal waters off Oregon and Washington. These events affect weather in the Pacific Northwest, often result in stronger winter storms and transport of warm, offshore waters into the coastal zone. The transport of warm waters toward the coast, either from the south or from offshore, also creates unusual mixes of zooplankton and fish species.

The Pacific Decadal Oscillation (PDO) is a climate index based on patterns of variation in sea surface temperature of the North Pacific from 1900 to the present (Mantua et al. 1997). While derived from sea surface temperature data, the PDO index is well correlated with many records of North Pacific and Pacific Northwest climate and ecology, including sea level pressure, winter land-surface temperature and precipitation, and stream flow. The index is also correlated with salmon landings from Alaska, Washington, Oregon, and California.

Since 1955, the presence/absence of conditions caused by the El Niño Southern Oscillation (ENSO) has been gauged using the Multivariate ENSO Index (MEI). El Niño conditions were observed infrequently before 1977 (during the cool phase of the PDO).

Both the PDO and MEI can be viewed as "leading indicators" of ocean productivity because after a persistent change in sign of either index, ocean conditions in the California Current soon begin to change. Most recently, in September 2005, the MEI appears to have signaled a return to warmer ocean conditions.

4.3.2 Marine Predation

Both bird and fish predators congregate at the freshwater-saltwater interface of the freshwater plume of the Columbia River where juvenile salmon feed (Casillas 2007). In spring 2003, there were many species of bird predators. Marine fish that intensively prey on juvenile salmon include Pacific hake (*Merluccius productus*), rockfish (*Sebastes spp*.), and to a lesser degree, jack mackerel (*Trachurus symmetricus*), Pacific mackerel (*Scombrus japonicus*), and spiny dogfish (*Squalus acanthias*). The abundance of bird and fish predators has been highly correlated with juvenile salmon abundance off the coast of Washington. However, the impact of predation on the number of returning adult salmon has not been quantified.

The primary marine mammals preying on salmonids are pinnipeds, including harbor seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), and Steller's sea lions (*Eumetopia jubatus*) (Spence et al. 1996). Pacific striped dolphin (*Lagenorhynchus obliquidens*) and killer whale (*Orcinus orca*) also prey on adult salmonids in the nearshore marine environment. Seal and sea lion predation is primarily in saltwater and estuarine environments, although they are known to travel well into freshwater after migrating fish. All of these predators are opportunists, searching out locations where juveniles and adults are most vulnerable.

4.3.3 Adult Commercial and Sport Harvest

Extensive ocean recreational and commercial troll fisheries for Chinook salmon exist along the Central California coast, and an inland recreational fishery exists in the Central Valley for Chinook salmon and steelhead. Ocean harvest of Central Valley Chinook salmon is estimated using an abundance index, called the Central Valley Index (CVI). The CVI is the ratio of Chinook salmon harvested south of Point Arena (where 85 percent of Central Valley Chinook salmon are caught) to the sum of the estimated escapements and harvest of Central Valley fish.

Ocean fisheries have affected the age structure of Central Valley spring-run Chinook salmon through targeting large fish for many years and reducing the numbers of 4- and 5-year-old fish (DFG 1998). Ocean harvest rates of Central Valley spring-run Chinook salmon are thought to be a function of the CVI (Good et al. 2005). Harvest rates of Central Valley spring-run Chinook salmon ranged from 55 percent to nearly 80 percent between 1970 and 1995, when harvest rates were adjusted to protect Sacramento River winter-run Chinook salmon. The drop in the CVI in 2001 as a result of high fall-run Chinook salmon escapement to 27 percent also reduced harvest of Central Valley spring-run Chinook salmon.

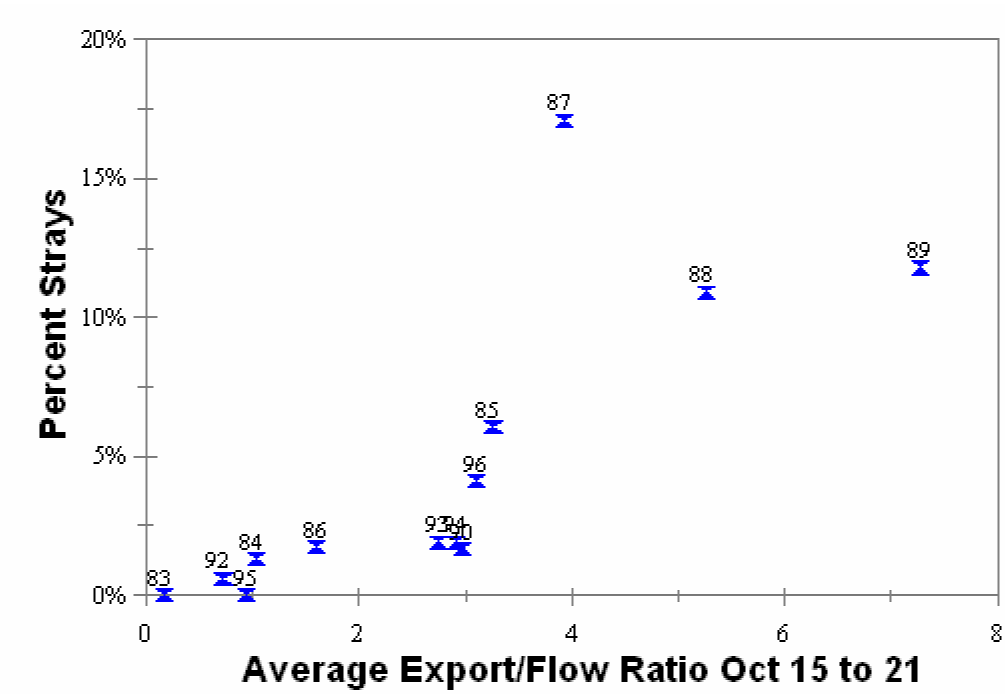
In-river recreational fisheries historically have taken Central Valley spring-run Chinook salmon throughout the species' range. During the summer, holding adult Central Valley spring-run Chinook salmon are targeted by anglers when they congregate in large pools. Poaching also occurs at fish ladders, and other areas where adults congregate; however, the significance of poaching on the adult population is unknown. Specific regulations for the protection of Central Valley spring-run Chinook salmon in Mill, Deer, Butte, and Big Chico creeks were added to existing DFG regulations in 1994. The current regulations, including those developed for Sacramento River winter-run Chinook salmon, provide some level of protection for spring-run Chinook salmon (DFG 1998).

4.4 Adult Migration

Adult Chinook salmon will have to navigate approximately 270 miles from the ocean to spawning habitat downstream from Friant Dam. The number of Chinook salmon that successfully complete their migration will partly depend on environmental conditions that are needed for the fish to home to their natal stream as well as other factors, such as predation and harvest, that result in mortality.

4.4.1 Inadequate Flows and High Delta Export Rates

An important factor for successful upstream migration is sufficient flow throughout the migratory corridor that provide olfactory cues allowing the adult salmon to home to their natal stream. This has been a concern for adult fall-run Chinook salmon in the San Joaquin River Basin since 1996 when Delta export rates at the CVP and SWP were increased to near maximum (about 9,600 cfs) to "make up" for reduced pumping rates during the spring outmigration period. When exports are high relative to San Joaquin River flows, it is likely that little, if any San Joaquin River water reaches the San Francisco Bay where it may be needed to help guide the Chinook salmon back to their natal stream. An analysis of recovered adult Chinook salmon with CWT that had been reared at the Merced River Fish Facility and released in one of the San Joaquin tributaries suggests straying occurred when the ratio of exports to flows was high (Mesick 2001b). The analysis indicates that during mid-October from 1987 through 1989, when export rates exceeded 400 percent of Vernalis flows, straying rates ranged between 11 percent and 17 percent (Figure 4-3). In contrast, straying rates were estimated to be less than 3 percent when Delta export rates were less than about 300 percent of San Joaquin River flow at Vernalis during mid-October.



Source: Mesick 2001b.

Notes:

1. Juveniles were released in the San Joaquin River Basin and subsequently strayed to the Sacramento River and eastside tributary basins to spawn.
2. Average Export/Flow Ration is based on the average ratio of the export rate at the CVP and SWP pumping facilities in the Delta compared to the flow rate in the San Joaquin River at Vernalis between 15 and 21 October, from 1983 to 1996.

Figure 4-3.
Estimated Percent of Adult Merced River Hatchery Coded Wire Tagged Chinook Salmon Strays Relative to Export to Flow Ratio

4.4.2 High Water Temperatures

In general, Chinook salmon appear capable of migrating upstream under a wide range of temperatures. Bell (1986) reported that salmon migrate upstream in water temperatures that range from 37°F (2.8°C) to 68°F (20°C). Bell (1986) reports that temperatures ranging between 37°F (2.8°C) and 55°F (12.8°C) are suitable for upstream migration of spring-run Chinook salmon, and between 50°F (10°C) and 66°F (18.9°C) for fall-run Chinook salmon. Based on numerous studies, Rich (2007), cites 59°F (15°C) as the upper limit to the optimal temperature range for adult Chinook migration. Thermal stress in migrating adults is detectable from 62.6 to 68°F (17 to 20°C) (Marine 1992) and significant mortality is observed at temperatures above this range (Marine 1992).

4.4.3 Physical Barriers and Flow Diversion

Historically, adult spring-run Chinook salmon migrated as far upstream as Graveyard Meadows (Lee 1998). The amount of holding and spawning habitat available to spring-run Chinook salmon was reduced around 1920, when Kerckhoff Dam "blocked the spring-run Chinook salmon from their spawning areas upstream and seasonally reduced flows in about 14 miles of stream, below the dam, where there were pools in which the fish would have held over the summer" (DFG 1921, as cited in Yoshiyama et al. 1996). The completion of Friant Dam in 1941 blocked access to approximately 16 additional miles of habitat that was historically used by spring-run Chinook salmon for spawning, representing an estimated 36 percent loss of the historic spawning habitat (Hatton 1940, as cited in Yoshiyama et al. 1996).

Passage below Friant Dam during the 1940s was inhibited by low flows in the channel. In 1944 and 1947, DFG (1955) observed from 5,000 to 6,000 spring-run Chinook salmon migrating up the San Joaquin River as far as Mendota Dam in a flow that was estimated to be 100 cfs in the reach between Sack Dam and the confluence with the Merced River. DFG observed that "many of these fish have rubbed themselves raw going over the shallow sandbars" between Sack Dam and the confluence with the Merced River (a distance of approximately 50 miles). Such abrasions can increase the risk of mortality from disease for spring-run Chinook salmon, since they must hold in pools throughout the summer before spawning. Passage for the San Joaquin River adult spring-run Chinook salmon has been completely blocked in the Restoration Area since the 1950s, when the river was dewatered below Sack Dam except during uncontrolled flow releases in wet years.

The Settlement prescribes that passage will be restored at all structures that may impede the passage of adult Chinook salmon through the Restoration Area. Improvements will be made at the following structures during Phase 1:

- Mendota Dam – A bypass channel will be created around Mendota Pool (RM 205)
- Reach 4B headgate and Sand Slough control structures (RM 168.5)
- Arroyo Canal Water Diversion – Screens will be installed (RM 182)
- Sack Dam, a diversion dam for the Arroyo Canal (RM 182)
- Eastside Bypass structures (RM 138 and RM 168)
- Mariposa Bypass structures (RM 147.2)
- Salt and Mud sloughs – Seasonal barriers will be installed to prevent adult Chinook salmon from entering these false migration pathways

Improvements will be made at Chowchilla Bifurcation Structure (RM 216) during Phase 2. McBain and Trush (2002) identified at least one earthen diversion dam just downstream from Gravelly Ford (RM 227) that may be potential impediments to both upstream and downstream fish movement.

4.4.4 Delta Water Quality

Hallock et al. (1970) showed that radio-tagged adult fall-run Chinook salmon delayed their migration in the Delta at Stockton whenever DO concentrations were less than 5 mg/L and/or water temperatures exceeded about 65°F (18.3°C) in October. Delaying the migration of adult fall-run Chinook salmon in the Stockton Deepwater Ship Channel may reduce gamete viability if the fish are exposed to high temperatures for prolonged periods. DFG reports that the quality and survival of eggs was poor from females exposed to water temperatures that exceeded 56°F (13.3°C) (DFG 1992).

DO concentrations near Stockton in October were greater than 5 mg/L from 1983, when DWR began monitoring, to 1990, but were lower than 5 mg/L for most of October in 1991 and 1992. The Head of the Old River Barrier was installed in fall 1992, but it did not correct the problem until late October (Figure 4-4). In 1993, DO levels were low until about October 10, and it is likely that pulse flows that raised Vernalis flows to about 4,000 cfs on October 7 were responsible for increasing DO levels at Stockton (Figure 4-4). Similarly in 1994, DO levels were low until October 15, when pulse flows raised Vernalis flows to about 2,000 cfs (Figure 4-4). In 1995, DO levels were at least 6 mg/L in October when Vernalis flows ranged from about 3,000 cfs to 6,000 cfs through mid-October. DO levels were low or fluctuated greatly in 1996 until October 13, when pulse flow releases increased Vernalis flows from 2,000 to about 3,000 cfs (Figure 4-4).

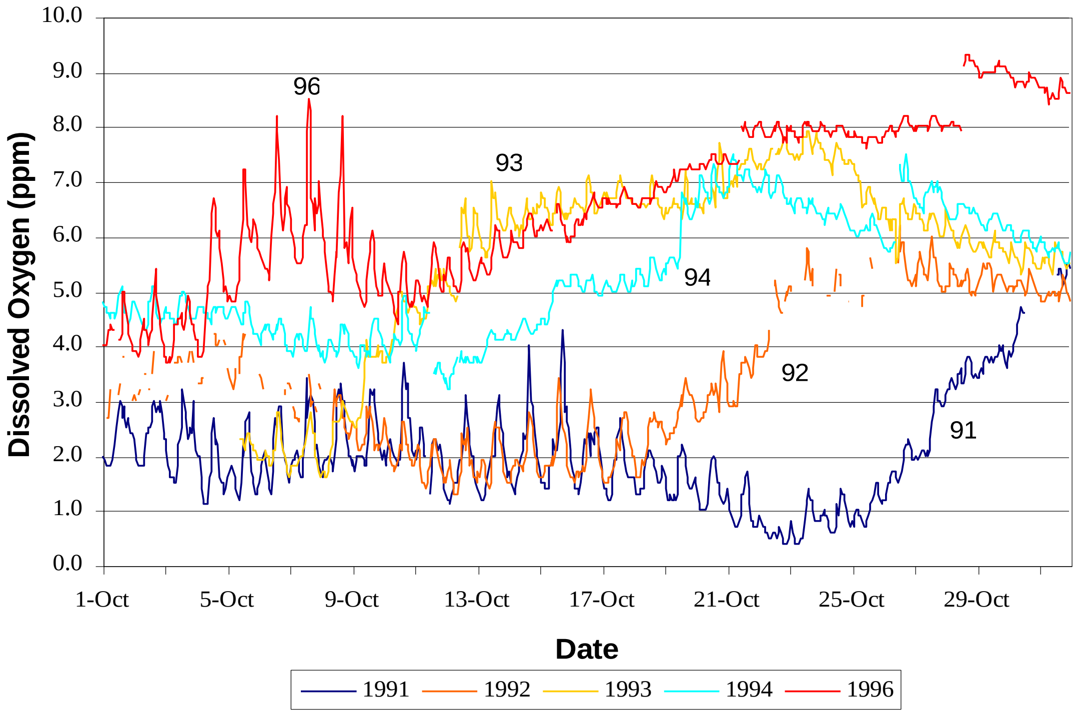


Figure 4-4.
Hourly Dissolved Oxygen Measurements at Burns Cut Off Road Monitoring Station During October in 1991 Through 1994 and 1996

4.4.5 In-River Harvest

During the 1940s, DFG (1946) reported that low flows resulted in high rates of harvest and incidental mortality from spearing in the lower river. In 1944, approximately 200 people were observed spearing salmon at each sand bar in the lower river. Some people used pitch forks, which wounded many fish that probably died before spawning (DFG 1946). Although spearing is no longer legal, the illegal poaching of adult Chinook salmon will still be a concern.

Current bag limits specified by State fishing regulations allow legal catch throughout the year of one salmon in the San Joaquin River from Friant Dam downstream to the Highway 140 Bridge (DFG 2007b). Size restrictions, however, are not designated for salmon in any portion of the San Joaquin River. Downstream from the Highway 140 Bridge, one salmon may be harvested from January through October. During November and December, a zero bag limit for salmon is enforced downstream from the Highway 140 Bridge that requires any salmon caught during these months to be unharmed and not removed from the water.

4.5 Adult Holding

When adult spring-run Chinook salmon begin their migration to their natal streams, they are sexually immature, unable to spawn. After they arrive in their natal streams in the spring, they hold in deep pools through the summer, conserving energy until the fall when their gonads ripen and they spawn. Fall-run Chinook salmon generally do not hold in pools for long periods of time (more than 1 week), but they may briefly use large resting pools during upstream migration.

4.5.1 Historical Habitat in the San Joaquin River

Adult spring-run Chinook salmon held in pools above Friant Dam before its construction (DFG 1921, as cited in Yoshiyama et al. 1996), probably as far upstream as Mammoth Pool Reservoir (Yoshiyama et al. 1996). Hatton described “long, deep pools” in the canyon above Friant (1940, as cited in Yoshiyama et al. 1996). The amount of holding and spawning habitat available to spring-run Chinook salmon was reduced around 1920, when Kerckhoff Dam “blocked the spring-run salmon from their spawning areas upstream and seasonally dried up about 14 miles (22.5 kilometers) of stream, below the dam, where there were pools in which the fish would have held over the summer” (DFG 1921, as cited in Yoshiyama et al. 1996). The completion of Friant Dam in 1941 further reduced the holding and spawning habitat available to spring-run Chinook salmon by completely blocking access to upstream areas.

4.5.2 Habitat Below Friant Dam

In July 1942, Clark (1943) observed an estimated 5,000 adult spring-run Chinook salmon holding in two large pools directly downstream from Friant Dam. He reported that the fish appeared to be in good condition, and that they held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 72°F (22.2°C) in July. Several hundred yards downstream, there is another pool that has a maximum depth of 25 feet (8 meters) with an average depth of 11 feet (3 meters), with an approximate area of average depth of 93,000 square feet (8,600 square meters) (Stillwater Sciences 2003). Chinook generally do not feed while they hold; therefore, they can hold at very high densities. It is possible that these pools can hold up to about 20,000 adult spring-run Chinook salmon.

Although some fish may have held in pools downstream from Lanes Bridge, Clark (1943) concluded that the abundant spawning he observed in September and October in riffles between Friant Dam and Lanes Bridge were from fish holding in the pools below the dam that had moved back downstream to spawn.

4.5.3 Harvest

Current bag limits specified by State fishing regulations allow legal catch throughout the year of one Chinook salmon in the San Joaquin River from Friant Dam downstream to the Highway 140 Bridge (DFG 2007b).

Illegal harvest of holding spring-run Chinook salmon remains a concern because fish are vulnerable for several months in a confined location at high densities. The banks of the pool below Friant Dam are fenced off, thus minimizing access for poachers. However, the North Fork Road Bridge downstream from the dam has a boat launch that provides access to the river where poachers could gain access to the pool.

