STUDY REPORT W&AR-5
SALMONID INFORMATION INTEGRATION & SYNTHESIS

ATTACHMENT B

CHINOOK SALMON CONCEPTUAL MODELS BY LIFE STAGE

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1.0 INTRODUCTION

This document has been prepared in support of, and accompanying a discussion of issues affecting Tuolumne River fall-run Chinook salmon (*Oncorhynchus tshawytscha*) as part of the initial study report of the *Salmonid Populations Information Integration and Synthesis Study Plan* (W&AR-5) for the ongoing ILP Relicensing Studies for the Don Pedro Project (FERC Project No. 2299-075). Because the geographic scale of Chinook salmon habitat extends across local (in-river) and regional (Delta and Pacific Ocean) scales, a number of potential factors may affect Tuolumne River Chinook salmon throughout their life cycle. Conceptual models for Chinook salmon were developed in consultation with relicensing participants to identify factors that may affect salmonids at different life stages throughout the species range in the Tuolumne River, lower San Joaquin River, Delta, San Francisco Bay estuary, and Pacific Ocean.

Recognizing that not all factors affecting Tuolumne River salmonids may be known or well understood, the identified issues and supporting discussion in the following sections attempt to identify factors that may potentially affect Tuolumne River Chinook salmon life-history and overall population levels. The discussion below refers to habitat conditions corresponding to the life-history timing (Table B-1) and seasonal residency (Figure B-1) of various Tuolumne River Chinook salmon life stages, and assumes the reader has some familiarity with relevant information provided in the PAD as well as information presented in the *Salmonid Populations Information Integration and Synthesis Study* report ("synthesis") regarding primary ecosystem inputs as well as historical habitat modifications and other factors affecting Tuolumne River Chinook salmon. These factors include, but are not limited to: 1) historical modifications to water supplies and instream flows (e.g., water development in the Tuolumne River and broader Central Valley, FERC (1996) instream flow requirements for the benefit of salmonids and other aquatic resources); 2) effects of historical water supply development (e.g., dam construction, hydrograph modification, Delta water exports, etc.) as well as in-channel and floodplain mining upon sediment supplies and transport; 3) anthropogenic influences on land uses along the lower Tuolumne River and Delta (e.g., agriculture, mining, urbanization, levees, etc.) as well as introductions of both chemicals (e.g., fertilizers, pesticides, herbicides, etc.) and non-native fish species (e.g., bass and other sport-fish, salmon hatcheries); 4) seasonal and longer-term variations (e.g., ENSO, PDO) in climate and meteorology upon local and regional water temperatures and runoff as well as broader effects upon ocean circulation and productivity. The following sections discuss issues affecting individual life stages (e.g., spawning gravel availability, predation, food availability, etc.), separated into mechanisms affecting reproduction, growth, as well as sources of direct and indirect mortality.

Table B-1. General life history timing of Fall-run Chinook salmon in the.Study Area

Life Stage	Fall			Winter			Spring			Summer		
	(Sep-Nov)			(Dec-Feb)			(Mar-May)			(Jun-Aug)		
Adult Upstream Migration												
Adult Spawning												
Egg Incubation and Fry Emergence												
In-river Rearing (Age 0+)												
Delta Rearing (Age 0+)												
Smolt Outmigration (Riverine/Delta)												
Ocean Rearing and Adult Residency												

Note: Timing adapted from NMFS (2009) and historical Tuolumne River monitoring data (TID/MID 2005a) with periods of life-stage absence (no shading), potential presence (grey), and peak activity (dark grey) shown.