4.5.4 High Water Temperatures

Table 3-1 lists optimal adult holding temperatures of less than or equal to 59°F (15°C) for long-term population sustainability. Moyle reports water temperatures for adult Chinook salmon holding are optimal when less than 60.8°F (16°C). Moyle et al. (1995) reported that spring-run Chinook salmon in the Sacramento River typically hold in pools that have temperatures below 69.8°F (21°C) to 77°F (25°C), however, in Butte Creek in 2003, 11,000 adults died before spawning, while more than 6,000 survived to spawn. Mortalities were attributed to high temperatures, large numbers of fish and outbreaks of two pathogens, Columnaris and Ich. Average daily temperatures exceeded 59oF (15°C) at all sites from late-June until the first week of September, exceeded 63.5°F (17.5°C) by July 12, and exceeded 68oF (20°C) for 7 days during the holding period at the uppermost holding pool (Quartz Bowl) in 2003 (Ward et al. 2004). In Butte Creek, prespawn adult mortalities were minimal when average daily temperatures were less than 66.9°F (19.4°C) with only brief periods of high temperatures up to about 70°F (21°C) in July between 2001 and 2004 (Ward et al. 2006). Based on these and other studies, critical temperatures that cause thermal stress for holding adults in Table 3-1 are in the range of 62.6 to 68°F (17 to 20°C) with significant mortality occurring above that range.

4.5.5 Disease

Diseases such as BKD, C*eratomyxosis shasta* (C-shasta), columnaris, furunculosis, infectious hematopoietic necrosis, redmouth and black spot disease, whirling disease, and erythrocytic inclusion body syndrome are known, among others, to affect Chinook salmon (NMFS 1996, 1998). Many pathogens are ubiquitous along the northwestern Pacific coast of the United States in salmon populations. However, the pathogens are normally present at low levels and do not usually affect the host to the point of causing disease (Arkoosh et al. 1998). Only when other stressors are present are there increased incidences of disease outbreaks. These stressors can include elevated water temperature, low DO, crowding, high levels of ammonia, and presence of pollutants (Wedemeyer 1974). The susceptibility of anadromous salmonids to these pathogens is also influenced by hydrological regime, behavior, and physiological changes associated with spawning activity.

Two extreme cases of disease-related fish kills occurred in the Klamath River and Butte Creek in 2003. In September 2002, 34,000 adult salmon, mostly Chinook, died in the lower 25 miles of the Klamath River, California due to a combination of low flows, high temperatures, and high infestation rates of Ich and/or columnaris. Significant prespawning mortality of spring-run Chinook salmon also occurred in Butte Creek, California, during 2003 as a result of high temperatures and subsequent infection of columnaris and Ich (Ward et al. 2006).

4.5.6 Predation

Mammals may be an agent of mortality to salmonids in the Central Valley. Predators such as river otters (*Lutra Canadensis*), raccoons (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and western spotted skunk (*Spilogale gracilis*) are common. Other mammals that take salmonids include badger (*Taxidea taxus*), bobcat (*Linx rufis*), coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), long-tailed weasel (*Mustela frenata*), mink (*Mustela vison*), mountain lion (*Felis concolor*), red fox (*Vulpes vulpes*), and ringtail (*Bassariscus astutus*). These animals, especially river otters, are capable of removing large numbers of salmon and trout (Dolloff 1993). Mammals have the potential to consume large numbers of holding adults, but generally scavenge post-spawned salmon.

4.6 Spawning

Clark (1943) estimated that about 267,000 square feet (64 percent) of spawning habitat remained after Friant Dam had been constructed in 1941. Chinook salmon were observed spawning in large numbers on all the riffles in the 10-mile reach between Friant Dam and Lanes Bridge in 1942. Since the 1940s, spawning habitat has been highly degraded by dams that block gravel recruitment, in-river gold and gravel mining, and water diversions that reduce flows and increase water temperatures. It is assumed that the Restoration Flow Schedule will provide suitable water depths and velocities for spawning based on a Physical Habitat Simulation study conducted by USFWS in 1993.

4.6.1 Insufficient Spawning-Sized Gravels

The abundance of spawning-sized gravels below Friant Dam has gradually decreased as a result of upstream dams blocking sediment recruitment and gravel mining from the river terrace and low-flow channel. The estimated average unimpaired coarse sediment supply for the mainstem San Joaquin River is approximately 48,600 cubic yards/year (Cain 1997). There is relatively little gravel recruitment from the tributaries below Friant Dam: Cottonwood Creek (RM 267.4) contributes about 55 cubic yards/year and Little Dry Creek (RM 261) contributes an average of about 335 cubic yards/year (Cain 1997).

An absence of gravel recruitment reduces the amount of useable spawning habitat in three ways. First, without recruitment, uncontrolled high flow releases scour the gravel from the spawning beds so that they gradually become smaller in length and the depth of the gravel becomes shallower. Cain (1997) compared the 1939 and 1996 measurements of the channel thalweg elevation at seven cross sections in Reach 1A. At four cross sections, the thalweg elevation decreased by 4.5 to 7.0 feet whereas it increased by 0.8 to 3.2 feet at three cross sections. Second, smaller gravels tend to be mobilized at the highest rates, which causes the bed surface to armor with large rocks that can be too large for the salmon to move for redd construction. Both the reduction in spawning bed size and the armoring of the bed’s surface has the effect of crowding spawners into the remaining usable spawning areas. Crowding is thought to increase the rate of redd superimposition, when spawners construct their redds on top of preexisting redds, thereby killing or burying some of the eggs in the preexisting redds. The third problem caused by reduced gravel recruitment is that uncontrolled scouring flows also erode sediment from the floodplains.

A reduction in upstream gravel supply can disrupt the balance between sediment supply and transport capacity, disturbing the longitudinal continuity of the river system and altering channel pattern (Kondolf and Swanson 1993, Kondolf 1997). The excess energy of sediment-starved water is typically expended on the bed, causing incision and likely channel narrowing. Sediment-starved channels can also respond through lateral migration into banks and floodplains, potentially causing greater rates of bank failure as the channel pattern adjusts to a new sediment supply and transport equilibrium (Simon 1995). Channel widening is a problem in some reaches of the Stanislaus River (Schneider 1999) and it appears to be a problem in Reach 1 of the Restoration Area (FMWG 2007). Bank erosion degrades the spawning habitat by reducing water depths and velocities and degrades the egg incubation habitat by increasing the rate that fine sediments are deposited on the spawning beds.

Instream aggregate extraction may have further reduced the amount of spawning-sized gravel in Reach 1A, where the majority of the Chinook salmon are expected to spawn. In Reach 1A, Cain (1997) estimated that 1,562,000 cubic yards were removed from the active channel of the San Joaquin River between 1939 and 1989 (3,124 cubic yards/year), and 3,103,000 cubic yards were removed from the floodplain and terraces. Nine large captured mine pits occur from about 8.7 miles (RM 258.8) to about 34.3 miles (RM 233.2) below Friant Dam (Table 3-16 in McBain and Trush 2002); therefore, it is likely that many spawning beds were highly degraded by gravel mining.

During July 2007, the FMWG observed one spawning bed with suitably sized gravels near the dam and three highly silted spawning beds during foot and canoe surveys of the first 5 miles of the low-flow channel below Friant Dam (RM 262.5 to RM 267.5) where a majority of the spring-run Chinook salmon would be expected to spawn. They also observed 22 potential spawning beds in the next 4.4-mile-long reach (RM 257.75 to RM 262.15) that had moderate levels of silt and suitably sized gravels for spawning. The D_{50} of the surface substrate at three of these riffles ranged between 40 and 47 mm based on pebble counts (Table 3-7 in McBain and Trush 2002).

4.6.2 High Water Temperatures

Preferred spawning temperatures for spring-run and fall-run Chinook salmon are between 42°F (5.6°C) and 57°F (13.9°C) (Bell 1986). Temperatures above the preferred spawning range have been observed to increase the occurrence of abnormal fry and mortality, and lengthen the duration of the hatching period (Spence et al. 1996). The FMWG recommends 57°F as a target for maintaining optimal spawning temperatures for Chinook salmon.

4.6.3 Hybridization Between Spring-Run and Fall-Run Salmon

Historically, spring-run Chinook salmon spawned in the upper watersheds whereas fall-run Chinook salmon were confined to the lower watersheds when fall flows dropped and barriers prevented their migration to the areas used by the spring-run Chinook salmon. Currently, with access to historical higher elevation spring-run Chinook salmon spawning habitat blocked by Friant Dam, both runs would share the available spawning habitat downstream from Friant Dam, posing the risk of hybridization. Forced coexistence of these two runs caused by substantial damming and loss of habitat in other river systems has led to concern for their genetic integrity (Cope and Slater 1957, Banks et al. 2000). However, despite spatial and temporal overlap of Chinook salmon spawning runs in the Central Valley, no evidence for natural hybridization among runs has been documented (Banks et al. 2000).

Genetic effects of run hybridization on Chinook salmon populations remain unclear. It is likely, however, that hybridization between spring- and fall-run Chinook salmon in the San Joaquin River would influence the life-history strategy adopted by genetically mixed progeny. Given the potential for water temperatures in large portions of the Restoration Area to exceed suitable limits during key periods of upstream migration (late summer and fall) and rearing (spring and early summer), altered run timing is of particular concern. To prevent spawning overlap by the two runs, it may be necessary to construct artificial barriers to separate spring- and fall-run spawners.

4.6.4 Instream Flows

The relationship between instream flow and spawning habitat availability was modeled by USFWS (1994b). Although the study assessed spawning habitat availability for fall-run Chinook salmon, the relationships can be transferable to spring-run Chinook salmon. USFWS (1994b) found stream flows of 150 cfs to provide close to optimal spawning conditions in Reach 1A. Settlement flows for incubation range from 120 cfs to 350 cfs, depending on water year type (Settlement, Exhibit B). Settlement flows appear adequate for incubation and emergence; however, this information should be taken cautiously, as it is extrapolated from fall-run Chinook salmon work conducted in 1993.

4.6.5 Harvest

Currently, fishing regulations in the San Joaquin River permit the harvest of one Chinook salmon year-round from Friant Dam downstream to the Highway 140 Bridge; therefore, a majority of the spawning adults should be protected.

Poaching of adult fall-run Chinook salmon from their spawning beds is a common occurrence in the Stanislaus, Tuolumne, and Merced rivers based on reports from DFG wardens; however, the number of adult fish taken has not been estimated. Most poachers snag fish with large treble hooks, but others use gill nets to catch fish. It is likely that spring- and fall-run Chinook salmon will be illegally harvested from the Restoration Area, but the likely extent of the problem in the Restoration Area is unknown.

4.7 Hatchery Impacts

The goal of the SJRRP is to restore naturally reproducing and self-sustaining populations of Chinook salmon and native fish species. However, it is increasingly evident that some form of hatchery intervention will be required by the SJRRP to help achieve this goal. Allowing only natural recolonization is problematic for spring-run Chinook, given the lack of geographically proximal spring-run populations, and the low census and protected status of spring-run Chinook salmon in California prohibits excessive take of this species, which will severely limit the availability of donor fish. Also, relocating adult and juvenile fish to the Restoration Area is complicated by stress-related mortality and other technical challenges, and some number of study fish will be needed for telemetry, habitat, and other types of controlled research studies.

Hatcheries can generally be classified as supplementation hatcheries or conservation hatcheries, with the latter differing in its emphasis on not only producing desired numbers of fish for hatchery release, but also reducing genetic and ecological impacts of releases on wild fish (Flagg and Nash, 1999). As many Pacific Coast salmon populations continue to decline, the use of supplementation hatcheries has been relied on to recover populations; however, there is controversy concerning the role of hatcheries in the recovery and supplementation of wild salmon stocks (Brannon et al. 2004). Recent literature suggests that supplementation hatchery programs have had negative impacts on wild fish due to genetic, domestication, physiological, behavioral, disease, and population level effects. Recent efforts to reform hatchery management and minimize impacts to native salmonid populations are ongoing and have placed increasing emphasis on the role of conservation hatcheries. Objectives of developing a conservation hatchery include:

- Create breeding protocols and standard operation procedures for hatchery operations to allow for maximum effective population sizes, minimum impact on wild (or naturalized) spring-run Chinook and nontarget populations

- Employ physical and genetic marking techniques to evaluate and adapt hatchery contribution to the census size of returning upper San Joaquin River Chinook salmon populations

- Evaluate effective population size and genetic diversity for the hatchery population

The goal of hatchery implementation for the SJRRP is to restore naturally reproducing, viable spring- and fall-run Chinook salmon populations, and so its success is marked by the ability to ultimately phase out hatchery production. This will reduce the negative influences that continued hatchery supplementation can have on the reestablished spring- and fall-run Chinook salmon populations. Use of spring- or fall-run Chinook salmon hatchery production will be determined by an adaptive management approach given the likely uncertainty of initial restoration phases. Genetic accommodation of the natural population, quantitative natural population targets (e.g. N_e, census size, genetic diversity), and other community and ecosystem indicators of reintroduction success will be derived and periodically evaluated to phase out hatchery production. Hatchery production phase-out will be further detailed in ESU-specific Hatchery and Genetic Management Plans, as per NMFS guidelines. Additionally, uncertainties such as local habitat change, climate change, and others, will be given consideration in phase-out determinations.

Traditional supplementation hatchery models have a low likelihood of achieving the Restoration Goals of the SJRRP without detrimental genetic impacts to the reintroduced population. However, the FMWG supports the use of a Conservation Hatchery for the initial reintroduction effort of salmonids into the Restoration Area as one strategy to be used in combination with other reintroduction strategies to best meet the population objectives developed by the FMWG. Therefore, the SJRRP is advancing plans for the development of a salmon conservation and research hatchery to provide facilities available to meet SJRRP timelines.

4.8 Climate Change

The world is about 1.3°F (0.7°C) warmer today than a century ago. The latest computer models predict that, without drastic cutbacks in emissions of carbon dioxide and other gases released by the burning of fossil fuels, the average global surface temperature may rise by two or more degrees in the 21st century (IPCC 2001). Much of that increase will likely occur in the oceans, and evidence suggests that the most dramatic changes in ocean temperature are now occurring in the Pacific (Noakes 1998). The northwestern U.S. has warmed by between 1.3°F to 1.6°F (0.7°C and 0.9°C) during the 20th century (Battin et al. 2007).

Sea levels are expected to rise by 1.5 to 3.3 feet (0.5 to 1.0 meters) along the northeastern Pacific coasts in the next century, mainly due to warmer ocean temperatures, which lead to thermal expansion much the same way that hot air expands. This may trigger increased sedimentation, erosion, coastal flooding, and permanent inundation of low-lying natural ecosystems (e.g., salt marsh, riverine, mud flats) affecting salmonid primary constituent elements. Increased winter precipitation, decreased snowpack, permafrost degradation, and glacier retreat due to warmer temperatures will cause landslides in unstable mountainous regions, and destroy fish and wildlife habitat, including salmon-spawning streams. Glacier reduction could affect the flow and temperature of rivers and streams that depend on glacier water, with negative impacts on fish populations and the habitat that supports them.

Summer droughts along the south coast and in the interior of the northwest Pacific coastlines will mean decreased stream flow in those areas, decreasing salmonid survival and reducing water supplies in the dry summer season when irrigation and domestic water use are greatest. Global warming may also change the chemical composition of the water that fish inhabit by potentially reducing the oxygen in the water, while pollution, acidity, and salinity levels increase. This will allow more invasive species to overtake native fish species and impact predator-prey relationships (Peterson and Kitchell 2001).

It is expected that Sierra snowpacks will decrease with global warming, and that the majority of runoff in California will shift to winter rainfall instead of melting snowpack in the mountains. This will alter river runoff patterns and transform the tributaries that feed the Central Valley from a spring/summer-snowmelt-dominated system to a winter-rain-dominated system. In addition, the cold snowmelt that furnishes the late spring and early summer runoff will be replaced by warmer precipitation runoff. This may truncate the period of time that suitable cold water conditions persist below existing reservoirs and dams because of the warmer inflow temperatures to the reservoir from rain runoff. Without the necessary cold water pool developed from melting snowpack filling reservoirs in spring and early summer, late summer and fall temperatures below reservoirs could potentially rise above thermal tolerances for juvenile and adult salmonids.

New efforts on salmonid habitat restoration will need to accommodate the imminent impact of climate change. Recent simulation studies indicate that climate change is bound to have a large negative impact on freshwater salmonid habitat. For instance, Battin et al. (2007) predict the combined effect of climate change and habitat restoration will be a change in salmonid population abundance with a spatial shift toward lower elevations preferred by “ocean-type’ salmon runs such as fall-run Chinook salmon. An Adaptive Management Approach will provide the flexibility to track significant changes in the life history of restored Chinook salmon challenged by the most human-induced rapid environmental change in the San Joaquin River watershed.

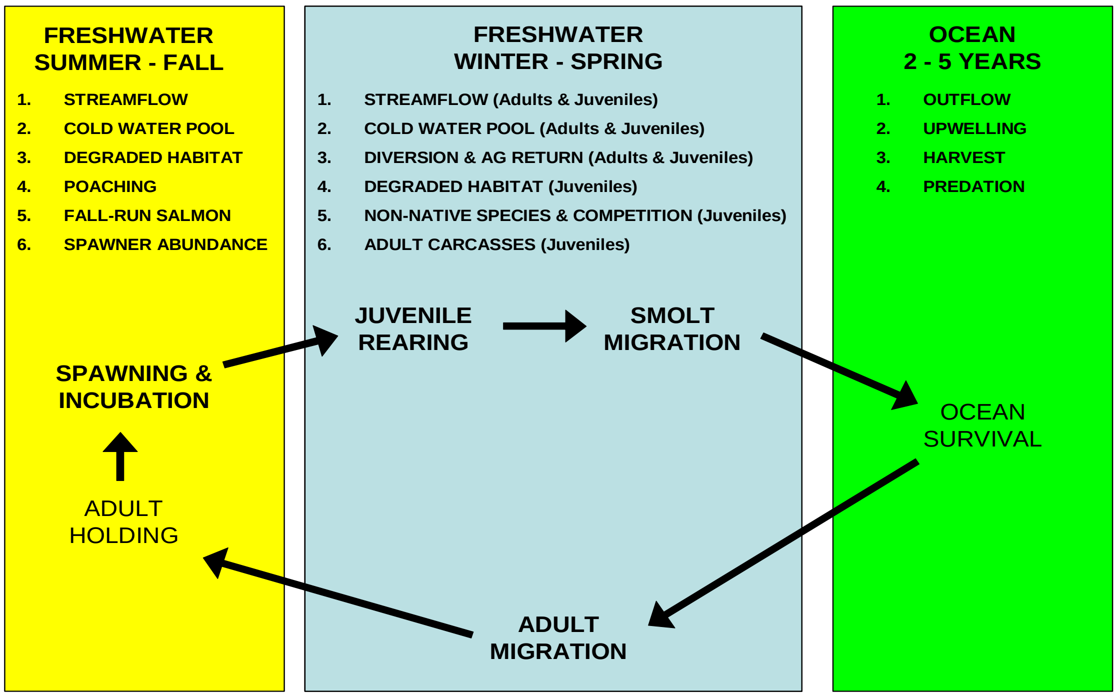
Chapter 5 Conceptual Models

The following conceptual models represent the FMWG understanding of how the limiting factors may affect each life history stage of spring- and fall-run Chinook salmon in the San Joaquin River Basin. For the SJRRP, limiting factors are defined as the physical, biological, or chemical conditions and associated ecological processes and interactions that influence the abundance and productivity of San Joaquin River Chinook salmon. The FMWG recognizes that it is possible that not all limiting factors have been identified, and that the identified limiting factors may not be fully understood. Recognizing these uncertainties, the conceptual models will be developed into a series of testable hypotheses and appropriate studies described in the SJRRP Adaptive Management Approach (as described in the FMP) to help evaluate the effectiveness of all restoration and management actions implemented to achieve the Restoration Goal.

The conceptual models assume that all actions prescribed in the Settlement, such as screening the bypass channels and improving passage conditions, will be implemented. The Adaptive Management Approach will include monitoring to determine the effectiveness all actions, including those described in the Settlement.

5.1 Spring-Run Chinook Salmon

The abundance of adult spring-run Chinook salmon that return to spawn in the Restoration Area will probably be affected by numerous factors, only some of which will be under the control of the SJRRP whereas other factors will be outside the control of the SJRRP (Figure 5-1).



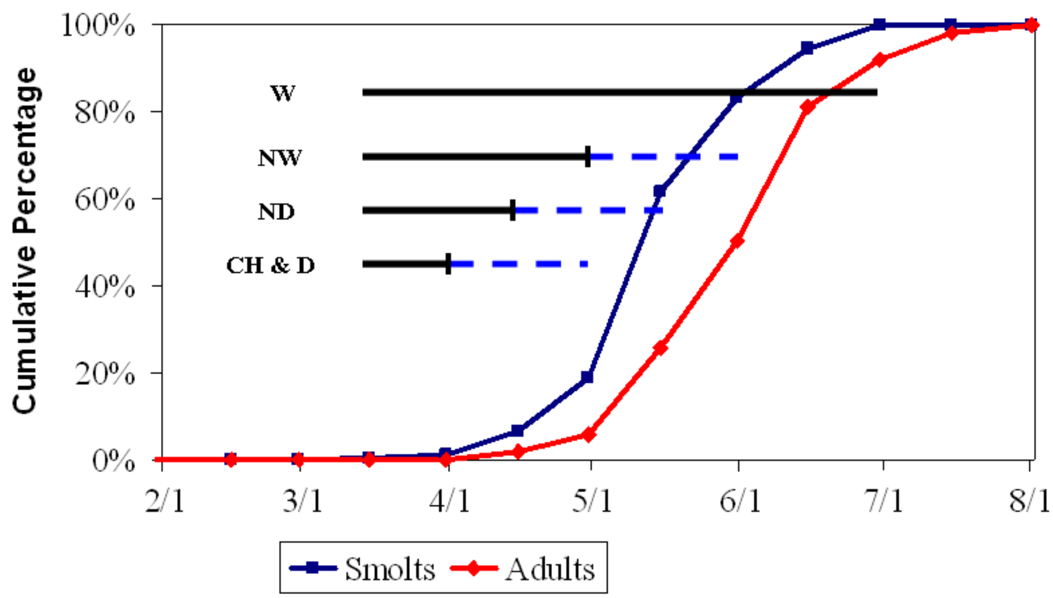
Note: The life stages in bold type are assumed to be the most critical for achieving the Restoration Goal.

Figure 5-1.
Overall Conceptual Model for San Joaquin River Spring-Run Chinook Salmon

Potential limiting factors that the SJRRP will have some control over include the following:

- **Inadequate Streamflows** –The Restoration Flow Schedule has truncated spring pulse flows that may protect no more than 83 percent of the migrating smolt-sized juveniles (greater than or equal to 70-mm FL) and no more than 50 percent of the migrating adults during all but wet years. This is based on the assumption that Restoration Flow Schedule can be shifted up to 4 weeks, and that reintroduced San Joaquin fish behave similarly to those that rear in the upper reaches of Butte Creek in the Sacramento River Basin (Figure 5-2).

In the Merced, Tuolumne, and Stanislaus rivers, Chinook salmon production seems highest during wet years, characterized by high flows from February through June. It is unknown whether it will be possible to shift the Restoration Flow Schedule into May to protect migrating adults and juvenile Chinook salmon; provide at least periodic floodplain inundation during the March through May rearing period; maintain suitable water temperatures for juvenile and adult Chinook salmon (target less than or equal to 68°F (20°C)); and not exhaust the cold water pool in Millerton Lake. Extending the high-flow period into May and June would probably increase smolt production and survival by improving or ameliorating a combination of factors, which include food availability, predation, disease, water temperatures, contaminants, water quality, harvest, and entrainment. However, it is also possible that many fry will migrate to the downstream reaches of the Restoration Area where they will rapidly grow to a smolt size in restored floodplain and wetland habitats before May. If true, pulse flows between February and April may produce a sufficient number of smolts to sustain the spring-run Chinook salmon populations.



Sources: Hill and Webber 1999, Ward and McReynolds 2001, Ward et al. 2002, DFG 1998.

Notes:

1. The solid black horizontal lines represent the release period for spring pulse flows as prescribed in the Settlement during Critical High (CH), Dry (D), Normal Dry (ND), Normal Wet (NW) and Wet (W) years. No spring pulse flows would be released during Critical Low years.
2. The dashed blue horizontal lines represent the maximum flexibility to shift the flow schedule as prescribed by the Settlement.

Figure 5-2.
Relationship Between Timing of Settlement Spring Pulse Flows and Mean Cumulative Percentage of Fish Passage for Butte Creek Subyearling Spring-Run Smolts and Historical Populations of Adult Spring-Run Chinook Salmon in the Sacramento Basin

- **Inadequate Cold Water Pool –** The volume of the cold water pool in Millerton Lake may be insufficient to provide the prescribed summer and fall flow releases and maintain suitable water temperatures for holding adult spring-run Chinook salmon during the summer (target less than 70°F (21°C)) and incubating salmon eggs during the fall (target less than 58°F (14°C)).

- **Degraded Habitat –** The highly degraded channel and floodplain morphology, loss of native riparian vegetation, and exotic species below Friant Dam to the confluence with the Merced River may result in high rates of mortality for juvenile spring-run Chinook salmon. In addition, the reduced gravel recruitment from lateral and upstream sources and high flow events (e.g., 1997) have gradually scoured away the spawning gravels immediately downstream from Friant Dam. In the main San Joaquin River tributaries, it has been noted that regardless of the number of spawning adults, the habitat capacity for rearing fry and juveniles limits the actual Chinook salmon production.

- **Inadequate Spawner Abundance** – Legal and illegal harvest of yearling juveniles and holding and spawning adults may substantially limit adult recruitment, particularly if escapements are low. In addition, conditions that result in low production of juvenile spring-run Chinook salmon will limit the number of adult fish that return to spawn 2 to 4 years later.

Factors outside the control of the SJRRP that have been identified include the following:

- **Streamflow Releases Outside the Restoration Area –** Stream flow releases in the Stanislaus, Tuolumne, and Merced rivers that contribute to flows in the mainstem San Joaquin River, Delta, and San Francisco Estuary are expected to affect the survival of rearing and migrating juvenile and the survival and homing ability of adults.

- **Degraded Habitat –** The highly degraded channel and floodplain morphology, loss of native riparian vegetation, and exotic species below the confluence with the Merced River, the Delta, and San Francisco Estuary are expected to substantially reduce the survival of rearing and migrating juvenile spring-run Chinook salmon.

- **Degraded Water Quality –** Pesticides and other contaminants may substantially reduce the food resources needed by juvenile spring-run Chinook salmon within and below the Restoration Area, and to a lesser degree, result in direct mortality of juveniles. In addition, poor water quality (e.g., low DO and high ammonia concentrations) in the mainstem channel may affect the survival of juvenile, and to a lesser degree, adult spring-run Chinook salmon.

- **Delta Exports –** Springtime Delta exports at the CVP and SWP pumping facilities affect entrainment of juvenile Chinook salmon. Delta exports also reduce flow in the Stockton Deepwater Ship Channel and the amount of freshwater outflow into the ocean, all of which affect the survival of juvenile Chinook salmon and the ability of adults to home to the Restoration Area.

- **Low Ocean Productivity –** Ocean productivity (food resources), as affected by upwelling, coastal currents, El Niño events, and the amount of freshwater outflow from the San Francisco Bay, will affect the survival of juvenile and adult spring-run Chinook salmon.

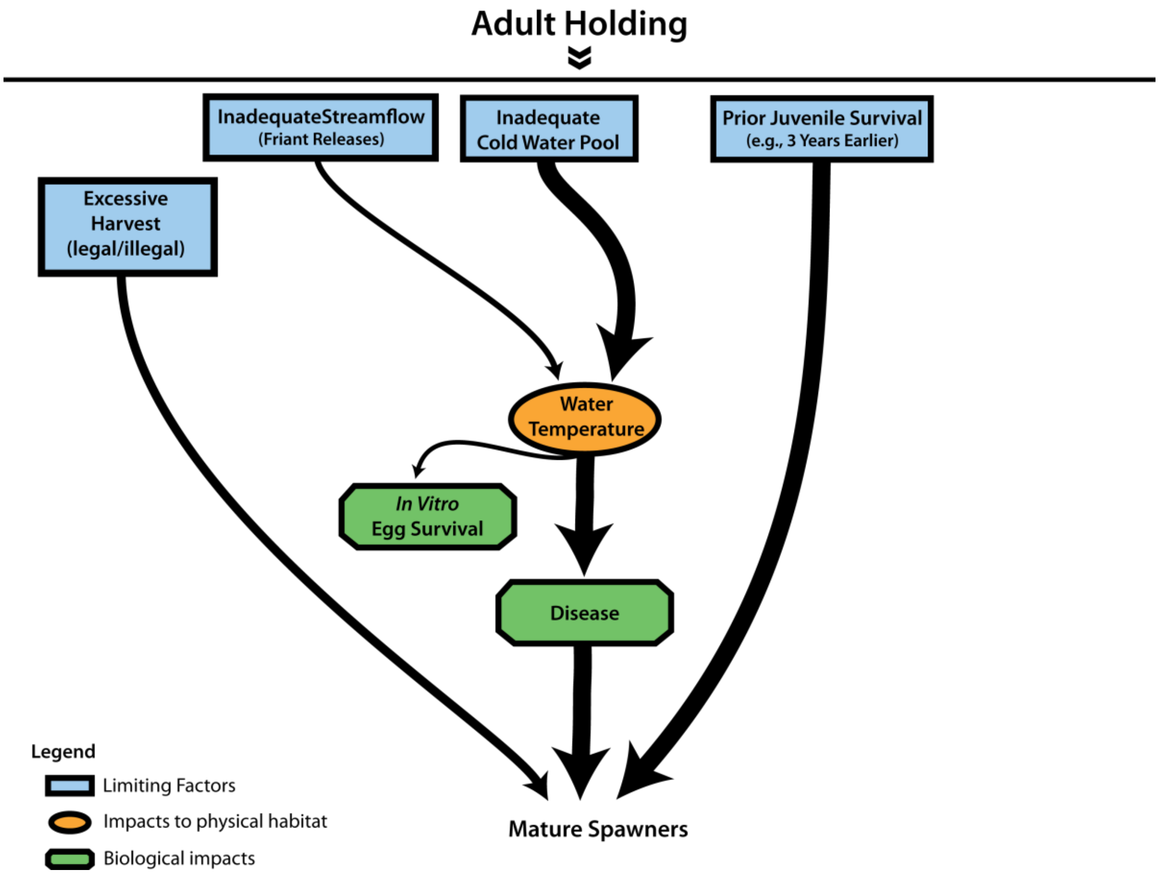
- **Climate Changes –** Climate changes are expected to affect inland water temperatures, hydrographs (i.e., floodplain inundation), and ocean productivity conditions, and therefore, affect the survival of juvenile and adult spring-run Chinook salmon.

- **Excessive Harvest and Predation in the Ocean –** Ocean harvest of adults and predation of juvenile and adults in the ocean affect the number of adults that return to spawn, which may affect the number of juveniles produced during the following spring.

The following are potential mechanisms by which the above limiting factors are expected to affect each life-history stage of spring-run Chinook salmon, including adult holding, spawning, juvenile rearing, smolt migration, ocean survival, ocean harvest, and adult migration. Potential benefits and impacts of hatcheries and climate change are also discussed in terms of overall population effects.

5.1.1 Adult Holding

There are currently several holding pools below Friant Dam that were extensively used by spring-run Chinook salmon during the 1940s. These pools may be able to sustain at least 20,000 fish. However, there are concerns that high water temperatures, and to a lesser degree, predation and harvest (legal and illegal) may affect the ability of spring-run salmon to hold in these pools (Figure 5-3). The number of spawners is also substantially affected by the survival of the fish when they were juveniles, 2 to 5 years earlier.



Note: The width of the arrows indicates the relative importance of each mechanism.

Figure 5-3.
Possible Limiting Factors, Impacts to Physical Habitats, and Biological Impacts that May Affect Holding Adult Spring-Run Chinook Salmon

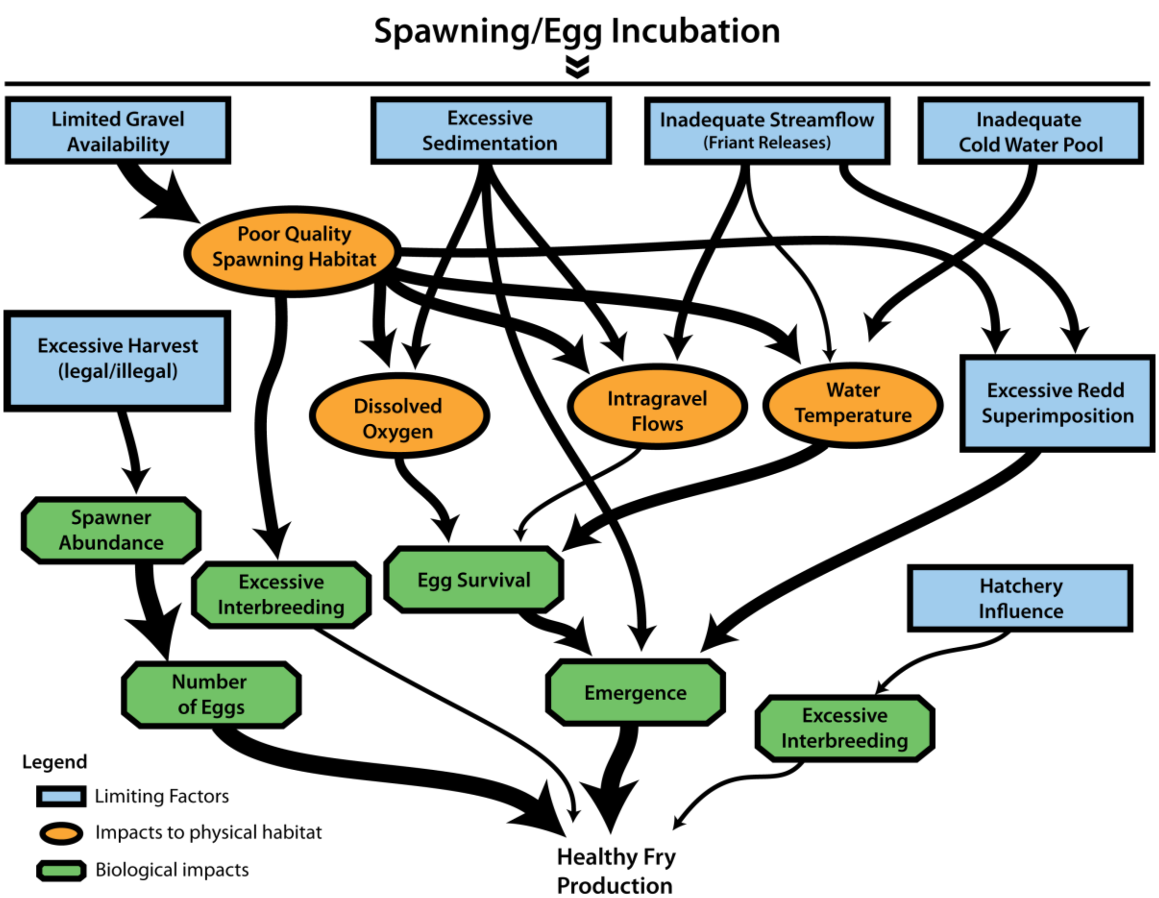
- **Excessive Water Temperatures –** If the cold water pool in Millerton Lake is exhausted as a result of increased summer and fall flows, the temperature of the release flows could exceed suitable levels for holding adults. If temperatures become unsuitably high, disease may become a likely cause of mortality.

- **Excessive Harvest** – Adults will be susceptible to legal and illegal harvest while they hold in the pools below the dam. If escapements are too low to saturate the rearing habitat with juvenile fish, the harvest of adult spawners from the holding pools could become a substantial limiting factor.

- **Excessive Predation** – Mammals have the potential to consume large numbers of spawners, but generally scavenge post-spawned fish. It is assumed that predation of holding adults will not have a population level effect. Therefore, predation will not be directly evaluated unless routine monitoring indicates that adult mortality rates during the holding period are higher than expected.

5.1.2 Spawning and Egg Incubation

Spring-run Chinook salmon will probably spawn in the reach immediately downstream from Friant Dam, where water temperatures should be suitable for spring-run spawning and egg incubation between August and January. However, there are only a few, highly silted beds in this reach because Friant Dam has blocked most of the gravel recruitment, and high flows since 1950 have scoured the gravels from these beds. It is likely that the adults would be forced to spawn in either the highly degraded habitats immediately below the dam or in the downstream habitats where egg survival and alevin emergence could be highly impaired by high water temperatures. Another substantial concern is that the increased summer and fall flows required by the Settlement may exhaust the cold water pool in Millerton Lake such that water temperatures of the release flows become unsuitable for adult spawners and egg incubation (Figure 5-4). Other concerns include sedimentation of spawning gravels, turbid storm runoff during egg incubation, redd superimposition by fall-run Chinook salmon, hybridization with fall-run Chinook salmon, and legal and illegal harvest of adults (Figure 5-4).



Note: The width of the arrows indicates the relative importance of each mechanism.

Figure 5-4.
Possible Limiting Factors, Impacts to Physical Habitats, and Biological Impacts that May Affect Spawning and Incubation Habitat for Spring-Run Chinook Salmon

- **Excessive Redd Superimposition by Fall-Run Chinook Salmon –** Fall-run Chinook salmon will probably spawn at the same locations where spring-run Chinook salmon spawn; thus, there is potential that spring-run Chinook salmon redds would be superimposed by fall-run spawners, thereby killing spring-run Chinook salmon eggs, especially when fall-run Chinook salmon escapements are high.