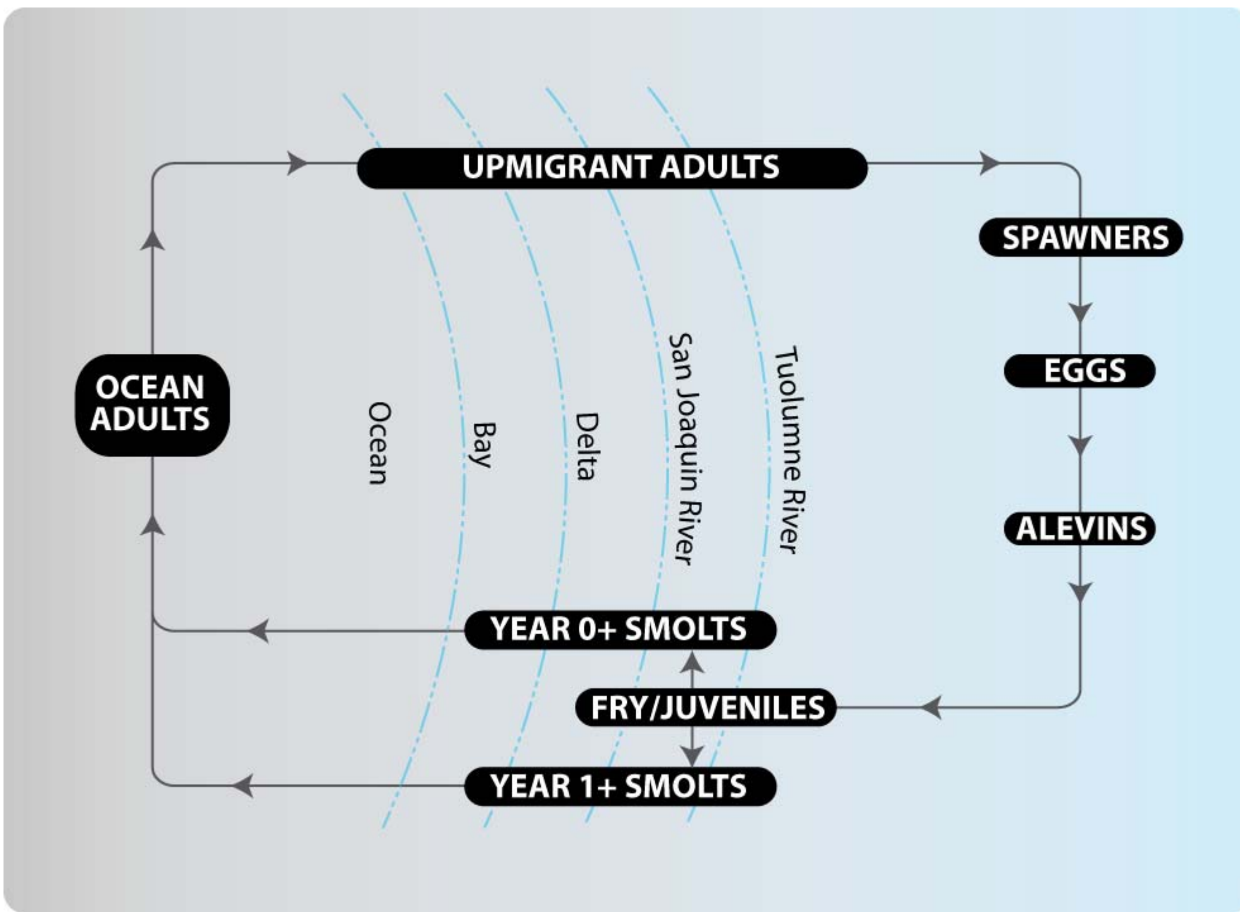

Figure B-1. Fall-run Chinook salmon life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

2.0 CHINOOK SALMON UPMIGRATION

As shown in Figure B-2, a number of factors may potentially affect homing fidelity and arrival timing and potential mortality of Chinook salmon in the lower Tuolumne River, including attraction flows, water quality, water temperature, as well as straying of hatchery origin fish from other river systems. The following sections discuss issues affecting upmigration separated into mechanisms affecting reproduction, growth, as well as sources of direct and indirect mortality.

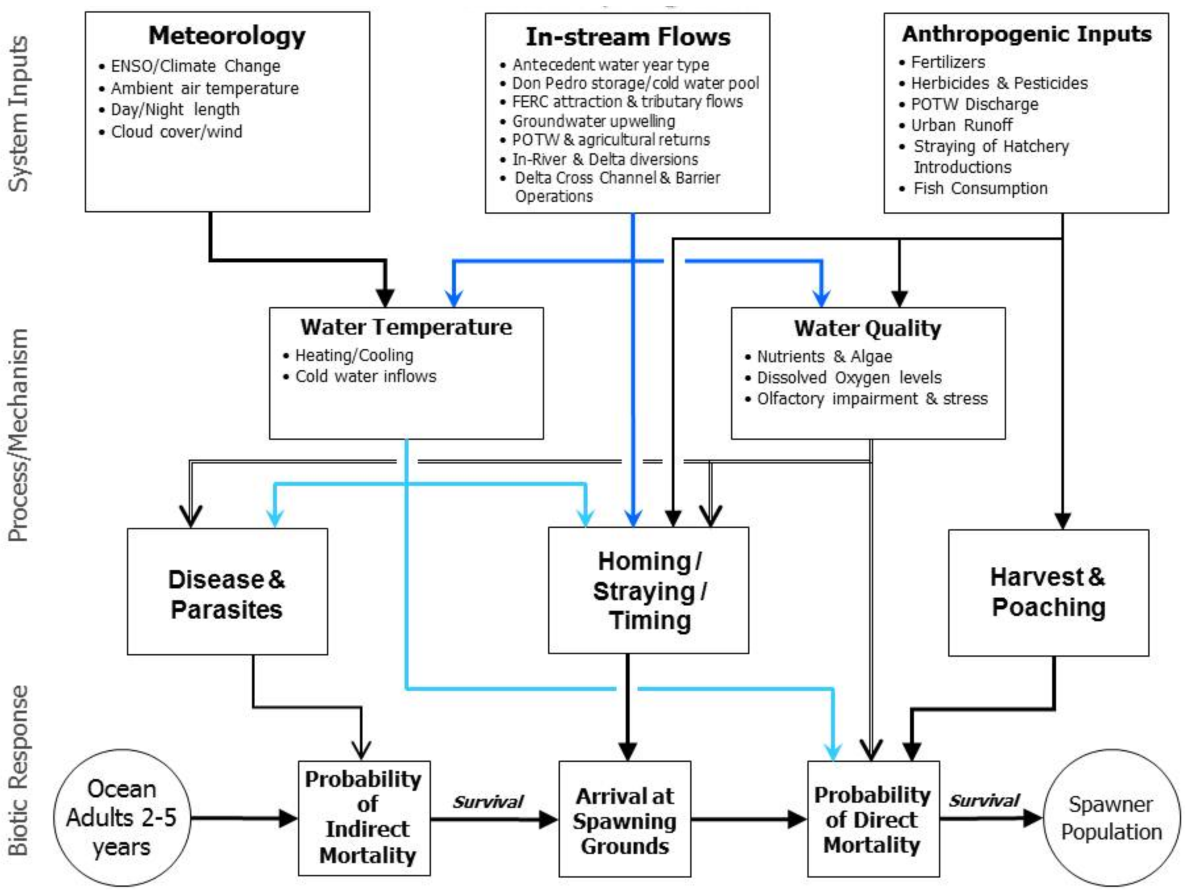

Figure B-2. Potential issues affecting fall-run Chinook salmon upmigration through the San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

2.1 Processes/Mechanisms Affecting Arrival at Spawning Grounds

The only Tuolumne-specific data available to assess issues related to arrival are related to the examination of arrival timing variations with flow as well as water temperature. USFWS and CDFG have recently initiated an adult tracking study of upmigrant Chinook salmon captured at Jersey Point in the Delta. The studies will examine the effectiveness of fall attraction flows in determining movement patterns, water temperature exposure history, and potential effects upon egg viability of spawned fish in the Tuolumne River and other San Joaquin River tributaries.

Below, we discuss potential factors associated with variations in arrival timing, homing and straying of Chinook salmon in the Tuolumne River.

2.1.1 Flow Effects on Arrival Timing, Homing, and Straying

Fall attraction pulse flows have been included in the current FERC (1996) license for the Tuolumne River. However, the poor relationship between observed arrival timing at the La Grange powerhouse and antecedent flows (Figure B-3) suggests these factors may have little influence on Chinook salmon arrival timing. Flow may potentially affect tributary homing (e.g., Dittman and Quinn 1996). In studies of the effects of the Delta cross channel barrier operations on the Mokelumne River, Del Real and Saldate (2011) showed that variations in daily passage at Woodbridge was partially explained by flow (R^2=0.41), water temperature (R^2=0.46), and precipitation (R^2=0.15). Mesick (2001) has developed the only report that shows relationships between homing/straying of up-migrant Chinook salmon and flows at Vernalis and exports, but since this study was limited to returns of CWT fish to hatcheries in the Sacramento and San Joaquin River basin, the relationship between tributary homing and attraction flows remains poorly understood.

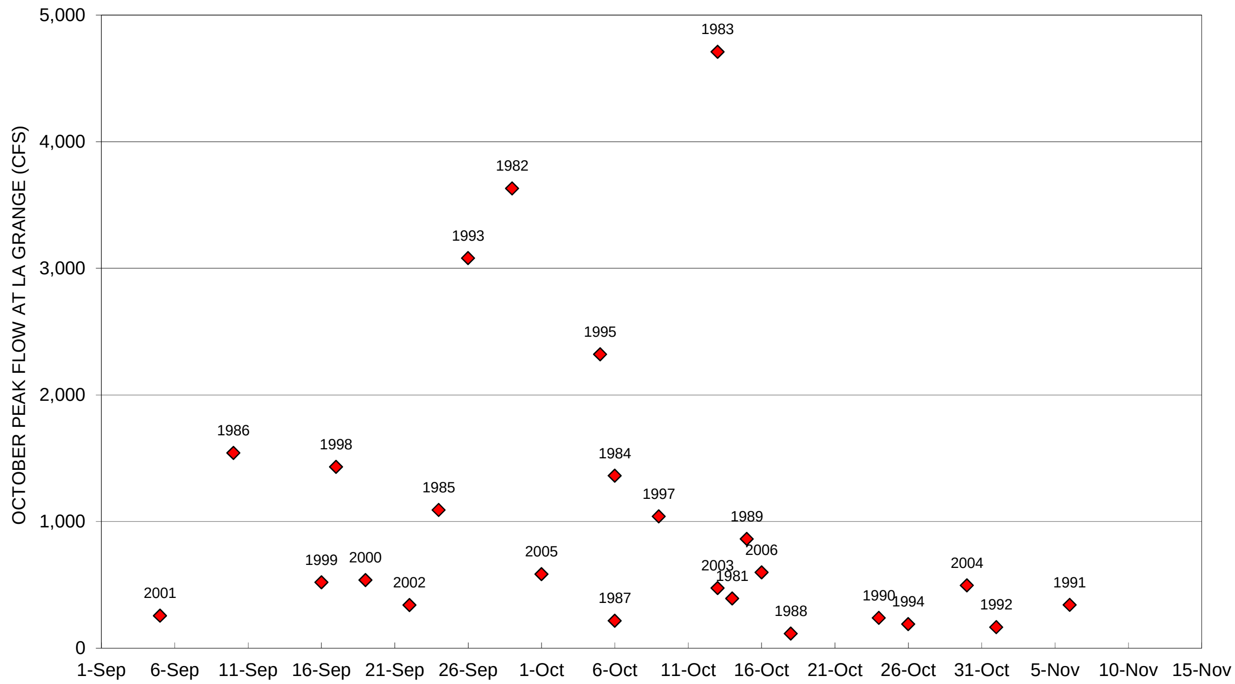

Figure B-3. Relationship between Chinook salmon arrival timing as observed near La Grange and peak flows at La Grange during October from 1981–2006.

2.1.2 Water Quality Effects on Arrival Timing, Homing, and Straying

In addition to factors affecting instream flows in the San Joaquin River and Delta, anthropogenic inputs of nutrients, as well as accidental discharges of other contaminants may result in unsuitable water quality conditions for up-migrating salmon. Although existing data does not show relationships between arrival timing with Tuolumne River fall attraction flows, dissolved oxygen has been suggested as factors affecting the timing of salmon passage at Stockton in 1966 (Hallock et al. 1970) and by inference, the timing of adults arriving at tributary spawning grounds in the Tuolumne River in other years with poor water quality conditions as well. Recent water quality improvements such as in-channel aeration and nutrient load reductions have served to reduce algal blooms and improve dissolved oxygen conditions (e.g., >5 mg/L) in the lower San Joaquin River during summer and fall and no recent evidence of migration delays due to low DO have been reported (Newcomb and Pierce 2010).