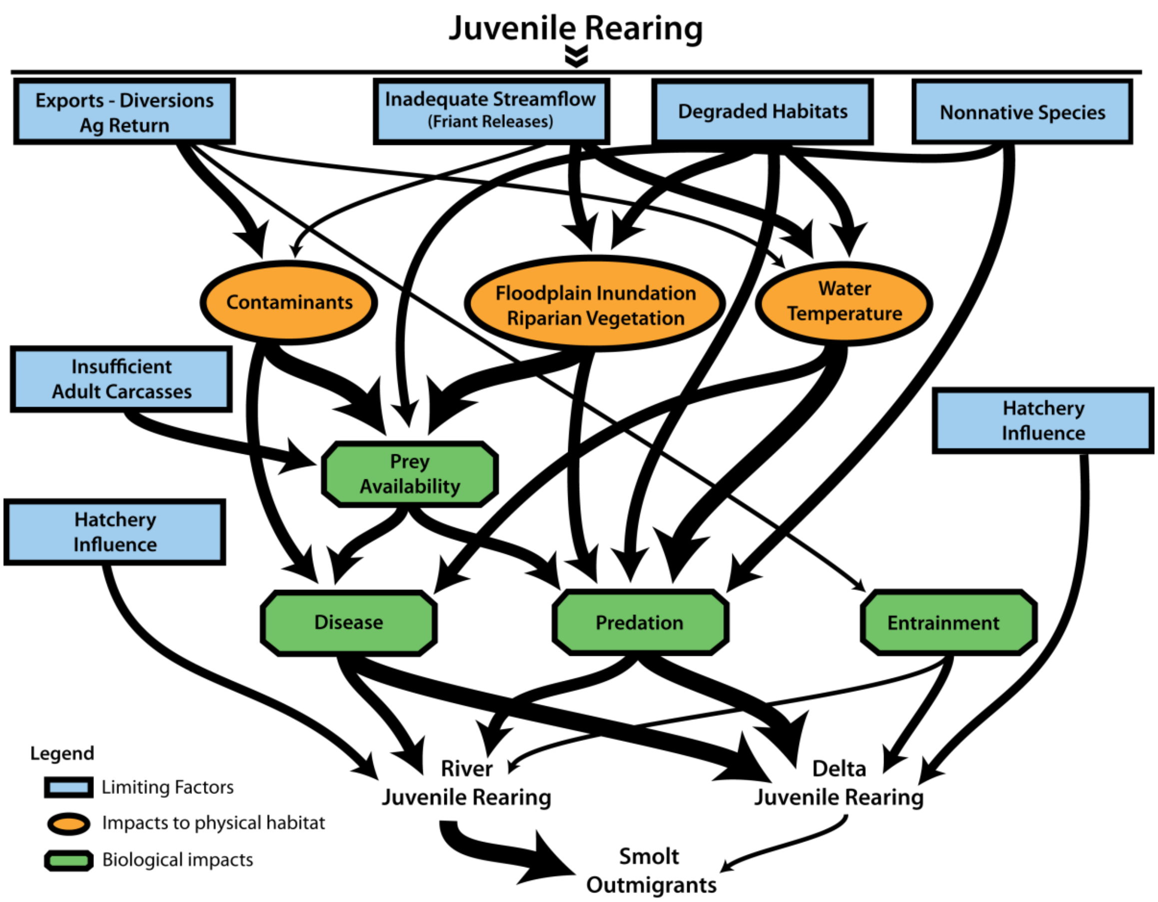
- **Excessive Hybridization with Fall-Run Chinook Salmon** – A small percentage of fall-run Chinook salmon will probably spawn at the same time and location as spring-run fish, so there is potential for hybridization. Some levels of hybridization may occur naturally between Chinook salmon runs, in which case increased genetic variation may counteract inbreeding and natural selection pressures, maintain fit hybrids while eliminating unfit hybrids, thus increasing fitness. However, when excessive hybridization occurs, reduced fitness may result from outbreeding depression. Excessive hybridization may result in fish with migratory behaviors that might not be viable in the San Joaquin River Basin. For example, hybridization between fall-run and spring-run Chinook salmon in the Feather River Hatchery has resulted in adult fish that primarily migrate during the summer (current passage rates at RBDD as shown in Figure 3-5).

- **Excessive Sedimentation** – High permeability measurements made in Reach 1A in 2002 (McBain and Trush 2002) suggest that sedimentation has not adversely affected spawning habitat quality at those locations. However, turbid storm runoff may cause egg mortality, particularly if ground-disturbing activities (e.g., construction or bank erosion) occur near Friant Dam or in one of the upper tributaries (e.g., Cottonwood Creek). It is possible that coating eggs with clay-sized particles suffocates the embryos, or at least stunts their growth.

- **Excessive Harvest** – Adults will be susceptible to legal and illegal harvest particularly while they spawn on shallow gravel beds. If escapements are too low to saturate the rearing habitat with juvenile fish, the harvest of adult spawners from the spawning beds could be a substantial limiting factor.

5.1.3 Juvenile Rearing

Juvenile Chinook salmon that rear in the upper SJRRP reaches and begin their downstream migration in May and June are expected to be substantially impacted by the truncated spring Restoration Flow Schedule prescribed in the Settlement, the highly degraded physical habitats within and downstream from the Restoration Area, and exotic species that potentially compete for food or prey on juvenile Chinook salmon (Figure 5-5). The primary mechanisms by which these factors will affect the production of Chinook salmon smolts are probably linked to reduced food resources, temperature-increased metabolic demands, and abnormally high rates of predation and disease. In the upstream reaches, it is likely that the combined effects of limited food resources and low water temperatures will result in slow growth rates for juvenile Chinook salmon that delay the onset of smoltification until late spring (May and June) when downstream conditions in the Delta are usually unsuitable for migrating smolts. In the downstream reaches, the lack of inundated floodplain and wetland habitats from late January through early May may limit their survival.



Note: The width of the arrows indicates the relative importance of each mechanism.

Figure 5-5.
Possible Limiting Factors, Impacts to Physical Habitats, and Biological Impacts that May Affect Juvenile to Smolt Survival of Spring-Run Chinook Salmon in the San Joaquin River

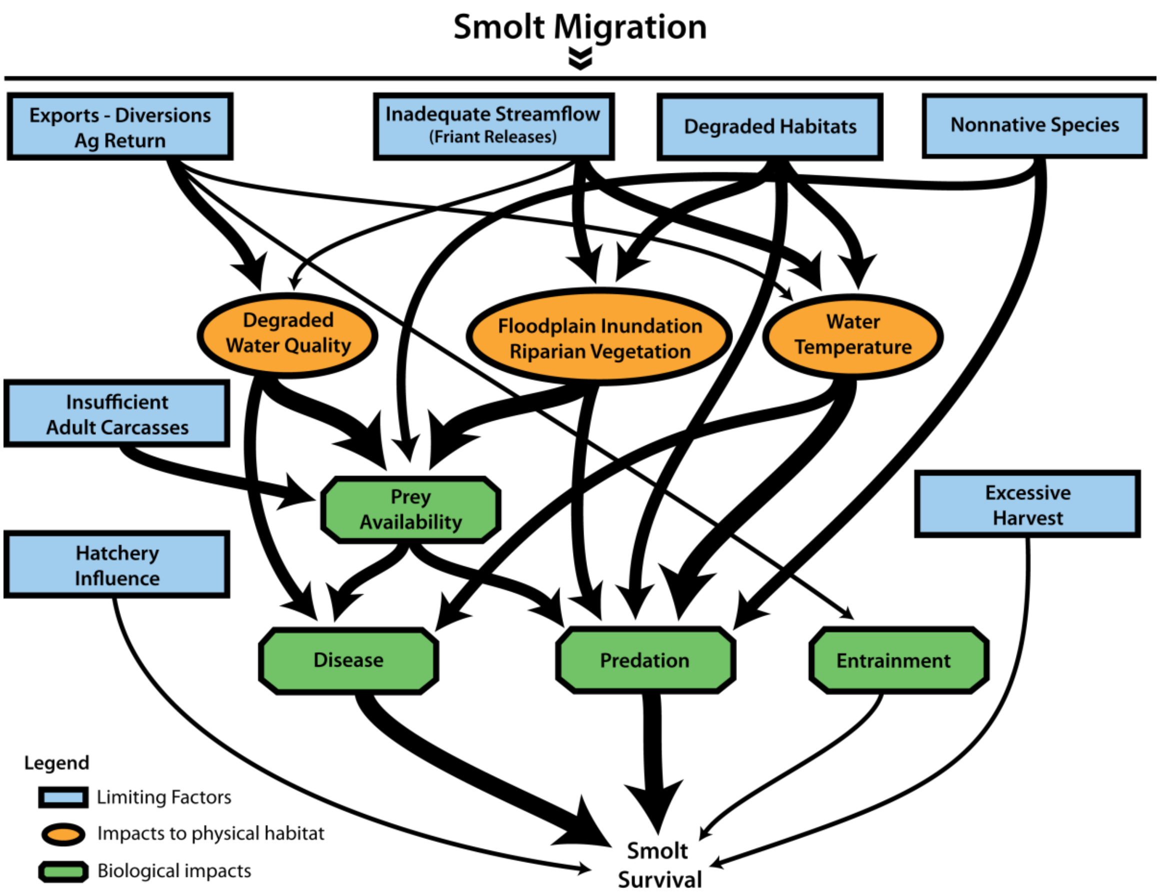
The following summarizes the key mechanisms by which the limiting factors may affect the survival of rearing juvenile spring-run Chinook salmon.

- **Inadequate Food Resources** can result from many potential causes:
  - Reduced magnitude and duration of winter and spring flows (presumably February through mid-June) reduces floodplain inundation that provides food organisms and organic detritus supporting the food web for juvenile spring-run Chinook salmon.
  - Pesticides and other contaminants may reduce the abundance of food organisms.
  - Elevated water temperatures may increase food requirements beyond the amount available to juvenile spring-run Chinook salmon.
  - Levees, dikes, and dredger tailings reduce floodplain habitat inundation that provides food organisms and organic detritus supporting the food web for juvenile spring-run Chinook salmon.
  - Low numbers of adult Chinook salmon carcasses will reduce food resources for juveniles. This will be a particular problem for the first few years before adults begin to return.
  - Loss of riparian vegetation on floodplain and wetland habitats reduces the input of organic detritus that drives the juvenile spring-run Chinook salmon's food web.
  - Nonnative invasive species include plants that may not augment the salmon's food supply. Invertebrate species, such as Asiatic freshwater clams, and fish, such as centrarchids, may compete with Chinook salmon for food.
  - Competition with other native fish species, including fall-run Chinook salmon juveniles may reduce food resources for spring-run Chinook salmon juveniles.
  - Intermittent flows in bypass channels used as rearing areas may reduce food resources. Typically when floodplains or bypass channels become inundated, there is an initial pulse in terrestrial food resources followed by a gradual increase in aquatic food resources.
  - Sedimentation and gravel extraction affects the composition of the invertebrate community, although it is unknown whether the change in species composition substantially affects the availability of food for juvenile spring-run Chinook salmon.

- **Excessive Predation** – Predation by native and introduced fish species can be abnormally high when flows are confined to the main channel and water temperatures are high.
  - Key predators are thought to include Sacramento pikeminnow, which feeds all year, striped bass, which typically begins migrating into tributary habitats in April, and introduced centrarchids, when they begin feeding in April or May as water temperatures rise. These fish tend to use dredged habitats in the Restoration Area and Delta, including captured mine pits, the Stockton Deepwater Ship Channel, and canals leading to the CVP and SWP pumping facilities. Nonnative submerged aquatic vegetation provides habitat for nonnative predators.
- **Disease –** Disease may be a substantial source of mortality when food resources are low, water quality is poor, and/or water temperatures are high**.**
- **Entrainment –** The bifurcation structures in the Restoration Area will be screened as directed by the Settlement; however, it is uncertain whether the screens will be fully effective. Large unscreened diversions, such as those of the West Stanislaus Irrigation District, Patterson Water Company, and El Solyo Water Company, may entrain a substantial number of fry and parr. There is no information on entrainment rates at the numerous small diversions throughout the basin.
- **Degraded Habitat –** Loss of connected floodplain habitats, in-river gravel extraction, blocked sediment recruitment by upstream dams, bank stabilization, and reduced recruitment of IWM reduce the suitability of the habitats used by parr-sized juveniles (50- to 80-mm FL) for feeding stations and predator refuge.
- **Contaminants** – It is assumed that contaminants do not directly cause juvenile mortality, but rather have indirect effects by reducing food resources or accelerating disease infestation rates.
- **Excessive Water Temperatures –** Water temperatures that exceed 77°F (greater than 25°C) in late spring may cause juvenile mortality. However, it is assumed that juvenile Chinook salmon die from other factors, such as predation, disease, or starvation, as water temperatures approach lethal levels.

5.1.4 Smolt Migration

The likely causes of mortality for migrating subyearling smolts are expected to be similar to those for rearing juveniles, including the truncated spring hydrographs prescribed in the Settlement, the highly degraded physical habitats within and downstream from the Restoration Area, and exotic species that potentially compete for food or prey on juvenile Chinook salmon (Figure 5-6). However, it is likely that the negative impacts of high water temperatures, contaminants, water quality (e.g., ammonia near wastewater treatment plants, DO concentrations in the Stockton Deepwater Ship Channel), entrainment, and predation will be much worse for juveniles that slowly grow to a smolt size in the upper reaches and then outmigrate between April and mid-June compared to those that rapidly grow in warmer downstream reaches and then outmigrate between late March and early May. Another problem that may affect smolts is sport harvest.



Note: The width of the arrows indicates the relative importance of each mechanism.

Figure 5-6.
Possible Limiting Factors, Impacts to Physical Habitats, and Biological Impacts that May Affect Survival of Migrating San Joaquin River Spring-Run Chinook Salmon Smolts

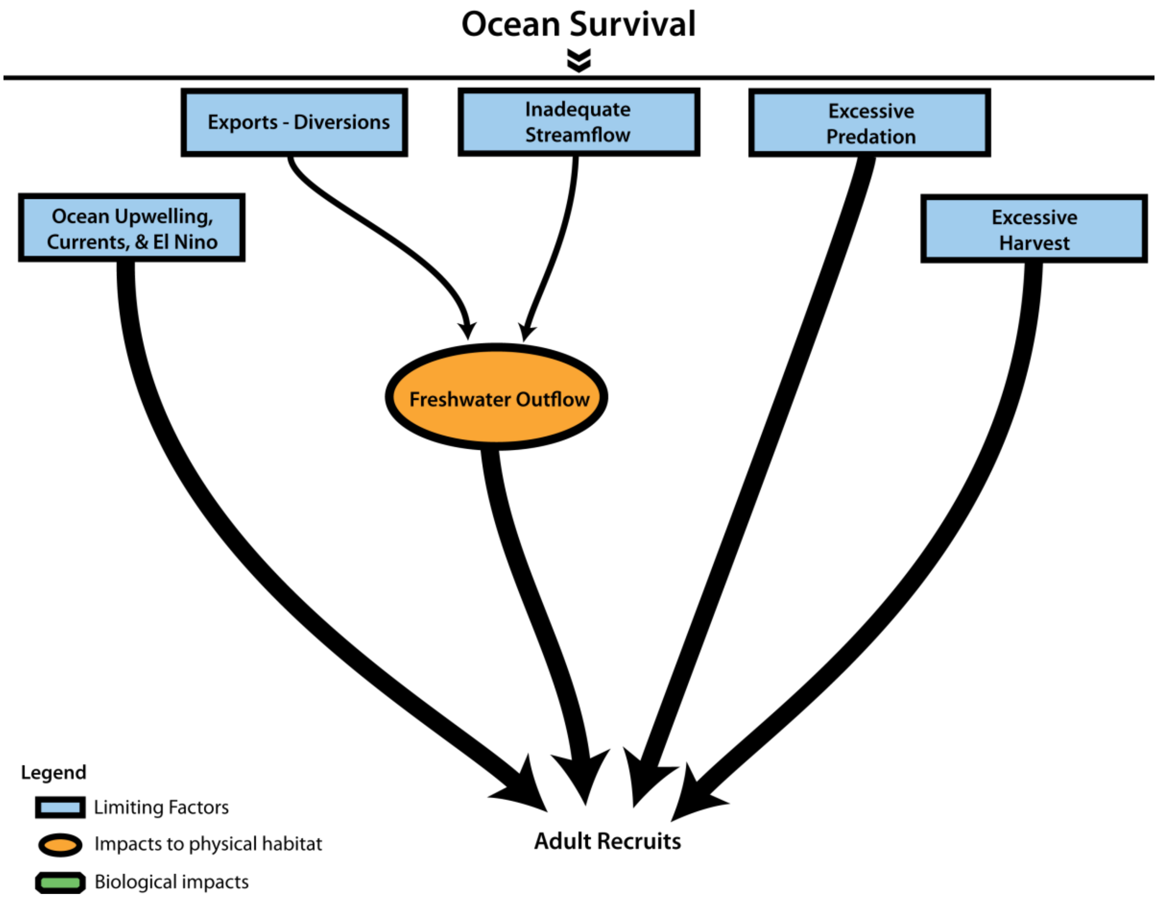
The relative importance of these stressors may partially depend on whether the smolts migrate through the natural channels or bypass channels. It is expected that predation will be a greater problem in the natural channel compared to the bypass channels, which would only receive intermittent flows during the migratory period. In contrast, the bypass channels may have higher water temperatures that would improve the growth of fry between January and April, but negatively impact spring-run Chinook salmon smolts migrating in May and June.

5.1.5 Ocean Survival

The survival of spring-run Chinook salmon smolts entering the ocean during June and July is probably the most critical phase for Chinook salmon in the ocean (Figure 5-7). Freshwater outflow from the estuary is highly correlated with smolt survival and the availability of food resources at the interface between freshwater and saltwater. Coastal upwelling, ocean currents, and El Niño events also affect ocean productivity and the survival of smolts entering the ocean. Indices of ocean productivity conditions will be incorporated into the assessment of adult Chinook salmon production in the Restoration Area.

5.1.6 Ocean Harvest

It is anticipated that ocean harvest rates will have population level effects whenever harvest rates reduce escapement to the point that there are too few spawners to saturate the habitat with juveniles (Figure 5-7). Estimates of ocean harvest rates will be incorporated into the assessment of adult Chinook salmon production in the Restoration Area.