Separate dissolved oxygen issues discussed above, studies in other estuaries have shown that homing from the ocean is primarily related to olfactory cues that are specific to the water and sediment chemistry of each watershed (Hasler et al. 1978, Quinn 1990). For this reason, olfactory impairments due to early life history exposure to copper and organophosphate pesticides (e.g., Hansen et al. 1999, Scholz et al. 2000) as well as entrainment of San Joaquin River flows into the SWP and CVP export facilities under various barrier operations may affect the sequence of olfactory cues encountered by upmigrating salmon, resulting in straying of salmonids into non-natal tributaries.

2.1.3 Water Temperature Effects on Arrival Timing

In addition to factors affecting instream flows in the San Joaquin River and Delta, water temperatures in late summer and early fall may affect arrival timing of Chinook salmon in the Tuolumne River. In an acoustic tag study of migrating Chinook salmon, Hallock et al. (1970) attributed salmon migration delays past Stockton to water temperature in 1964, 1965 and 1967. Migration timing of Chinook salmon has been shown to be related to water temperatures in studies of Pacific Northwest rivers as well (Goniea et al. 2006). However, since water temperatures near the lower Tuolumne River confluence (RM 3.6) were only weakly related to variations in instream flows during September and October (Stillwater Sciences 2011b), other factors such as day-length effects on regional meteorology may affect upmigration timing in the lower San Joaquin and Tuolumne Rivers, as found by Strange (2010) in an acoustic tag study of Chinook salmon upmigration on the Klamath River.

2.1.4 Influence of Hatchery Straying on Spawning Grounds Arrival

Separate from potential instream flow, water quality, and water temperature issues discussed above, straying of hatchery-reared Chinook salmon from other river systems is generally greater than their wild counter-parts (Candy and Beacham 2000; CDFG and NMFS 2001) and straying of hatchery origin fish may potentially affect the numbers and timing of Chinook salmon arriving in the Tuolumne River. Adipose-fin clipped fish from hatcheries have been found at high levels in Tuolumne River carcass surveys in some years (e.g., TID/MID 2005a; TID/MID 2012, Report 2011-8). Recent studies have provided local evidence of high rates of straying into the Tuolumne River resulting from off-site hatchery releases by the Merced River Fish Facility and Mokelumne River Hatchery (Mesick 2001; ICF Jones & Stokes 2010). Although no local evidence of altered run timing in the Tuolumne River resulting from hatchery influences was identified for this synthesis, in the absence of appropriate hatchery management practices, hatcheries examined in the Pacific Northwest have been found to inadvertently select for early run timing by spawning a disproportionately higher percentage of earlier returning fish (Flagg et al. 2000).

2.2 Processes/Mechanisms Affecting Direct Mortality

2.2.1 Ocean Harvest of Fall-run Chinook salmon

Ocean harvest of adult salmon that escape the ocean fishery, inland sport fishing and illegal poaching may potentially affect the number of adults that return to their natal streams to spawn, and in turn, affect subsequent juvenile production. Although historical ocean recovery information does not allow the separation of Tuolumne River Chinook salmon harvest from other Central Valley tributaries (PFMC 2012), the Central Valley Harvest Rate Index (i.e., catch/(catch+escapement) has been in excess of 60% in many years, suggesting year-to-year variations in ocean harvest may affect Tuolumne River escapement and subsequent population levels.

2.2.2 Water Quality

In addition to factors affecting instream flows in the San Joaquin River and Delta, anthropogenic inputs of nutrients, as well as accidental discharges of other contaminants may result in unsuitable water quality conditions for up-migrating salmon. However, other than potential avoidance of low DO conditions at Stockton discussed by Hallock et al. (1970) and Newcomb and Pierce (2010), no reports of upmigrant Chinook salmon mortality due to water quality in the Tuolumne River or lower San Joaquin River were identified. For this reason, water quality effects upon direct mortality during Chinook salmon upmigration is not considered further in this synthesis.

2.2.3 Water Temperature

Meteorology and to a minor degree, instream flows, combine to affect exposure of up-migrating adults to elevated water temperatures with varying probabilities of direct or delayed mortality (e.g., Marine 1992). However, low pre-spawn mortality levels in the neighboring Stanislaus River were documented in the range of 1–4% in carcass surveys conducted during 2004–2005 (Guignard 2006) and no evidence of pre-spawn mortality due to water temperature in the lower Tuolumne River has been identified to date. For this reason, water temperature effects upon direct mortality during Chinook salmon upmigration is not considered further in this synthesis.

2.2.4 In-River Harvest and Poaching

Historical inland harvest of Tuolumne origin salmon, primarily occurring in the Bay and Delta, as well as potential poaching in the San Joaquin River system has not been quantified, but potentially reduces the number of adults that successfully spawn, and in turn, affects subsequent juvenile production. CDFG implemented sport catch limits on salmon in the early 2000s within a portion of the Tuolumne River and salmon fishing is currently banned in the lower Tuolumne River and San Joaquin River upstream of the Delta (<http://www.dfg.ca.gov/regulations/>). Although the effects of in-river harvest do not contribute to direct mortality of Chinook salmon, the effects of illegal poaching upon Tuolumne River Chinook salmon remain unknown.

2.3 Processes/Mechanisms Affecting Indirect Mortality

2.3.1 Disease and Parasites

As examined in the current *Water Temperature Modeling Study* (Study W&AR-15), local meteorology and instream flows in the lower Tuolumne River are well related to instream water temperatures. In addition to the effects of water temperature upon disease incidence summarized by Myrick and Cech (2001), Wedemeyer (1974) summarizes general conditions contributing to stress and disease incidence resulting from exposure to adverse water quality conditions such as low dissolved oxygen. During upmigration through the Delta and lower San Joaquin River, elevated water temperatures and adverse water quality conditions, including low dissolved oxygen, high pH (alkalinity), and unionized ammonia may be contributing factors to potential disease incidence or parasite infestation. However, no reports of disease incidence were identified and because of the potential exposure time to adverse water temperature or water quality conditions during upmigration is short, disease and parasite effects upon Chinook salmon during upmigration are not considered further in this synthesis.

3.0 CHINOOK SALMON SPAWNING

As shown in Figure B-4, several processes and mechanisms may potentially affect spawning success of Chinook salmon arriving in the lower Tuolumne River. In addition to the numbers and timing of up-migrant adults arriving from the ocean which affects overall escapement (Figure B-5), competition and exclusion from accessing suitable spawning sites may occur depending upon, spawning area availability, spawning gravel quality, the presence of hatchery introduced salmon arriving from other river systems, as well as pre-spawn mortality due to water temperature.

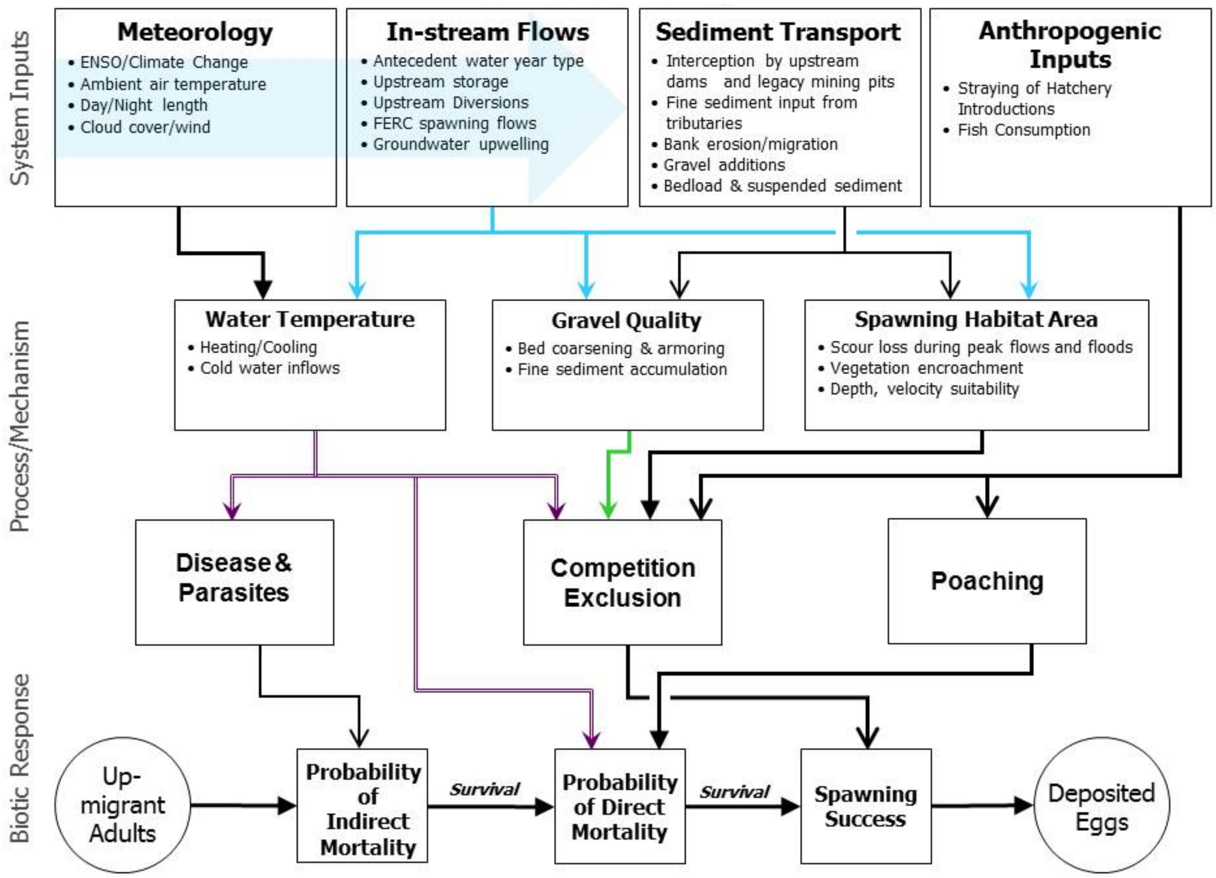

Figure B-4. Potential issues affecting fall-run Chinook salmon spawning in the lower Tuolumne River.