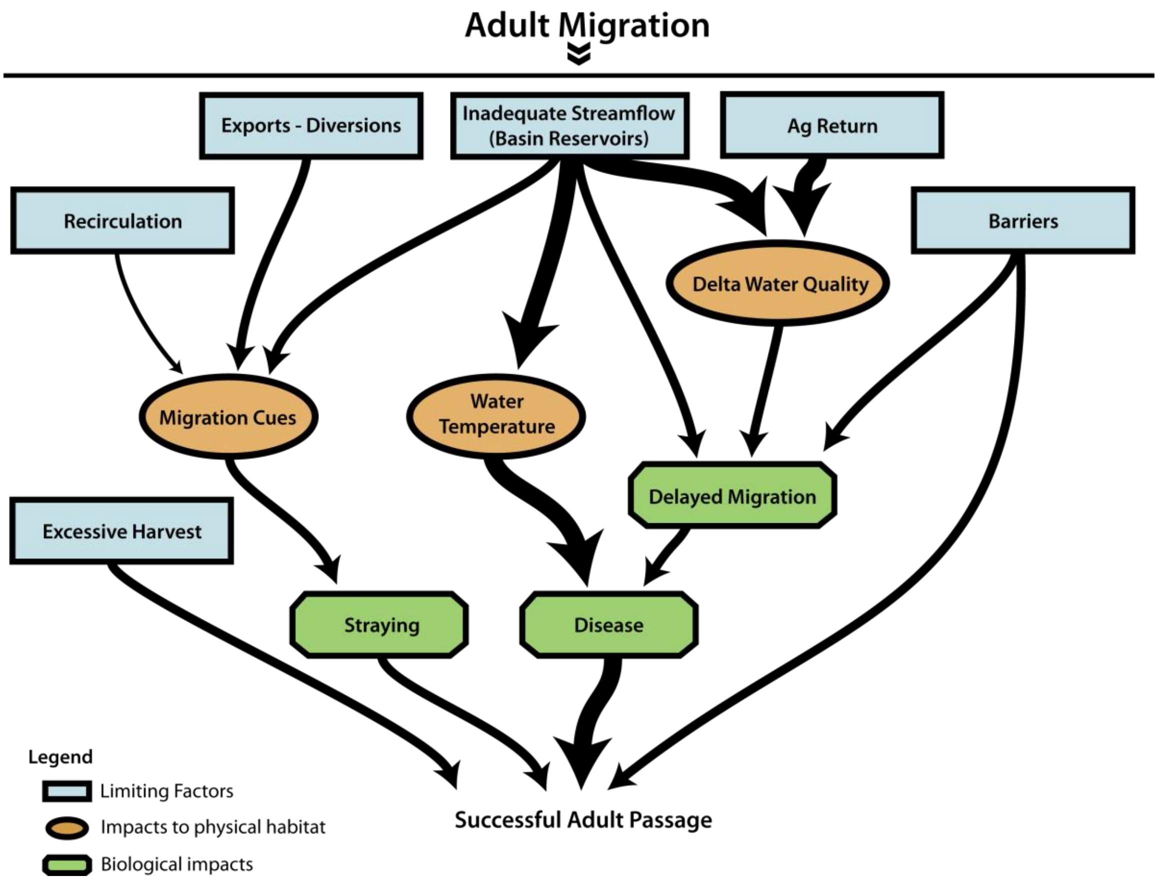


Note: The width of the arrows indicates the relative importance of each mechanism.

Figure 5-7.
Possible Limiting Factors, Impacts to Physical Habitats, and Biological Impacts that May Affect Survival of San Joaquin River Spring-Run Chinook Salmon in the Ocean

5.1.7 Adult Migration

Conditions in Reaches 3 through 5 and the Delta may affect adults in terms of passage and straying rates. The most significant concern is that when the spring-pulse flows cease, water temperatures will become unsuitable and the adults will succumb to disease or other sources of mortality (Figure 5-8). It is also important to remember that the conditions that affect juvenile survival in freshwater and ocean habitats also affect the number of adults that return to spawn.



Note: The width of the arrows indicates the relative importance of each mechanism.

Figure 5-8.
Possible Limiting Factors, Impacts to Physical Habitats, and Biological Impacts that May Affect Survival of Migrating Adult San Joaquin River Spring-Run Chinook Salmon

- **Excessive Water Temperature** – It is unlikely that without spring pulse flow releases, water temperatures will become high enough (70 to 80°F) (21 to 27°C) in late spring and early summer to cause high rates of adult mortality due to disease. It is unlikely that suboptimal water temperatures would affect gamete viability because he fish migrate when they are sexually immature.

- **Delta Water Quality** – Low DO concentrations and possibly high water temperatures may delay passage for adults in the Stockton Deepwater Ship Channel, particularly when the tributary pulse flows cease in mid- to late May and thereby worsen high temperature-related impacts.

- **Delta Exports** – High export rates relative to flows (export rates greater than or equal to 400 percent of Vernalis flows) can cause up to 20 percent of adult San Joaquin spring-run Chinook salmon to stray to the Sacramento River Basin.

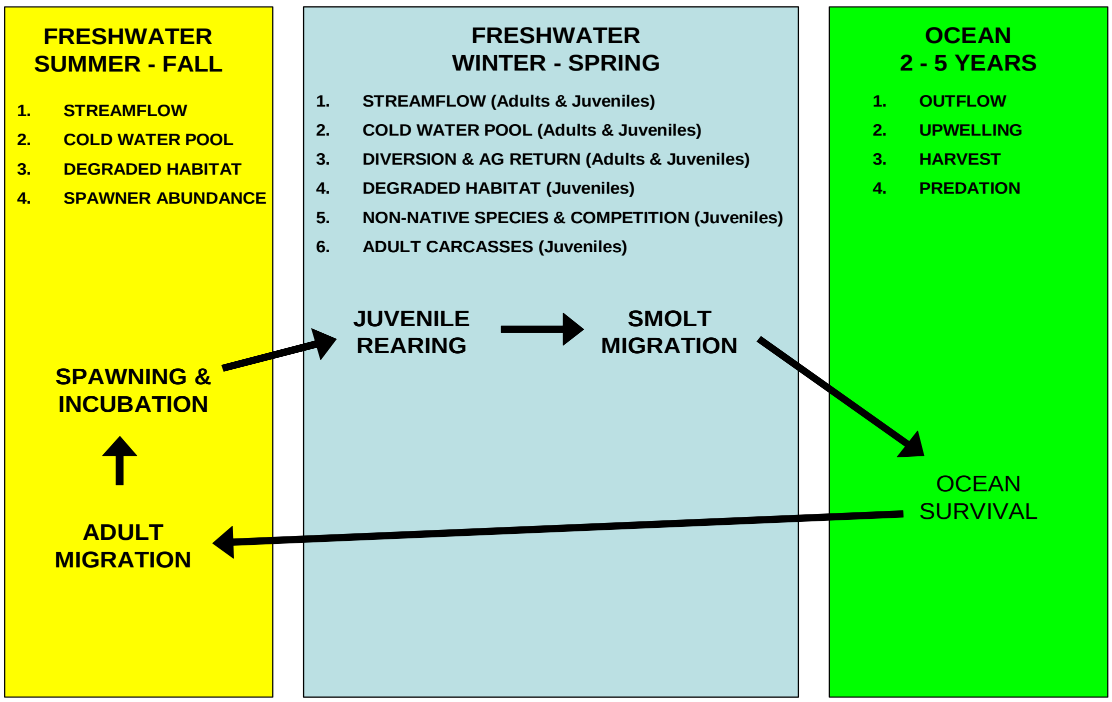
- **Excessive Harvest** – Legal and illegal harvest of adult fish in freshwater habitats may result in an inadequate number of spawners to saturate the rearing habitat with juveniles.

5.1.8 Hatcheries

Hatcheries can benefit or impact the natural Chinook salmon population depending on how they are operated. Potential beneficial uses of hatcheries include (1) incubating eggs from a source population of spring-run Chinook salmon for the purposes of reintroduction, (2) sustaining the Chinook salmon populations during drought conditions when flows are not sufficient for juvenile survival, and (3) providing fish for rotary screw trap calibration studies and smolt survival studies that identify high priority restoration projects, passage problems, and critical flow periods. Potential negative impacts to the natural population include genetic contamination (i.e., decreased fitness), sources of disease, and competition with naturally produced juveniles.

5.2 Fall-Run Chinook Salmon

The environmental factors that are likely to affect the production of fall-run Chinook salmon are nearly identical to those that affect spring-run Chinook salmon, with a few exceptions (Figure 5-9). The primary difference is that adult fall-run Chinook salmon do not require summer holding habitat, because they mostly migrate in October and November and then spawn shortly thereafter. The key management issues are whether the cold water pool in Millerton Lake will be sufficient to restore naturally reproducing populations of both Chinook salmon runs.



Note: The life stages in bold type are assumed to be the most critical for achieving the Restoration Goal.

Figure 5-9.
Overall Conceptual Model for San Joaquin River Fall-Run Chinook Salmon

5.2.1 Spawning

Adult fall-run Chinook salmon have nearly the same spawning habitat requirements as those described for spring-run fish and it is likely that they will use the same spawning beds after the spring-run have completed their spawning. It is possible that this overlap in habitat use will result in excessive redd superimposition and hybridization impacts on the spring-run population.

5.2.2 Adult Migration

Adult fall-run Chinook salmon have nearly the same migration requirements as those described for spring-run fish, except that fall-run fish typically migrate in the San Joaquin system in October and November when high flows will be needed to provide suitable water temperatures. The main concern is whether fall pulse flows of sufficient magnitude and duration to permit passage for migrating adult fall-run Chinook salmon would exhaust the cold water pool in Millerton Lake and thereby potentially increase the temperature of Friant releases above the levels needed to successfully incubate spring-run Chinook salmon eggs from August through December.

5.2.3 Juvenile Rearing

The limiting factors analyses suggest that juvenile survival in the Restoration Area will be an important determinant of adult production, and that there is potential for competition between juvenile spring-run Chinook salmon and juvenile fall-run Chinook salmon. Juveniles of both runs will probably use the same resources since their rearing periods are expected to overlap substantially. It is possible that spring-run Chinook salmon juveniles will have a competitive advantage over the fall-run Chinook salmon juveniles for the limited food resources and habitats, because they will emerge first and be slightly larger than the fall-run Chinook salmon juveniles. However, it is also possible that large numbers of juvenile fall-run Chinook salmon could substantially reduce the survival of spring-run Chinook salmon juveniles.

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Chapter 6 Data Needs

The following are key information needs, and tasks required to address the needs for spring-run and fall-run Chinook salmon in the San Joaquin River and for downstream Chinook salmon populations.

6.1 Spring-Run Chinook Salmon

To effectively manage the recovery of a naturally reproducing spring-run Chinook salmon population, the following information should be considered:

- **Source Populations** – Identify potential source populations for reintroduction. (see Draft Stock Selection Analysis)
  - Provide a thorough description of available stocks, including life history/phenotypic expression, existing conditions in which they occur, population size, genetic distinction, and history of hatchery influence on the population.
  - Develop comparisons of available stocks
  - Conduct a risk/benefit analysis of potential source populations.
  - Develop a alternatives based approach for selecting appropriate stocks for the Restoration Area.
  - Develop reintroduction strategies to maximize survival and sustainability of source stock populations.
- **Adult Fish Passage –** Evaluate the effects of the Restoration Flow releases, water temperatures, and Delta exports on adult fish passage.
  - Develop a quantitative model of the relationship of the effects of flow, water temperature, DO concentrations in the Stockton Deepwater Ship Channel, and Delta export rates on straying rates and gamete viability of adult spring-run Chinook salmon. Use existing data to estimate straying rates and gamete viability relative to flow and water temperatures. Use the CALFED-sponsored water temperature model for the San Joaquin River below the confluence of the Merced River.
  - Evaluate adult passage relative to potential barriers and structural improvements to be implemented in the Restoration Area.

- Determine the impact of altered groundwater inflow on water temperatures and flow in the adult migration corridor.

- **Spawning Habitat Assessment –** Determine the distribution and quality of spawning habitat below Friant Dam:

  - Survey the location of spawning habitats.
  - Obtain and analyze sediment bulk samples from likely spawning beds located throughout the 10-mile-long reach immediately below Friant Dam.
  - Measure sedimentation rates and turbidity in the primary spawning reach during the spring-run spawning period.

- **Holding Habitat –** Evaluate the effects of the Restoration Flow releases and water temperatures on the suitability of holding habitat:

  - Use the SJRRP water temperature model to estimate the water temperature at one-mile intervals for the 5-mile-long reach immediately below Friant Dam in 6-hour timesteps from April 15 to August 31 for each Restoration Flow Schedule.
  - Determine temperature tolerances for holding adult spring-run Chinook salmon for each potential source population.

- **Cold Water Pool –** Evaluate the effects of the Restoration Flow releases and water diversions on the size of the cold water pool in Millerton Lake and the suitability of the release temperatures for spring-run spawning habitat:

  - Use the SJRRP's water temperature model to estimate the water temperature of the release flows from Friant Dam in 6-hour timesteps from April 15 to December 31 for each Restoration Flow Schedule.
  - Evaluate the benefits of installing temperature control devices on release and diversion structures to conserve the volume of the cold water pool in Millerton Lake.

- **Spawning/Incubation –** Evaluate the effects of the Restoration Flow releases and water temperatures on spawning and egg incubation habitats. Evaluate how redd superimposition from fall-run spawners may affect the production of juvenile spring-run Chinook salmon.

  - Use the SJRRP water temperature model to estimate the water temperature at one-mile intervals for the 5-mile-long reach immediately below Friant Dam in 6-hour timesteps from September 1 to December 31 for each Restoration Flow Schedule.

- Evaluate the benefits of installing temperature control devices on release and diversion structures to conserve the volume of the cold water pool in Millerton Lake.

- Determine temperature tolerances for adult spring-run spawners for each potential source population.

- Develop a quantitative model of the relationship between flow, water temperature, the amount of suitable spawning habitat, redd superimposition with and without fall-run Chinook salmon, and the expected maximum number of fry that could be produced.

- **Poaching –** Estimate how poaching may impact the abundance of spring-run Chinook salmon spawners in the San Joaquin River:

  - Assess the effects of legal and illegal harvest of Chinook salmon and other fish.

- **Juvenile Survival –** Evaluate how the Restoration Flow releases and water temperatures will affect the number of spring-run juveniles that survive to a smolt size in the San Joaquin River:

  - Use the SJRRP water temperature model to estimate the water temperature at 10-mile intervals throughout Reach 1 in 6-hour timesteps from March 1 to May 31 for each Restoration Flow Schedule.
  - Estimate the impact of altered groundwater inflow on water temperatures and flow in rearing habitats.
  - Estimate the benefits of restoring channel width, channel depth, and widths of mature riparian tree forests or wetland habitats on water temperatures throughout the Restoration Area.
  - Survey the size, location, and potential for predation at the in-river gravel excavation sites in the Restoration Area.
  - Develop a quantitative model to compare the effects of flow, water temperature, and other potential stressors for juveniles rearing in the upper reaches with those rearing in the lower reaches. Stressors evaluated should include food resources, predation, disease, contamination, and entrainment.

- **Smolt Survival –** Evaluate how Restoration Flow releases and water temperatures will affect the survival of spring-run smolts migrating from the San Joaquin River:

  - Link U.S. Department of the Interior, Bureau of Reclamation's HEC-5Q River temperature model for the Restoration Area with the HEC 5Q CALFED temperature model for the lower San Joaquin River below the confluence of the Merced River to estimate the water temperature at 20-mile intervals throughout the migratory corridor (Friant Dam to Dos Reis) in 6-hour timesteps for smolt outmigrants (March 15 to June 15) for each Restoration Flow Schedule.

- Determine the impact of altered groundwater inflow on water temperatures and flow in juvenile migration corridors.
- Estimate the benefits of restoring channel width, channel depth, and widths of mature riparian tree forests or wetland habitats on water temperatures throughout the Restoration Area.
- Survey the size, location, and potential for predation at the in-river pits and other gravel excavation sites in the Restoration Area.
- Develop suitability criteria for juvenile spring-run Chinook salmon for each potential source population.
- Develop a quantitative model of the effects of flow, water temperature, and smolt survival between Friant Dam and the confluence with the Merced River.

- **Food Availability –** Evaluate how the Restoration Flows, water temperatures, floodplain inundation, exotic species, contaminants, channel morphology, and fine sediments affect food availability for Chinook salmon juveniles:

  - Survey the location of functional and diked floodplain habitats, wetland habitats, exotic plant and fish species, agricultural lands that discharge irrigation runoff into the river, and fine sediment sources between Friant Dam and the confluence with the Merced River.

  - Update the hydraulic and digital terrain models used to evaluate relationships between flow and floodplain inundation.

  - Develop a quantitative food supply model that includes the effects of flow, nutrients, floodplain inundation, wetland habitat inundation, native and exotic riparian vegetation, instream production, channel morphology, and reservoir (Millerton Lake) production.

- **Limiting Factors Assessment –** Evaluate the relative importance of unscreened diversions, predators in captured mine pits and other degraded habitats, starvation, contamination, and disease to juvenile mortality in the San Joaquin River:

  - Survey the unscreened diversions, predators and their habitats, contaminated agricultural runoff, and riparian vegetation on functional floodplains.
  - Incorporate the results of these studies into the quantitative model.

- **Delta Survival –** Evaluate the effects of flow, water temperature, exports, the Head of the Old River Barrier, water quality and ocean-vessel traffic in the Stockton Deepwater Ship Channel, and conditions in the Old River channel on the survival of spring-run smolts in the Delta. Evaluate the effects of ocean conditions on the survival of San Joaquin River Chinook salmon smolts:

  - Incorporate the results of the VAMP studies into the quantitative model.
  - Incorporate the results of ongoing ocean studies.

- **Quantitative Models** – Predict the abundance of adult spring-run Chinook salmon in the San Joaquin River below Friant Dam using the quantitative models developed for the above tasks.

6.2 Fall-Run Chinook Salmon

To effectively manage the recovery of a naturally reproducing fall-run Chinook salmon population, the following information should be considered:

- **Adult Fish Passage and Gamete Viability** – Evaluate the effects of the Restoration Flow releases, water temperatures, and Delta exports on adult fish passage and gamete viability:
  - Same tasks as for spring-run Chinook salmon.
  - Assess gamete viability at the Merced River hatchery relative to flow releases, Delta exports, and water temperatures in the river and Delta.
- **Spawning Habitat** – Determine the distribution and quality of spawning habitat below Friant Dam.
  - Same tasks as for spring-run Chinook salmon.
- **Cold Water Pool** – Evaluate the effects of the Restoration Flow releases and water diversions on the size of the cold water pool in Millerton Lake and the suitability of the release temperatures for spring-run spawning habitat. Determine if it is necessary to enhance spawning habitat downstream from Friant Dam where water temperatures will be suitable under the Restoration Flows. Determine if it is necessary to block fall-run spawners from spring-run spawning areas to prevent superimposition on spring-run Chinook salmon redds.
  - Same tasks as for spring-run Chinook salmon.
- **Spawning/Incubation** – Evaluate the effects of the Restoration Flow releases and water temperatures on spawning and egg incubation habitats:
  - Same tasks as for spring-run Chinook salmon.
- **Juvenile Survival** – Evaluate how Restoration Flow releases and water temperatures will affect the number of fall-run Chinook salmon juveniles that survive to a smolt size in the San Joaquin River:
  - Same tasks as for spring-run Chinook salmon.

- **Smolt Survival –** Evaluate how the Restoration Flow releases and water temperatures will affect the survival of fall-run Chinook salmon smolts migrating from the San Joaquin River:
  - Same tasks as for spring-run Chinook salmon.
- **Food Availability –** Evaluate how the Restoration Flows, water temperatures, floodplain inundation, exotic species, contaminants, channel morphology, and fine sediments affect food availability for juvenile Chinook salmon:
  - Same tasks as for spring-run Chinook salmon.
- **Juvenile Mortality –** Evaluate the relative importance of unscreened diversions, predators in captured mine pits and other degraded habitats, starvation, contamination, and disease to juvenile mortality in the San Joaquin River:
  - Same tasks as for spring-run Chinook salmon.
- **Smolt Survival –** Evaluate the effects of flow, water temperature, exports, the Head of the Old River Barrier, water quality and ocean-vessel traffic in the Stockton Deepwater Ship Channel, and conditions in the Old River channel on the survival of spring-run Chinook salmon smolts in the Delta:
  - Same tasks as for spring-run Chinook salmon.
- **Adult Abundance –** Predict the abundance of adult fall-run Chinook salmon in the San Joaquin River below Friant Dam using the quantitative models developed for the above tasks.