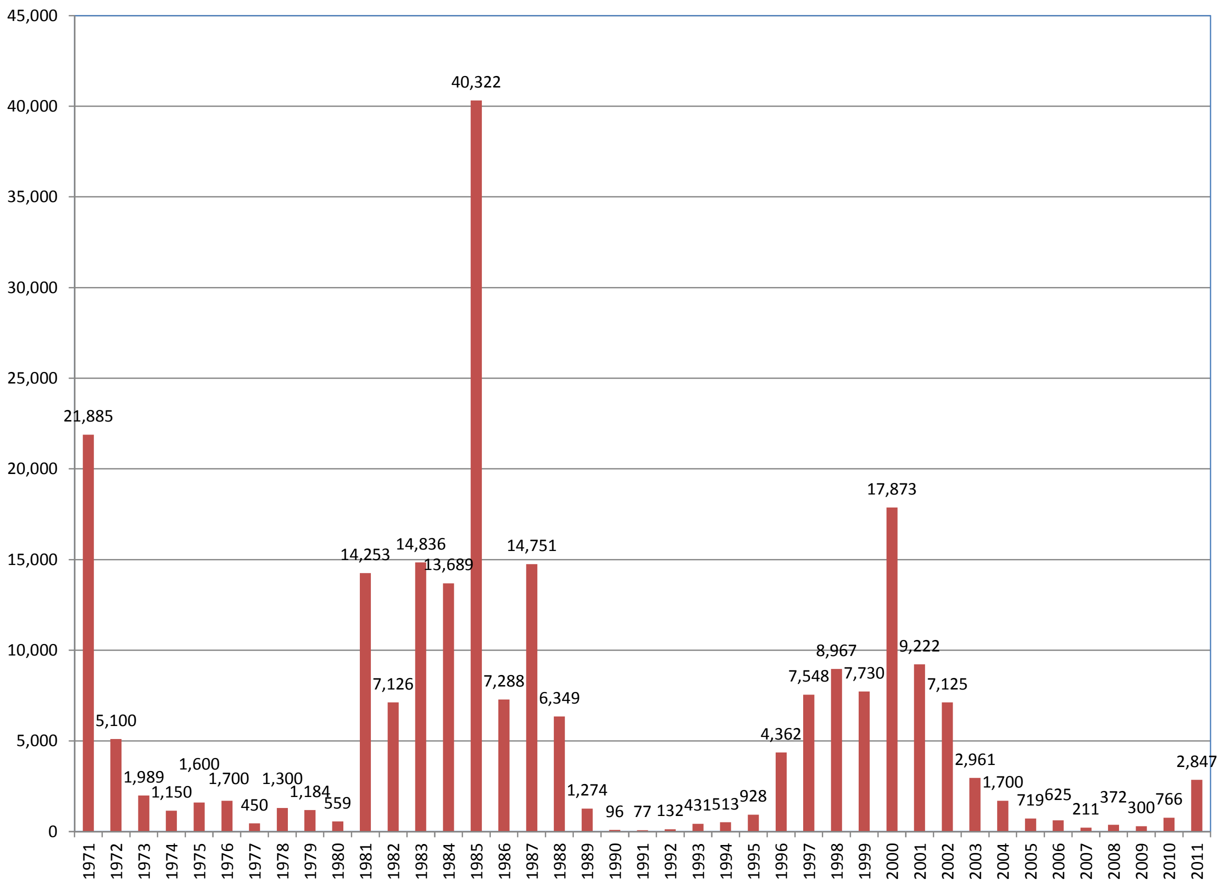

Figure B-5. **Tuolumne River Chinook salmon run estimates, 1971-2011 (Years 2009-2011 based on weir counts).**

3.1 Processes/Mechanisms Affecting Spawning Success

3.1.1 Effects of Spawning Habitat Availability

At the ecosystem level, Figure B-4 shows spawning habitat area availability in the lower Tuolumne River (RM 52–24) is affected by meteorological effects upon precipitation and flood flows, flows provided by the Project for spawning under the current FERC (1996) license, as well as long-term effects of upstream dams upon sediment supply and transport (McBain and Trush 2000, 2004). Changes in riffle area availability assessed by McBain and Trush (2004) as well as the current *Spawning Gravel Study* (W&AR-4) show lower gravel area within upstream riffles under current conditions than under historical conditions (TID/MID 1992, Appendix 8).

Annual CDFG spawning survey reports provide estimates of escapement as well as maximum redd counts by river-mile (e.g., TID/MID 2011, Report 2010-1) and generally show increased spawning activity at upstream riffles nearest La Grange Dam (RM 52). Multi-year comparisons of the relative preferences of upstream and downstream riffles used by spawning Chinook salmon has also been assessed in prior reports (TID/MID 1992, Appendix 6; TID/MID 2005a) and Table B-1 shows a long-term estimate of the proportion of redds from annual spawner surveys (1981–2009), separated by reaches used in the current *Spawning Gravel Study* (W&AR-4).

Table B-2. Long-term (1981–2009) spawning utilization estimated by annual distribution of Chinook salmon redd counts before and after the 1997 flood-scour event.

River Mile	Redd Observations from 1981–1996 Surveys	Redd Observations from 1997–2009 Surveys
RM 52.1–46.6	53 ± 12%	50 ± 11%
RM 46.6–40.3	22 ± 3%	23 ± 6%
RM 40.3–34.2	13 ± 4%	15 ± 5%
RM 34.2–24.0	10 ± 9%	9 ± 7%

Data Source: CDFG, La Grange CA.

Evidence of competition for suitable spawning areas was documented by tracking the periods of redd defense by females as well as evidence of redd superimposition during intensive redd mapping (n=385) conducted in 1988 and 1989 (TID/MID 1992, Appendix 6). In addition, using intensive foot surveys to calibrate the float survey methodology used in annual spawning surveys in 1999 and 2000, CDFG crews documented undercounting of redds on the order of 50% within heavily used upstream riffles (TID/MID 2000, Report 1999-1; TID/MID 2001, Report 2000-1). Taken together, these studies suggest that at high escapement levels, upstream spawner preferences may result in competition and exclusion of spawners from suitable spawning sites at locations nearest to La Grange Dam (RM 52.2). The effects of redd superimposition on egg incubation success are further discussed in Section 4.2.3.