Chapter 7 References

Airola, D.A., and B.D. Marcotte. 1985. A survey of holding pools for spring-run Chinook salmon in Deer and Mill Creeks. USDA Forest Service, Lassen National Forest, Chester, California.

Alderdice, D.F., and F.P.J. Velsen. 1978. Relation between temperature and incubation time for eggs of Chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Fisheries Research Board of Canada 35: 69-75.

Alderdice, D.F., W.P. Wickett, and J.R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. Journal of the Fisheries Research Board of Canada 15: 229-250.

Allan, J.D. 1995. Stream ecology: structure and function of running waters. Chapman & Hall, London.

Amweg, E.L., D.P. Weston, and N.M. Ureda. 2005. Use and toxicity of pyrethroid pesticides in the Central Valley, California, USA. Environmental Toxicology and Chemistry 24: 966-972.

Arkoosh, M.R. 1998. Effect of pollution on fish diseases: potential impacts on salmonid populations. Journal of Aquatic Animal Health 10: 182-190.

Arkoosh, M.R., E. Casillas, P. Huffman, E. Clemons, J. Evered, J.E. Stein, and U. Varanasi. 1998. Increased susceptibility of juvenile Chinook salmon from a contaminated estuary to *Vibrio anguillarum.* Transactions of the American Fisheries Society 127: 360-374.

Bams, R.A. 1967. Differences in performance of naturally and artificially propagated sockeye salmon migrant fry as measured with swimming and predation tests. Journal of the Fisheries Research Board of Canada 24: 1117-1153.

———. 1976. Survival and propensity for homing as affected by presence or absence of locally adapted paternal genes in two transplanted populations of pink salmon (*Oncorhynchus gorbuscha*). Journal of the Fisheries Research Board of Canada 33: 2716-2725.

Banks, M.A., V.K. Rashbrook, M.J. Calavetta, C.A. Dean, and D. Hedgecock. 2000. Analysis of microsatellite DNA resolves genetic structure and diversity of chinook salmon (Oncorhynchus tshawytscha) in California's Central Valley. Canadian Journal of Fisheries and Aquatic Sciences 57: 915-927.

Battin J., M.W. Wiley, M.H. Ruckelshaus, R.R. Palmer, E. Korb, K.K. Bartz, and H. Imaki. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences of the United States of America. 104(16):6720-6725.

Bax, N.J. 1983. Early marine mortality of marked juvenile chum salmon (*Onchrhynchus keta*) released into Hood Canal, Puget Sound, Washington, in 1980. Canadian Journal of Fisheries and Aquatic Sciences 40: 426-435.

Bayer, R.D. 2003. Review: bird predation of juvenile salmonids and management of birds near 14 Columbia Basin dams. Yaquina Studies in Natural History No. 10. http://www.orednet.org/~rbayer/salmon/salmon.htm#bird-dams.

Beacham, T.D., and C.B. Murray. 1985. Effects of female size, egg size, and water temperature on developmental biology of chum salmon (*Oncorhynchus keta*) from the Nitinat River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 42: 1755-1765.

Beckon, W. 2007. Selenium Risk to Salmonids with particular reference to the Central Valley of California. Poster presented at the American Fisheries Society 137th Annual Meeting, San Francisco, California. September 2-6, 2007. U.S. Fish and Wildlife Service, Sacramento, California.

Bell, M.C. 1973. Fisheries handbook of engineering requirements and biological criteria. Fish Engineering Research Program, ACOE, North Pacific Division, Portland, Oregon.

———. 1986. Fisheries handbook of engineering requirements and biological criteria Report No. NTIS AD/A167-877, Fish Passage Development and Evaluation Program, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Benke, A.C. 2001. Importance of flood regime to invertebrate habitat in an unregulated river-floodplain ecosystem. Journal of North American Benthological Society 20: 225-240.

Beschta, R.L., and W.L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. Journal of the Fisheries Research Board of Canada 36: 204-210.

Bilby, R.E., Fransen, B.R., and Bisson, P.A. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53: 164-173.

Bilby, R.E., Fransen, B.R., Bisson, P.A., and J.K. Walter. 1998. Response of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) to the addition of salmon carcasses to two streams in southwestern Washington, USA. Canadian Journal of Fisheries and Aquatic Sciences 55: 1909-1918.

Bottom, D. 2007. Salmon life histories, habitats, and food webs in the Columbia River Estuary. Oral presentation given at the Science Policy Exchange, Pacificorp Auditorium, Portland State University, Portland, Oregon, September 12-13, 2007. The exchange was part of the Columbia River Fish and Wildlife Program amendment process sponsored by the Northwest Power and Conservation Council. http://www.nwcouncil.org/fw/program/2008amend/spe/agenda.htm.

Boullion, T. 2006. Cantara Project Sacramento River benthic macroinvertebrate sampling program: 2001 results progress report. Unpublished report. Submitted to the Cantrara Program, California Department of Fish and Game by California Department of Water Resources, Red Bluff, California.

Brandes, P.L., and J.S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. Pages 39-138 *in* Brown, R.L., editor. Fish Bulletin 179: Contributions to the biology of Central Valley salmonids. Volume 2. California Department of Fish and Game, Sacramento, California.

Brannon, E.L., and T.P. Quinn. 1990. Field test of the pheromone hypothesis for homing by Pacific salmon. Journal of Chemical Ecology 16: 603–609.

Brannon, E.L., D.F. Amend, M.A. Cronin, J.E. Lannan, S. LaPatra, W.J. McNeil, R.E. Noble, C.E. Smith, A.J. Talbot, G.A. Wedemeyer, and J. Westers. 2004. The controversy about salmon hatcheries. Fisheries 29: 12-31. American Fisheries Society, Bethesda, Maryland.

Brown, L. 1996. Aquatic biology of the San Joaquin-Tulare basins, California: analysis of available data through 1992. Report prepared in cooperation with the National Water-Quality Assessment Program by the U.S. Geological Survey. Water Supply Paper 2471.

———. 1997. Concentrations of chlorinated organic compounds in biota and bed sediment in streams of the San Joaquin Valley, California. Archives of Environmental Contamination and Toxicology 33: 357-368.

Brown, L., and J.T. May. 2000. Macroinvertebrate assemblages on woody debris and their relations with environmental variables in the lower Sacramento and San Joaquin river drainages, California: Environmental Monitoring and Assessment 64: 311-329.

Brown, L.R. 1998. Assemblages of fishes and their associations with environmental variables, lower San Joaquin River drainage, California. Open-File Report 98-77. U.S. Geological Survey, National Water-Quality Assessment Program, Sacramento, California.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildlife Service. Fishery Bulletin 52: 97-110.

Cain, J.R. 1997. Hydrologic and geomorphic changes to the San Joaquin River between Friant Dam and Gravelly Ford. Master's thesis. University of California, Berkeley.

CALFED. 2000. Final Programmatic EIR/EIS. CALFED Ecosystem Restoration Program. July 2000.

———. 2001. Scrutinizing the Delta Cross Channel. News from the CALFED Bay-Delta Science Program, Science in Action. June.

California Advisory Committee on Salmon and Steelhead Trout. 1988. Restoring the balance. Annual Report.

California Department of Fish and Game (DFG). 1946. Thirty-ninth biennial report of the Division of Fish and Game for the years 1944-1946. Sacramento, California.

———. 1955. DFG testimony for a DWR hearing on San Joaquin River water applications. The Salmon Fishery of the San Joaquin River, California: its history, its destruction, and its possible re-establishment. Term paper, David Cone, 1973.

———. 1991–2005. Annual reports, fiscal years 1987-2004, San Joaquin River Chinook Salmon Enhancement Project. Sport Fish Restoration Act. Region 4, Fresno.

———. 1992. Interim actions to reasonably protect San Joaquin fall run Chinook salmon. WRINT-DFG Exhibit 25. Prepared by CDFG, Fresno for the Water Rights Phase of the State Water Resources Control Board Bay-Delta Hearing Proceedings.

———. 1998. Report to the Fish and Game commission: A status review of the spring-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento River Drainage. Candidate Species Status Report 98-01. June.

———. 2001. Operation of the Hills Ferry Barrier, 2000. Final report prepared by D.A. Gates, Department of Fish and Game, San Joaquin Valley and Southern Sierra Region, Fresno, California. June.

———. 2004. Acute toxicities of herbicides used to control water hyacinth and Brazilian elodea on larval Delta smelt and Sacramento splittail. Office of Spill Prevention and Response, Administrative Report 04-003, June 8.

———. 2005. Operation of the Hills Ferry Barrier, 2004. Final report prepared by D.A. Gates, Department of Fish and Game, San Joaquin Valley and Southern Sierra Region, Fresno, California. December.

———. 2007a. San Joaquin River fishery and aquatic resources inventory. Cooperative Agreement 03FC203052.

———. 2007b. 2007-2008 California freshwater sport fishing regulations. Accessed online at: http://www.dfg.ca.gov/regulations/07-08-inland-fish-regs.pdf.

California Department of Water Resources (DWR). 2002. Riparian vegetation of the San Joaquin River. Prepared by DWR, San Joaquin District, Fresno for San Joaquin River Habitat Restoration Program, Fresno, California.

Central Valley Regional Water Quality Control Board (CVWB). 1998. The Water Quality Control Plan (basin plan) for the California Regional Water Quality Control Board Central Valley Region, Fourth Edition California Regional Water Quality Control Board Central Valley Region, Sacramento, California.

Calkins, R.D., W.F. Durand, and W.H. Rich. 1940. Report of the board of consultants on the fish problem of the upper Sacramento River. Stanford Univ., 34 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Cantara Trustee Council. 2007. Final report on the recovery of the upper Sacramento River – subsequent to the 1991 Cantara Spill. Prepared by the Cantara Trustee Council, Redding, California.

Carl Mesick Consultants. 2002a. Task 6 second year post-project evaluation report, fall 2000, Knights Ferry Gravel Replenishment Project. Final report produced for the CALFED Bay Delta Program and the Stockton East Water District, El Dorado, California. February 20.

Casillas, E. 2007. Coastal and ocean ecosystems – current findings linking plume and ocean conditions to salmon growth and survival. Oral presentation given at the Science Policy Exchange, Pacificorp Auditorium, Portland State University, Portland, Oregon, September 12-13, 2007. The exchange was part of the Columbia River Fish and Wildlife Program amendment process sponsored by the Northwest Power and Conservation Council. http://www.nwcouncil.org/fw/program/2008amend/spe/agenda.htm.

Castella, E., M. Richardot-Coulet, C. Roux, and P. Richoux. 1991. Aquatic macroinvertebrate assemblages of two contrasting floodplains: the Rhone and Ain rivers, France. Regulated Rivers: Research and Management 6: 289-300.

Cederholm, C.J., M.D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24(10): 6-15.

Chambers, J.S., G.H. Allen, and R.T. Pressey. 1955. Research relating to study of spawning grounds in natural areas. Annual Report, Contract No. DA 35026-Eng-20572. Prepared by Washington State Department of Fisheries, Olympia for U.S. Army Corps of Engineers, Fisheries-Engineering Research Program, North Pacific Division, Portland, Oregon.

Chambers, J.S., R.T. Pressey, J.R. Donaldson, and W.R. McKinley. 1954. Research relating to study of spawning grounds in natural areas. Annual Report, Contract No. DA 35026-Eng-20572. Prepared by Washington State Department of Fisheries, Olympia for U.S. Army Corps of Engineers, Fisheries-Engineering Research Program, North Pacific Division, Portland, Oregon.

Chapman W.M. 1943. The spawning of Chinook salmon in the main Columbia River. Copeia 1943: 168-170.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117: 1-21.

Chapman, DW, Bjornn, TC. 1969. Distribution of salmonids in streams, with special reference to food and feeding. In: Northcote, TG, editor. Symposium on salmon and trout in streams; Vancouver: UBC Press. p. 153-176. H. R. MacMillian Lectures in Fisheries.

Clark, G.H. 1929. Sacramento-San Joaquin Salmon (*Oncorhynchus tschawytscha*) Fishery of California. Division of Fish and Game of California. Fish Bulletin No. 17: 1-73.

———. 1943. Salmon at Friant Dam-1942. California Department of Fish and Game Fish Bulletin. 29: 89-91.

Clifford, M.A., K.J. Eder, I. Werner, and R.P. Hedrick. 2005. Synergistic effects of esfenvalerate and infectious hematopoietic necrosis virus on juvenile Chinook salmon mortality. Environmental Toxicology and Chemistry 24(7):1766-1772.

Coble, D.W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Transactions of the American Fisheries Society 90: 469-474.

Cohen, A.N., and P.B. Moyle. 2004. Summary of data and analyses indicating that exotic species have impaired the beneficial uses of certain California waters. Report submitted to the State Water Resources Control Board. June 14, 2004.

Collier, M., R.H. Webb, and J.C. Schmidt. 1996. Dams and rivers: primer on the downstream effects of dams. Circular No. 1126. U.S. Geological Survey.

Combs, B.D. 1965. Effect of temperature on the development of salmon eggs. The Progressive Fish-Culturist 27: 134-137.

Combs, B.D., and R.E. Burrows. 1957. Threshold temperatures for the normal development of Chinook salmon eggs. The Progressive Fish-Culturist 19: 3-6.

Cooper J.C., A.T. Scholz, R.M. Horrall, A.D. Hasler, and D.M. Madison. 1976. Experimental confirmation of the olfactory hypothesis with homing, artificially imprinted coho salmon. Journal of Fisheries Research Board Canada 33: 703–10.

Cope, O.B., and D.W. Slater. 1957. Role of Coleman Hatchery in maintaining a king salmon run. U.S. Fish and Wildlife Service, 47.

Cox, G. 1999. Alien species in North America and Hawaii: impacts on natural ecosystems. Island Press, Washington, D.C.

Cramer Fish Sciences. 2006. 2005-06 Stanislaus River Weir Data Report. Final report prepared for the Anadromous Fish Restoration Program. June.

———. 2007. Upstream Fish Passage at a Resistance Board Weir Using Infrared and Digital Technology in the Lower Stanislaus River, California, 2006−2007 Annual Data Report. Report prepared by Jesse T. Anderson, Clark B. Watry, and Ayesha Gray for the Anadromous Fish Restoration Program.

Central Valley Regional Water Quality Control Board (Central Valley Water Board). 1998. The Water Quality Control Plan (basin plan) for the California Regional Water Quality Control Board Central Valley Region, Fourth Edition California Regional Water Quality Control Board Central Valley Region, Sacramento, California. Available: http://www.swrcb.ca.gov/~CRegionalBoard5/home.html.

———. 2001. San Joaquin River Selenium TMDL. Central Valley Regional Water Quality Control Board, Rancho Cordova, California. http://www.waterboards.ca.gov/centralvalley/programs/tmdl/selenium.htm.

Central Valley Water Board. *See* Central Valley Regional Water Quality Control Board.

Dauble, D.D., T.L. Page, and R.W. Hanf. 1989. Spatial distribution of juvenile salmonids in the Hanford Reach, Columbia River. Fisheries Bulletin 87: 775-790.

Deas, M., Water Engineering, Inc., and D. Smith, RMA Associates. 2008. Presentation to FMWG on Water Temperature Model for San Joaquin. January.

Demko D.B., C. Gemperle, S.P. Cramer, and A. Phillips. 1998. Evaluation of juvenile Chinook behavior, migration rate and location of mortality in the Stanislaus River through the use of radio tracking. Report prepared for Tri-dam Project. Gresham, Oregon. December 1998.

Deverall, K.R., J.R.M. Kelso, and G.D. James. 1993. Redd characteristics and implications for survival of Chinook salmon (*Oncorhynchus tshawytscha*) embryos in the Waitaki River, New Zealand. New Zealand Journal of Marine and Freshwater Research 27: 437-444.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Can. J. Fish. Aquat. Sci. 54: 1685-1698.

DFG. *See* California Department of Fish and Game.

DFG and NMFS. *See* California Department of Fish and Game, and National Marine Fisheries Service

Dittman, A.H., T.P. Quinn, W.W. Dickhoff, and D.A. Larsen. 1994. Interactions between novel water, thyroxine and olfactory imprinting in underyearling coho salmon (*Oncorhynchus kisutch* Walbaum). Aquacult. Fish. Manag. 25 (Suppl. 2), 157–169.

Dittman, A.W., T.P. Quinn, and G.A. Nevitt. 1996. Olfactory electroencephalographic responses of homing coho salmon (*Onchorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 53: 434–442.

Dolloff, C.A. 1993. Predation by river otters (*Lutra canadensis*) on juvenile coho salmon (*Oncorhynchus kisutch*) and Dolly Varden (*Salvelinus malma*) in southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 50: 312-315.

Domagalski, J.L., D.L. Knifong, P.D. Dileanis, L.R. Brown, J.T. May, V. Connor, and C.N. Alpers. 2000. Water quality in the Sacramento River Basin, California, 1994-98. Circular 1215. USGS, National Water Quality Assessment Program. Available at http://pubs.usgs.gov/circ/circ1215/.

Domagalski, J.,D. Weston, M. Zhang, and M. Hladik. 2009. Pyrethroid insecticide concentrations, toxicity, and loads in surface waters of the San Joaquin Valley, California. U.S. Department of the Interior, U.S. Geological Survey.

Donaldson, J.R. 1955. Experimental studies on the survival of the early stages of Chinook salmon after varying exposures to upper lethal temperatures. Master's thesis. University of Washington, Seattle.

Donaldson, L.R., and G.H. Allen. 1957. Return of silver salmon, *Oncorhynchus kisutch* (Walbaum), to point of release. Transactions of the American Fisheries Society 87: 13-22.

Dubrovsky, N.M., C.R. Kratzer, L.R. Brown, J.M. Gronberg, and K.R. Burow. 1998. Water quality in the San Joaquin-Tulare basins, California, 1992-95. USGS Circular 1159. U.S. Geological Survey, Denver, Colorado.

DWR. *See* California Department of Water Resources.

Eddy, R.M. 1972. The influence of dissolved oxygen concentration and temperature on survival and growth of Chinook salmon embryos and fry. Master's thesis. Oregon State University, Corvallis.

Eder, K.J., H-R Köhler, and I. Werner. 2007. Pesticide and pathogen: heat shock protein expression and acetylcholinesterase inhibition in juvenile Chinook salmon in response to multiple stressors. Environmental Toxicology and Chemistry 26: 1233-1242.

Everest, F.H., and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile Chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29: 91-100.

Fisher, F.W. 1994. Past and present status of Central Valley Chinook salmon. Conservation Biology 8: 870-873.

Flagg, T.A., and C.E. Nash. 1999. A conceptual framework for conservation hatchery strategies for Pacific salmonids. NOAA Technical Memorandum NMFSMWMFSC-38.

FMWG (Fisheries Management Work Group). 2007. Canoe and foot surveys of Reach 1. Technical Memorandum. July 10-11.