3.1.2 Effects of Gravel Quality, Hydraulic Conditions, and Water Temperature

Gravel quality, hydraulic conditions, and water temperature may affect the suitability and use of available riffle habitat area (e.g., Reiser and Bjornn 1979) and several Tuolumne River studies examine the influence of these factors upon Chinook salmon spawning success. Although extensive gravel quality investigations have been previously conducted (TID/MID 1992, Appendices 6–8, 11; TID/MID 1997, Reports 96-6 through 96-8; TID/MID 2001, Report 2000-7, McBain and Trush 2004) gravel ripping experiments to improve gravel quality did not result in increased spawning activity (TID/MID 1992, Appendix 11). Because Chinook salmon are able to spawn in a wide range of gravel sizes, water depths, and velocities, river-wide variations in these parameters are unlikely to affect spawning success and long term population levels. Using estimates of weighted usable area (WUA) from Physical Habitat Simulation (PHABSIM) modeling of these parameters, the ongoing Instream Flow Incremental Methodology (IFIM) study (Stillwater Sciences 2009) will assess river-wide distribution of suitable spawning habitat, including the influence of water temperature. The current *Spawning Gravel Study* (W&AR-4) as well as the *Redd Mapping Study* (W&AR-8) will provide more up-to-date information on spawning habitat area availability in the lower Tuolumne River.

3.1.3 Effects of Hatchery Straying

No Tuolumne-specific data has been identified to directly assess effects of competition for suitable spawning sites between wild and introduced hatchery fish. Hatchery origin fish contribute disproportionately to the salmon runs of the Central Valley (Barnett-Johnson et al. 2007, Johnson et al. 2011) and adipose-fin clipped fish from hatcheries have been found at high levels in Tuolumne River carcass surveys in recent years (TID/MID 2005a; Mesick 2009; TID/MID 2012, Report 2011-8). Although the role of hatchery supplementation on the spawning success of wild and hatchery-reared stocks has not been well studied in the Tuolumne or in other Central Valley rivers, salmon returning to hatcheries studied in the Pacific Northwest have been shown to return both smaller and with earlier run timing than their wild counter-parts (Flagg et al. 2000). However, fish size at return does not appear to have decreased for the period 1981–2010 (e.g., TID/MID 2011, Report 2010-2) suggesting any hatchery influences on Tuolumne River spawner fecundity may be minor.

3.2 Processes/Mechanisms Affecting Direct Mortality

3.2.1 Water Temperature

Variations in meteorology and instream flows combine to affect exposure of spawning adults to elevated water temperatures with varying probabilities of direct or delayed mortality (e.g., Marine 1992). However, low pre-spawn mortality levels in the neighboring Stanislaus River were documented in the range of 1–4% in carcass surveys conducted during 2004–2005 (Guignard 2006) and no evidence of pre-spawn mortality due to water temperature in the lower Tuolumne River has been identified to date. For this reason, water temperature effects upon direct mortality during Chinook salmon spawning are not considered further in this synthesis.

3.2.2 In-river Harvest/Poaching

Inland harvest of Chinook salmon, as well as potential poaching in the San Joaquin and lower Tuolumne rivers has not been quantified, but potentially reduces the number of adults that successfully spawn, and in turn, affects subsequent juvenile production. CDFG implemented sport catch limits on salmon in the early 2000s within a portion of the Tuolumne River and salmon fishing is currently banned in the lower Tuolumne River and San Joaquin River upstream of the Delta (http://www.dfg.ca.gov/regulations/). Although the effects of in-river harvest do not contribute to direct mortality of Chinook salmon, the effects of illegal poaching upon Tuolumne River Chinook salmon remain unknown.

3.3 Processes/Mechanisms Affecting Indirect Mortality

3.3.1 Disease and Parasites

As examined in the current *Water Temperature Modeling Study* (Study W&AR-15), local meteorology and instream flows in the lower Tuolumne River are well related to instream water temperatures and exposure to elevated water temperature, which may contribute to stress and disease incidence in some fish (Myrick and Cech 2001, Holt et al. 1975, Wood 1979). However, no information was identified to address potential disease incidence in upmigrant or spawning Chinook adults in the Tuolumne or other San Joaquin River tributaries. Because of the low rates of pre-spawn mortality found in the nearby Stanislaus River (Guignard 2006) and low exposure time to potentially adverse water quality conditions in the lower San Joaquin and Tuolumne rivers during upmigration, disease and parasite effects upon indirect mortality of Chinook salmon during spawning is not considered further in this synthesis.

4.0 EGG/ALEVIN GROWTH AND FRY EMERGENCE

As shown in Figure B-6, several processes and mechanisms may potentially affect egg incubation and fry emergence of Chinook salmon in the lower Tuolumne River, including meteorological and instream flow effects upon sediment transport, gravel quality, water quality, water temperature, as well as the influence of stray hatchery fish from other systems. Although egg predation by steelhead has been documented on the Mokelumne River (Merz 2002), population level effects of egg mortality due to predation are considered minor and not considered further in this synthesis.