Foss, S. 2003. Chinook salmon loss estimation for Skinner Delta Fish Protective Facility and Tracy Fish Collection Facility. CDFG, 4001 N. Wilson Way, Stockton, California. Available at http://baydelta.ca.gov/Metadata/Salvage_Metadata.htm.

Francis, R.C., S.R. Hare, A.B. Hollowed, W.S. Wooster. 1998. Effect of interdecadal climate variability on the oceanic ecosystems of the northeast Pacific.

Fraser, F.J., P.J. Starr, and A.Y. Fedorenko. 1982. A review of the Chinook and coho salmon of the Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1126:130.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Gangmark, H.A. and R.G. Bakkala. 1958. Plastic standpipe for sampling streambed environment of salmon spawn. Bureau of Commercial Fisheries, United States Department of the Interior. Special Scientific Report, Fisheries No. 261. Washington, D.C.

———. 1960. A comparative study of unstable and stable (artificial channel) spawning streams for incubating king salmon at Mill Creek. California Fish and Game 46: 151-164.

Gangmark, H.A., and R.D. Broad. 1955. Experimental hatching of king salmon in Mill Creek, a tributary of the Sacramento River. California Fish and Game 41:233-242.

Garcia De Leaniz, C., N. Fraser, and F. Huntingford. 1993. Dispersal of Atlantic salmon fry from a natural redd: evidence for undergravel movements? Canadian Journal of Zoology 71: 1454-1457.

Gard, M. 1995. Upper Sacramento River IFIM study scoping report. U.S. Fish and Wildlife Services, 14 p.

Garland, R.D., K.F. Tiffan, D.W. Rondorf, and L.O. Clark. 2002. Comparison of subyearling fall Chinook salmon's use of riprap revetments and unaltered habitats in Lake Wallula of the Columbia River. North American Journal of Fisheries Management 22: 1283-1289.

Garling, D.L., and M. Masterson. 1985. Survival of Lake Michigan Chinook salmon eggs and fry incubated at three temperatures. The Progressive Fish-Culturist 47: 63-66.

Gilbert, C.H. 1912. Age at maturity of Pacific coast salmon of the genus Oncorhynchus. Bull. U.S. Fish Comm. 32:57-70.

Gilliom, R.J., and D.G. Clifton. 1990. Organochlorine pesticide residues in bed sediments of the San Joaquin River, California. Water Resources Bulletin 26: 11-24.

Gladden, J.E., and L.A. Smock. 1990. Macroinvertebrate distribution and production on the floodplains of two lowland headwater streams. Freshwater Biology 24: 533-545.

Good, T.P., R.S. Waples, and P. Adams. 2005. Updated status of federally listed ESUs of west coast salmon and steelhead. NOAA Technical Memorandum NMFS-NWFSC-66. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington and NMFS, Southwest Fisheries Science Center, Santa Cruz, California.

Goodbred, S.L., R.J. Gilliom, T.S. Gross, N.P. Denslow, W.L. Bryant, and T.R. Schoeb. 1997. Reconnaissance of 17B–estradiol, 11–ketotestosterone, vitellogenin, and gonad histopathology in common carp of United States streams: potential for contaminant-induced endocrine disruption. U.S. Geological Survey Open–File Report 96–627. Sacramento, California.

Gordus, A. 2009. Direct Testimony of Andrew G. Gordus, Ph. D. on behalf of the California Department of Fish and Game before the U.S. Federal Energy Regulatory Commission Office of Administrative Law Judges Exhibit No. DFG-4 Turlock Irrigation District and Modesto Irrigation District 6 New Don Pedro Project 7 Project Nos. 2299-065.

Gresh, T., J. Lichatowich, and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem. Fisheries 25: 15-21.

Grosholz, E., and E. Gallo. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. Hydrobiologia 568: 91-109.

Groves, A.B., G.B. Collins, and P.S. Trefethen. 1968. Roles of olfaction and vision in choice of spawning site by homing adult Chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Fisheries Research Board of Canada 25: 867-876.

Hallock, R.J., R.F. Elwell, and D.H. Fry, Jr. 1970. Migrations of adult king salmon *Oncorhynchus tshawytscha* in the San Joaquin Delta; as demonstrated by the use of sonic tags. California Department of Fish and Game, Fish Bulletin 151: 92.

Hallock, R.J., and W.F. Van Woert. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. California Fish and Game. 45: 227-296.

Hanson, C.H. 1997. Acute temperature tolerance of juvenile Chinook salmon from the Mokelumne River. Prepared by Hanson Environmental, Inc. Walnut Creek, California.

Harden-Jones, F.R. 1968. The reactions of fish to stimuli. Pages 187-198 in F.R. Harden-Jones, editor. Fish migration. St. Martin's Press.

Hare, S.R., and R.C. Francis. 1995. Climate change and salmon production in the northeast Pacific Ocean. Pages 357-372 *in* R.J. Beamish, editor. Ocean climate and northern fish populations. Special Publication of Canadian Fisheries and Aquatic Sciences.

Hatton, S.R. 1940. Progress report on the Central Valley fisheries investigations, 1939. California Fish and Game 26: 334-373.

Hawke, S.P. 1978. Stranded redds of quinnat salmon in the Mathias River, South Island, New Zealand. Journal of Marine and Freshwater Research 12: 167-171.

Healey, M.C. 1980. Utilization of the Nanaimo River estuary by juvenile Chinook salmon, *Oncorhynchus tshawytscha*. Fish. Bull. 77(3): 653-668.

———. 1991. Life history of Chinook salmon. Pages 311–393 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver.

Healey, T.P. 1979. The effect of high temperature on the survival of Sacramento River Chinook (king) salmon, *Oncorhynchus tshawytscha*, eggs and fry. Administrative Report 79-10. California Department of Fish and Game, Anadromous Fisheries Branch.

Helfield, J.M., and R.J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology. 82:2403-2409.

Hennessy, A., and K. Hieb. 2007. Zooplankton Monitoring 2006. IEP Newsletter 20(2):10-14. Interagency Ecological Program. Sacramento (California): California Department of Water Resources.

Herren, J.R., and S.S. Kawaski. 2001. Inventory of water diversions in four geographic areas in California’s Central Valley. Pages 343-3552 in Brown, R.L., editor. Fish Bulletin 179: Contributions to the biology of Central Valley salmonids. Volume 2. California Department of Fish and Game, Sacramento, California.

Higgs, D.A., J.S. MacDonald, C.D. Levings, and B.S. Dosanjh. 1995. Nutrition and feeding habits in relation to life history stage. Chapter 4 in C. Groot, L. Margolis, and W.C. Clarke, editors. Physiological Ecology of Pacific Salmon. UBC Press, Vancouver.

Hilborn, R. 1975. The effect of spatial heterogeneity on the persistence of predator-prey interactions. Theoretical Population Biology 8: 346-355.

Hill, K.A., and J.D. Webber. 1999. Butte Creek spring-run Chinook salmon, *Oncorhynchus tshawytscha*, juvenile outmigration and life history 1995-1998. Inland Fisheries Administrative Report No. 99-5. California Department of Fish and Game, Sacramento Valley and Central Sierra Region, Rancho Cordova.

Hocking, M.D., and T.E. Reimchen. 2002. Salmon-derived nitrogen in terrestrial invertebrates from coniferous forests of the Pacific Northwest. BMC Ecology.

Hollowed, A.B., S.R. Hare, and W.S. Wooster. 2001. Pacific Basin climate variability and patterns of Northeast Pacific marine fish production. Progress in Oceanography 49: 257-282.

Holmes, R.W., B.S. Anderson, B.M. Phillips, J.W. Hunt, D.B. Crane, A. Mekebri, and V. Connor. 2008. Statewide investigation of the role of pyrethroid pesticides in sediment toxicity in California's urban waterways. Environmental Science and Technology (Abstract).

Hughes, N.F. 2004. The wave-drag hypothesis: an explanation for size-based lateral segregation during the upstream migration of salmonids. Canadian Journal of Fisheries and Aquatic Sciences 61: 103-109.

Hunt, R.J., J.F. Walker, and D.P. Krabbenhoft. 1999. Characterizing hydrology and the importance of ground-water discharge in natural and constructed wetlands. Wetlands 19: 458-?

Independent Scientific Group, The. 1996. Return to the river: restoration of salmonid fishes in the Columbia River Ecosystem. Northwest Power Planning Council.

Intergovernmental Panel on Climate Change (IPCC). 2001 Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881 pages.

Jeffres, C.A., J.J. Opperman, P.B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California River. Environ. Biol. Fish 83:449–458.

Johnsen, P.B., and A.D. Hasler. 1980. The use of chemical cues in the upstream migration of coho salmon, *Oncorhynchus kisutch,* Walbaum. Journal of Fish Biology 17: 67-73.

Johnson, P., B. Nass, D. Degan, J. Dawson, M. Johnson, B. Olson, and C.H. Arrison. 2006. Assessing Chinook salmon escapement in Mill Creek using acoustic technologies in 2006. Report submitted to the U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program. November 2006.

Jones and Stokes. 2002a. Foundation runs report for restoration actions gaming trials. Prepared for Friant Water Users Authority, Lindsay, California and Natural Resources Defense Council, San Francisco, California by Jones and Stokes, Sacramento, California.

———. 2002b. Evaluation of Stockton Deep Water Ship Channel Water Quality Model Simulation of 2001 Conditions: Loading Estimates and Model Sensitivity. September. (J&S 01-417.) Prepared for CALFED Bay-Delta Program. Sacramento, California.

Kjelson, M.A., Raquel, P.F., and F.W. Fisher. 1982. Life history of fall-run juvenile Chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin Estuary, California. Estuarine Comparisons: 393-411.

Kondolf, G.M. 1997. Hungry Water: effects of dams and gravel mining on river channels. Environmental Management 21 (4): 533-551.

———. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129: 262-281.

Kondolf, G.M., and M.G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2275-2285.

Kondolf, G.M., and M.L. Swanson. 1993. Channel adjustments to reservoir construction and gravel extraction along Stony Creek, California. Environmental Geology 21: 251-256.

Koski, K.V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon streams. Master’s thesis. Oregon State University, Corvallis.

———. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled-stream environment at Big Beef Creek. PhD dissertation. University of Washington, Seattle.

Kratzer, C.R., and J.L. Shelton. 1998. Water quality assessment of the San Joaquin - Tulare basins, California: analysis of available data on nutrients and suspended sediment in surface water, 1972-1990. Professional Paper 1587. U.S. Geological Survey, National Water-Quality Assessment Program, Sacramento, California.

Kuivila, K.M. 1995. Dormant spray pesticides in the San Francisco Estuary, California. Pages 72-73 in The Wildlife Society second annual conference (abstracts). The Wildlife Society, Bethesda, Maryland.

———. 2000. Pesticides in the Sacramento-San Joaquin Delta: state of our knowledge. Presented at CALFED Bay-Delta Program Science Conference, Oct. 3-5, 2000, Sacramento, California. Abstract (#66).

Large, A.R.G., and G. Petts. 1996. Rehabilitation of River Margins. Pages 106-123 in G. Petts and P. Calow, editors. River restoration: selected extracts from the Rivers handbook. Blackwell Science Ltd., Oxford.

Lee, G.D. 1998. Walking Where We Lived - Members of a Mono Indian Family. University Oklahoma Press.

Lee, D. 2000. The Sacramento-San Joaquin Delta largemouth bass fishery. IEP Newsletter 13: 37-40. Interagency Ecological Program. Sacramento, California.

Lee, G.F. and Jones-Lee. 2003. Synthesis and Discussion of Findings on the Causes and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel Near 2 Stockton, CA: Including 2002 Data. Report Submitted to SJR DO TMDL Steering Committee and CALFED Bay-Delta Program, G. Fred Lee & Associates, El Macero, CA, March (2003). Available at http://www.gfredlee.com/SynthesisRpt3-21-03.pdf

Leitritz, E. 1959. Trout and salmon culture: hatchery methods. Fish Bulletin 107. State of California Department of Fish and Game, Sacramento, California.

Levy, D.A., and T.G. Northcote. 1981. The distribution and abundance of juvenile salmon in marsh habitats of the Fraser River Estuary. Technical Report No. 25. Westwater Research Centre, University of British Columbia.

Levy, D.A., and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Lindley, S.T., R. Schick, B.P. May, J.J. Anderson, S. Greene, C. Hanson, A. Low, D. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams. 2004. Population structure of threatened and endangered Chinook salmon ESUs in California's Central Valley Basin. Technical Memorandum NOAA-TM-NMFS-SWFSC-360. National Marine Fisheries Service, Southwest Fisheries Science Center.

Lindsay, R.B., W.J. Knox, M.W. Flesher, B.J. Smith, E.A. Olsen, and L.S. Lutz. 1986. Study of wild spring Chinook salmon in the John Day River system. 1985 Final Report, Contract DE-AI79-83BP39796, Project 79-4. Prepared by Oregon Department of Fish and Wildlife, Portland for Bonneville Power Administration, Portland, Oregon.

Lister, D.B., and H.S. Genoe. 1970. Stream habitat utilization of cohabiting underyearlings of Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Big Qualicum River, British Columbia. Journal of the Fisheries Research Board of Canada 27: 1215-1224.

MacFarlane, R.B., and Norton, E.C. 2002. Physiological ecology of juvenile Chinook salmon (Oncorhynchus tshawytscha) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fisheries Bulletin 100: 244-257.

Mantua, N.J., and S.R. Hare. 2002. The Pacific decadal oscillation. Journal of Oceanography 58: 35– 44.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin American Meteorological Society 78: 1069-1079.

Marcotte, B.D. 1984. Life history , status, and habitat requirements of spring-run Chinook salmon in California. USDA Forest Service, Lassen National Forest, Chester, California.

Marine, K.R. 1992. A background investigation and review of the effects of elevated water temperature on reproductive performance of adult chinook salmon (*Oncorhynchus tshawytscha*). Prepared for East Bay Municipal Utility District.

Mason, J.C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. Journal Fisheries Research Board of Canada 26: 63-91.

McBain, M.E., and W. Trush. 2002. San Joaquin River restoration study background report. Prepared for Friant Water Users Authority, Lindsay, California and Natural Resources Defense Council, San Francisco, California. Arcata, California. December.

McCain, M.E. 1992. Comparison of habitat use and availability for juvenile fall-run Chinook salmon in a tributary of the Smith River, California, FHR Currents. No. 7, USDA Forest Service, Region 5.

McCuddin, M.E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. Master’s thesis. University of Idaho, Moscow.

McIsaac, D.O., and T.P. Quinn. 1988. Evidence for a hereditary component in homing behavior of Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences 45: 2201–2205.

McLarney, W.O. 1964. The coastrange sculpin, Cottus aleuticus: Structure of a population and predation on eggs of the pink salmon, Oncorhynchus gorbuscha. M.S. thesis. University of Michigan, Ann Arbor.

Merkel, T.J. 1957. Food habits of the king salmon, *Oncorhynchus tshawytscha* (Walbaum), in the vicinity of San Francisco, California. California Fish and Game 43: 249-270.

Merz, J.E., and P.B. Moyle. 2006. Salmon, wildlife, and wine: marine-derived nutrients in human ecosystems in Central California. Ecological Applications16: 999-1009.

Mesick, C.F. 2001a. Studies of spawning habitat for fall-run Chinook salmon in the Stanislaus River between Goodwin Dam and Riverbank from 1994 to 1997. Pages 217-252 *in* R.L. Brown, editor. Fish Bulletin 179. Contributions to the biology of Central Valley salmonids. Volume 2. California Department of Fish and Game, Sacramento, California.

———. 2001b. The effects of San Joaquin River flows and delta export rates during October on the number of adult San Joaquin Chinook salmon that stray. Pages 139-161 in R.L. Brown, editor. Fish Bulletin 179. Contributions to the biology of Central Valley salmonids. Volume 2. California Department of Fish and Game, Sacramento, California.

Mesick, C.F., and D. Marston. 2007a. San Joaquin River fall-run Chinook salmon age cohort reconstruction. Provisional draft.

———. 2007b. Relationships between fall-run Chinook salmon recruitment to the major San Joaquin River tributaries and stream flow, delta exports, the Head of the Old River Barrier, and tributary restoration projects from the early 1980s to 2003. Provisional draft.

Montgomery, D.R., J.M. Buffington, N.P. Peterson, N.P. D. Schuett-Hames, and T.P. Quinn. 1996. Stream-bed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. Can. J. Fish. Aquat. Sci. 53: 1061-1070.

Moyle, P.B. 2000. Abstract 89. R.L. Brown, F.H. Nichols and L.H. Smith, editors. CALFED Bay-Delta Program science conference 2000. CALFED Bay-Delta Program, Sacramento, California.

———. 2002. Inland fishes of California: revised and expanded. University of California Press, Berkeley.

Moyle, P.B., P.K. Crain, and K. Whitener. 2005. Patterns in the use of a restored California floodplain by native and alien fishes. 26 November. Unpublished draft. http://baydelta.ucdavis.edu/files/crg/reports/MoyleFloodplainfishMS-26nov.pdf

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Final Report. Prepared by Department of Wildlife and Fisheries Biology, University of California, Davis for California Department of Fish and Game, Inland Fisheries Division, Rancho Cordova, California.

Mueller-Solger, A. 2007. The 2007 VAMP salmon kill near Stockton: What killed these fish? Presentation given to the participating agencies in the 2007 Vernalis Adaptive Management Program. October 12.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grant, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-35. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington.

Myrick, C.A., and J.J. Cech, Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Technical Publication 01-1. Published electronically by the Bay-Delta Modeling Forum at http://www.sfei.org/modelingforum/.

Natural Resource Scientists. 2007. High fish mortality near Stockton, California. Memorandum to the participating agencies in the 2007 Vernalis Adaptive Management Program. May 20.

Nicholas, J.W., and D.G. Hankin. 1989. Chinook salmon populations in Oregon coastal river basins: descriptions of life histories and assessment of recent trends in run strengths. Report EM 8402. Oregon Department of Fish and Wildlife, Research and Development Section, Corvallis.

Nichols, K. 2002. Merced River PKD survey – Spring 2002. Memorandum to the San Joaquin River Basin fish health information distribution list. U.S. Fish and Wildlife Service, CA-NV Fish Health Center, Anderson, California. December 6.

Nichols, K., and J.S. Foott. 2002. Health monitoring of hatchery and natural fall-run Chinook salmon juveniles in the San Joaquin River and tributaries, April – June 2001. FY 2001 Investigation Report by the U.S. Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, California.

NMFS (National Marine Fisheries Service). 2006a. Biological opinion for the *Egeria densa* Control Program. Issued April 18.

———. 2006b. Biological opinion for the water hyacinth Control Program. Issued April 4.

———. 1996. Factors for decline: a supplement to the notice of determination for west coast steelhead under the Endangered Species Act. National Marine Fisheries Service, Protected Resource Division, Portland, Oregon, and Long Beach California.

———. 1998. Factors Contributing to the Decline of Chinook Salmon: An Addendum to the 1996 West Coast Steelhead Factors For Decline Report. Protected Resources Division, National Marine Fisheries Service. Portland Oregon.

Noakes, D.J. 1998. On the coherence of salmon abundance trends and environmental trends. North Pacific Anadromous Fishery Commission Bulletin. pp. 454-463.

Nobriga, M., M. Chotkowski, and R. Baxter. 2003. Baby steps toward a conceptual model of predation in the Delta: preliminary results from the shallow water habitat predator-prey dynamics study. IEP Newsletter 16: 19-27. Interagency Ecological Program. California Department of Water Resources, Sacramento, California.

NRC (National Research Council). 1992. Restoration of aquatic ecosystems: science, technology, and public policy. Prepared by the Committee on Restoration of Aquatic Ecosystems-Science, Technology, and Public Policy, National Academy of Sciences, Washington, D.C.

Orlando, J.L., K.M. Kuivila, and A. Whitehead. 2003. Dissolved Pesticide Concentrations Detected in Storm-Water Runoff at Selected Sites in the San Joaquin River Basin, California, 2000-2001. Open File Report A946044, U.S. Geological Survey. Available at http://www.stormingmedia.us/94/9460/A946044.html

Oros, D.R., and I. Werner. 2005. Pyrethroid insecticides. An analysis of use patterns, distributions, potential toxicity and fate in the Sacramento-San Joaquin Delta and Central Valley. White paper for the Interagency Ecological Program. SFEI Contribution 415. San Francisco Estuary Institute, Oakland, California.

Pagliughi, S.P. 2008. Lower Mokelumne River Reach Specific Thermal Tolerance Criteria by Life Stage for Fall-Run Chinook Salmon and Winter-Run Steelhead. East Bay Municipal Utility District. Unpublished Report. 91pp.

Panshin, S.Y., N.M. Dubrovsky, J.M. Gronberg, and J.L. Domagalski. 1998. Occurrence and distribution of dissolved pesticides in the San Joaquin River Basin, California. Water-Resources Investigations Report 98-4032. U.S. Geological Survey, National Water-Quality Assessment Program, Sacramento, California.

Parker, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. Journal Fisheries Research Board of Canada 25: 757-794.

Pearcy, W.G. 1992. Ocean ecology of north pacific salmonids. University of Washington.

Pearsons, T.N., D.D. Roley, and C.L. Johnson. 2007. Development of a carcass analog for nutrient restoration in streams. Fisheries 32: 114-124.

Peterson, J.H., and J.F. Kitchell. 2001. Climate regimes and water temperature changes in the Columbia River: Bioenergetic implications for predators of juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences. 58:1831-1841.

Phillips, J.P. 2006. Acute and sublethal effects of lambda-cyhalothrin on early life stages of Chinook salmon (*Oncorhyncus tschawytscha*). Master's thesis. University of California, Davis.

Phillips, R.W., and E.W. Claire. 1966. Intragravel movement of the reticulate sculpin, *Cottus perplexus*, and its potential as a predator on salmonid embryos. Transactions of American Fisheries Society 95: 210-212.

Phillips, R.W., and H.J. Campbell. 1962. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. Pacific Marine Fisheries Commission 14th Annual Report for the year 1961: 60-75.

Pickard, A., A. Grover, and F.A. Hall, Jr. 1982. An evaluation of predator composition at three locations on the Sacramento River. Technical Report 2. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary.

Platts, W.S., M.A. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency Ecological Research Series EPA-600/3-79-043.

Pollard. 1955. Measuring seepage through salmon spawning gravel. Journal of Fisheries Research Board of Canada 12: 706-741.

Quinn, N.W.T., and A. Tulloch. 2002. San Joaquin River diversion data assimilation, drainage estimation, and installation of diversion monitoring stations. Report to CALFED Bay-Delta Program. CALFED Project #: ERP-01-N61-02. September 15.

Quinn, T.P. 1990. Current controversies in the study of salmon homing. Ethol Ecol Evol 2: 49–63.

———. 2005. The behavior and ecology of Pacific salmon and trout. American Fisheries Society, Bethesda and University of Washington Press, Seattle.

Quinn, T.P., and K. Fresh. 1984. Homing and straying in chinook salmon from Cowlitz River Hatchery, Washington. Canadian J. Fisheries and Aquatic Sciences 41: 1078–82.

Quinn, T.P., E.L. Brannon, and D.H. Dittman. 1989. Spatial aspects of imprinting and homing in coho salmon. Fish Bull 87: 769–74.

Randall, J., and M. Hoshovsky. 2000. California's wildland invasive plants. C. Brossard, J.C. Randall and M. Hoshovsky, editors. University of California Press, Berkeley.

Randall, R.G., M.C. Healey, and J.B. Dempson. 1987. Variability in length of freshwater residence of salmon, trout, and char. Am. Fish. Soc. Symp. 1:27-41.

Reclamation. *See* U.S. States Department of the Interior, Bureau of Reclamation.

Reimers, P.E. 1973. The length of residence of juvenile fall Chinook salmon in the Sixes River, Oregon. Oreg. Fish Comm. 4, 2-43 p.

Reiser, D.W., and R.G. White. 1988. Effects of two sediment size-classes on survival of steelhead and Chinook salmon eggs. North American Journal of Fisheries Management 8: 432-437.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Pages 1-54 *in* W.R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. General Technical Report PNW-96. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Rich, A.A. 1987. Report on studies conducted by Sacramento County to determine the temperatures which optimize growth and survival in juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Prepared for McDonough, Holland and Allen, Sacramento, California by A.A. Rich and Associates, San Rafael.

Rich, A.A. 2007. Impacts of Water Temperature on Fall-Run Chinook Salmon (Oncorhynchus tshawytscha) and Steelhead (O. mykiss) in the San Joaquin River System. Prepared for: Ca. Dept. of Fish and Game. Region 4. Fresno, California. 46pp.

Rich, A.A., and W.E. Loudermilk. 1991. Preliminary evaluation of Chinook salmon smolt quality in the San Joaquin drainage. California Department of Fish and Game and Federal Aid Sport Fish Restoration Report.

Roper, B., and D.L. Scarnecchia. 1996. A comparison of trap efficiencies for wild and hatchery Age-0 Chinook salmon. N. American J. Fish. Management 16: 214-217.

S.P. Cramer and Associates. 2004. 2002-04 Stanislaus River Weir Data Report. Final report prepared for the Anadromous Fish Restoration Program. October.

———. 2005. 2004-05 Stanislaus River Weir Data Report. Final report prepared for the Anadromous Fish Restoration Program. June.

San Joaquin River Dissolved Oxygen Technical Working Group (SJRDOTWG). 2007. Total Maximum Daily Load (DO TMDL) Technical Working Group (TWG) website: http://www.sjrdotmdl.org/index.html.

Saiki, M.K., M.R. Jennings, R.H. Wiedmeyer. 1992. Toxicity of agricultural subsurface drainwater from the San-Joaquin Valley, California, to juvenile Chinook salmon and Striped bass. Transactions of the America Fisheries Society 121: 78-93.

Schaffter, R. 2000. Mortality rates of largemouth bass in the Sacramento-San Joaquin Delta, 1980 through 1984. IEP Newsletter 13: 54-60. Interagency Ecological Program, California Department of Water Resources, Sacramento, California.

Schluchter, M.D., and J.A. Lichatowich. 1977. Juvenile life histories of Rogue River spring Chinook salmon Oncorhynchus tshawytscha (Walbaum), as determined by scale analysis. Oregon Dept. of Fish Wildl. Info. Rep. Fish. 77-5, 24 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Street, P.O. Box 59, Portland, OR 97207.)

Schneider, K. 1999. Channel adjustments downstream of Goodwin Dam, Stanislaus River: An examination of river morphology and hydrology from 1996-1999. Prepared for: LA 227, Restoration of Rivers and Streams, Professor G. Mathias Kondolf, University of California, Berkeley. Fall.

Scholz, N.L., N.K. Truelove, B.L. French, B.A. Berejikian, T.P. Quinn, E. Casillas, and T.K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in Chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish Aquat. Sci. 57:1911-1918.

Scholz, N.L., N.K. Truelove, J.S. Labenia, D.H. Baldwin, and T.K. Collier. 2006. Dose-additive inhibition of Chinook salmon acetylcholinesterase activity by mixtures of organophosphate and carbamate insecticides. Environmental Toxicology and Chemistry 25: 1200-1207.

Seymour, A.H. 1956. Effects of temperature upon young Chinook salmon. Ph.D. dissertation. University of Washington, Seattle, Washington.

Shelton, J.M., and R.D. Pollock. 1966. Siltation and egg survival in incubation channels. Transactions of the American Fisheries Society 95: 183-187.

Shumway, D.L., C.E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on growth of steelhead trout and coho salmon embryos. Transactions of the American Fisheries Society 93: 342-356.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and Chinook salmon embryos at different water velocities. Transactions of the American Fisheries Society 92: 327-343.

Simon, A. 1995. Adjustment and recovery on unstable alluvial channels: identification and approached for engineering and management. Earth Surface Processes and Landforms 20: 611-628.

SJRDOTWG. *See* San Joaquin River Dissolved Oxygen Technical Working Group.

SJRGA. *See* San Joaquin River Group Authority.

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. Canadian Journal of Fisheries and Aquatic Sciences 58: 325-333.

Sowden, T.K., and G. Power. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. Transactions of the American Fisheries Society 114: 804-812.

Spence, B.C., G.A. Lomnicky, R.M. Hughes and R.P. Novitzki. 1996. An Ecosystem Approach to Salmonid Conservation. Funded jointly by the U.S. EPA, U.S. Fish and Wildlife Service and National Marine Fisheries Service. TR-4501-96-6057. Man Tech Environmental Research Services Corp., Corvallis, Oregon.

Stephenson, A.E., and D.E. Fast. 2005. Monitoring and evaluation of avian predation on juvenile salmonids on the Yakima River, Washington. Annual Report 2004. March.

Stillwater Sciences. 2003. Draft restoration strategies for the San Joaquin River. Prepared for the Natural Resources Defense Council and the Friant Water Users Authority. Berkeley. February.

———. 2007. Big Bend restoration project interim technical memorandum: results of post-project monitoring 2005–2006. Unpublished draft. Prepared for Tuolumne River Trust, Modesto, California by Stillwater Sciences, Berkeley, California.

Stuart, T.A. 1953. Spawning migration, reproduction, and young stages of lock trout (*Salmotrutta* L.). Scottish Home Department, Freshwater and Salmon Fisheries Research 5, Edinburgh.

State Water Resources Control Board (SWRCB). 1995. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 95-1WR. May.

SWRCB. *See* State Water Resources Control Board.

Tagart, J.V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Master’s thesis. University of Washington, Seattle.

Tappel, P.D., and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3: 123-135.

Taylor, E.B. 1990. Environmental correlates of life-history variation in juvenile Chinook salmon, Oncorhynchus tshawytscha (Walbaum). J. Fish Biol. 37:1-17.

TID and MID. *See* Turlock Irrigation District and Modesto Irrigation District.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 1991. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project (Project No. 2299), Appendix 8 of the Fisheries Studies Report, Lower Tuolumne River Spawning Gravel Studies Report. Prepared by EA Engineering, Science, and Technology for the Federal Energy Regulatory Commission. Lafayette, California. November 20.

———. 1992. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project (Project No. 2299), Appendix 22 of the Fisheries Studies Report, Lower Tuolumne River Predation Study Report. Prepared by EA Engineering, Science, and Technology for the Federal Energy Regulatory Commission. Lafayette, California. February 5.

Tronstad, L.M., B.P. Tronstad, and A.C. Benke. 2005. Invertebrate seedbanks: rehydration of soil from unregulated river floodplain in the south-eastern U.S. Freshwater Biology 50: 646-655.

Tucker, M.E., C.M. Williams, and R.R. Johnson. 1998. Abundance, food habits, and life history aspects of Sacramento squawfish and striped bass at the Red Bluff Diversion Complex, California, 1994-1996. Red Bluff Research Pumping Plant Report No. 4. U.S. Fish and Wildlife Service, Red Bluff, California.

Urquhart KAF. 1987. Associations between environmental factors and the abundance and distribution of resident fishes in the Sacramento-San Joaquin Delta. Exhibit 24, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Stockton (CA): California Department of Fish and Game.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2006. Draft Environmental Assessment, Geologic Drilling & Aggregate Sampling Program, Upper San Joaquin River Basin Storage Investigation, Fresno and Madera Counties, California. EA-06-54. May. http://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=2271)

U.S. Environmental Protection Agency. 1999. 1999 Update of ambient water quality criteria for ammonia. EPA-822-R-99-014. National Technical Information Service, Springfield, Virginia.

U.S. Environmental Protection Agency. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

Unwin, M.J. and T.P. Quinn. 1993. Homing and straying patterns of Chinook salmon from a New Zealand hatchery: spatial distribution of strays and effects of release date. Canadian J. Fisheries and Aquatic Sciences 50: 1168–1175.

U.S. Fish and Wildlife Service (USFWS). 1994a. Abundance and survival of juvenile Chinook salmon in the Sacramento-San Joaquin Estuary: 1993 Annual Progress Report. Stockton, California.

———. 1994b. The relationship between instream flow, adult immigration, and spawning habitat availability for fall-run Chinook salmonin the upper San Joaquin River, California. Sacramento Field Office, Sacramento, California.

———. 2000a. 1996 annual progress report: Abundance and survival of juvenile Chinook salmon in the Sacramento-San Joaquin Estuary. Technical report produced for the Interagency Ecology Program, Stockton, California. May 2000.

———. 2000b. Impacts of riprapping to ecosystem functioning, lower Sacramento River, California. U.S. Fish and Wildlife Service, Sacramento Field Office, Sacramento, California. Prepared for US Army Corps of Engineers, Sacramento District.

———. 2001. Final Restoration Plan for the Anadromous Fish Restoration Program: A Plan to Increase Natural Production of Anadromous Fish in the Central Valley of California. Released as a Revised Draft on May 30, 1997 and Adopted as Final on January 9, 2001. Stockton, California.

USFWS. *See* U.S. Fish and Wildlife Service.

Viant, M.R., C.A. Pincetich, and R.S. Tjeerdema. 2006. Metabolic effects of dinoseb, diazinon and esfenvalerate in eyed eggs and alevins of Chinook salmon (*Oncorhyncus tshawytscha*) determined by H1 NMR metabolomics. Aquatic Toxicology 77:359-371.

Vogel, D.A. 2008. Pilot study to evaluate acoustic-tagged juvenile Chinook salmon smolt migration in the northern Sacramento-San Joaquin Delta. Prepared for California Department of Water Resources, Sacramento, California. March.

Vogel, D.A., and K.R. Marine. 1991. Guide to upper Sacramento River Chinook salmon life history . Prepared for U.S. Bureau of Reclamation, Central Valley Project by CH2M HILL, Redding, California.

Vronskiy, B.B. 1972. Reproductive biology of the Kamchatka River Chinook salmon [*Oncorhynchus tschawytscha* (Walbaum)]. Journal of Ichthyology 12: 259-273.

Ward, P.D., and T.R. McReynolds. 2001. Butte and Big Chico Creeks spring-run Chinook salmon, *Oncorhynchus tshawytscha*, life history investigation, 1998-2000. California Department of Fish and Game, Inland Fisheries Administrative Report.

Ward, P.D., T.R. McReynolds, and C.E. Garman. 2002. Butte and Big Chico Creeks spring-run Chinook salmon, *Oncorhynchus tshawytscha*, life history investigation, 2000-2001. California Department of Fish and Game, Inland Fisheries Administrative Report No. 2001-2.

———. 2004. Butte and Big Chico Creeks spring-run Chinook salmon, *Oncorhynchus tshawytscha*, life history investigation, 2002-2003. California Department of Fish and Game, Inland Fisheries Administrative Report No. 2004-6.

———. 2006. Butte Creek spring-run Chinook salmon, *Oncorhynchus tshawytscha* pre-spawn mortality evaluation. California Department of Fish and Game, Inland Fisheries Administrative Report No. 2006-1.

Warner, G. 1991. Remember the San Joaquin in A. Lufkin (ed.), California's salmon and steelhead, University of California Press, Los Angeles. 395 p.

Waters, T.F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7.

Wedemeyer, G.A. 1974. Stress as a predisposing factor in fish diseases. U.S. Fish and Wildlife Service, FDL-38, Washington, D.C.

Wells, R.A., and W.J. McNeil. 1970. Effect of quality of the spawning bed on growth and development of pink salmon embryos and alevins. U.S. Fish and Wildlife Service Special Scientific Report – Fisheries 616.

Werner, I., L.A. Deanovic, K. Kuivila, J. Orlando, and T. Pedersen. 2003. Concentrations of organophosphate pesticides and corresponding bioassay toxicity in the Sacramento-San Joaquin Delta. Poster presentation at the CALFED Science Conference 2003, Sacramento Convention, Center, January 14-16, 2003. Prepared by the Aquatic Toxicology Program, University of California, Davis and the U.S. Geological Survey, Sacramento.

Weston, D.P., R.W. Holmes, J. You, and M.J. Lydy. 2005. Aquatic toxicity due to residential use of pyrethroids. Environmental Science and Technology 39(24):9778-9784.

Weston, D. and M. Lydy. 2009. Pyrethroid pesticides in the Sacramento-San Joaquin Delta: Sources and impacts on Delta waters.

Wheelock, C.E., K.J. Eder, I. Werner, H. Huang, P.D. Jones, B.F. Brammell, A.A. Elskus, and B.D. Hammock. 2005. Individual variability in esterase activity and CYP1A levels in Chinook salmon (*Oncorhyncus tshawytscha*) exposed to esfenvalerate and chlorpyrifos. Aquatic Toxicology 74:172-192.

Williams, J. 2006. Central Valley salmon: a perspective on Chinook and steelhead of Central Valley California. San Francisco Estuary Watershed Science. Vol. 4(3).

Wisby, W.J., and A.D. Hasler. 1954. Effect of occlusion on migrating silver salmon (*Oncorhynchus kisutch*). J. Fish. Res. Board Can. 11: 472-478.

Yoshiyama, R.M., E.R. Gerstung, F.W. Fisher, and P.B. Moyle. 1996. Historical and present distribution of Chinook salmon in the Central Valley drainage of

California, Sierra Nevada Ecosystem Project: final report to congress, Volume III: Assessments, commissioned reports, and background information, University of California, Center for Water and Wildland Resources, Davis, California. pp. 309-362.

———. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Pages 71-177 *in* R.L. Brown, editor. Contributions to the biology of Central Valley salmonids. Volume 1. California Department of Fish and Game Fish Bulletin 179.

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.

Young, M.K., W.A. Hubert, and T.A. Wesche. 1990. Comments: fines in redds of large salmonids. Transactions of the American Fisheries Society 119: 156-162.

7.1 Personal Communications

Cramer, S. 2001. Principal Consultant. Cramer Fish Sciences, Gresham, Oregon.

Leary, Patricia. 2007. California Regional Water Quality Control Board, Central Valley Region. Letter to Mark Madison, Director, Department of Municipal Utilities, City of Stockton Regional Wastewater Control Facility. June 20, 2007.

McReynolds, T. 2005. Associate Fisheries Biologist, California Department of Fish and Game, Chico, California

Mitchell, Dale. 2006. Regional Fisheries Chief, California Department of Fish and Game, Region 4. Fresno, California. Meeting on May 10.

Vyverberg, K. 2004. Senior Engineering Geologist, California Department of Fish and Game, Fisheries Branch, Sacramento, California.