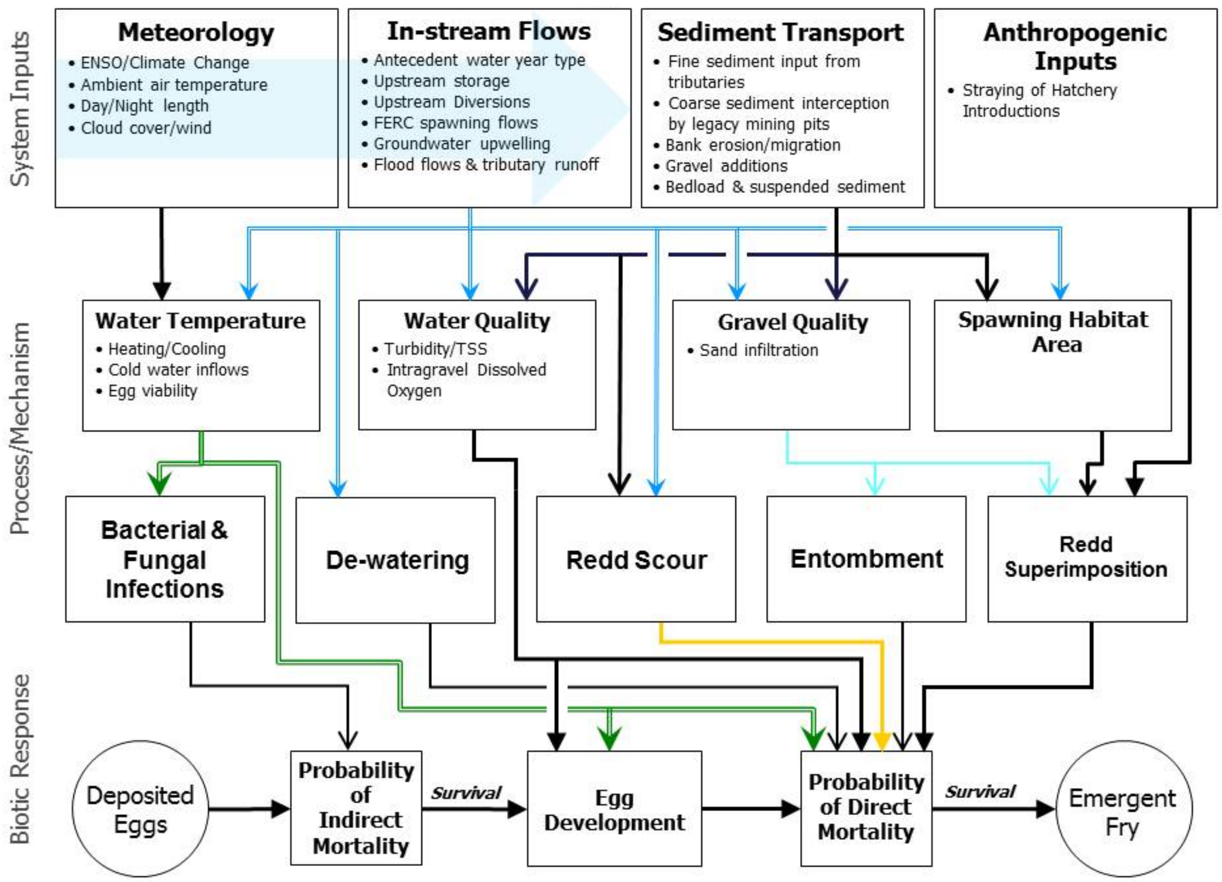

Figure B-6. Potential issues affecting fall-run Chinook salmon egg incubation, alevin development, and fry emergence in the lower Tuolumne River.

4.1 Processes/Mechanisms Affecting Egg/Alevin Growth and Fry Emergence

4.1.1 Water Temperature

Because water temperature has a direct effect on the timing of Chinook salmon embryo development (e.g., Beacham and Murray 1990, Murray and McPhail 1988; Myrick and Cech 2001), ecosystem level effects upon water temperature such as alterations in instream flows as well as inter-annual and decadal changes in climate and meteorology may affect Chinook salmon production (See Section 5.1 of the synthesis). Water temperature degree-day models have been used to successfully predict emergence timing of Chinook salmon fry (TID/MID 2007, Report 2006-7) and has been used in the formulation of a prior population model of the lower Tuolumne River (e.g., Jager and Rose 2003).

4.1.2 Water Quality

As with water temperature discussed above, successful Chinook salmon embryo and alevin development and emergence is dependent upon suitable water quality conditions, such as intragravel dissolved oxygen concentrations. Water column dissolved oxygen levels are generally at or near saturation in the Tuolumne River, as measured downstream of Don Pedro and La Grange Dams as part of the current *Water Quality Assessment Study* (W&AR-1) as well in prior water quality assessments at other times of year (TID/MID 2005b, Report 2004-10). Intragravel dissolved oxygen conditions measured in artificial redds on the Tuolumne River as part of a 2001 survival-to-emergence study found intragravel DO in the range of 7–12 mg/L (TID/MID 2007, Report 2006-7).

4.2 Processes/Mechanisms Affecting Direct Mortality

4.2.1 Water Temperature

Meteorology and instream flows may combine to affect exposure of deposited eggs to varying water temperatures, potentially reducing egg viability within upmigrant females, as well as reduced egg survival to emergence. Although no studies were identified examining reduced egg viability due to antecedent water temperatures in the Tuolumne River or other San Joaquin River tributaries, antecedent exposure of upmigrant adults upon egg viability has been attributed to reduced egg viability in broader studies (e.g., Mann and Peery 2005, Jensen et al. 2006). Myrick and Cech (2001) provide no data, but use general assessments of regional water temperatures to suggest that fall-run Chinook salmon eggs incubating between October and March are less likely to encounter unsuitable water temperatures except for early spawning fish during early October in some San Joaquin River tributaries. High intragravel water temperatures were suggested as a potential mortality factor in a 1988 survival-to-emergence study (TID/MID 1992, Appendix 8). Subsequent intragravel water temperature monitoring during February and March 1991 was conducted at several locations in the lower Tuolumne River generally fluctuating between 11–15°C (51–58°F), with lower daily maxima than water column recorders (TID/MID 1997, Report 96-11). During the 2001 survival-to-emergence study (TID/MID 2007, Rpt. 2006-7) intragravel water temperatures in constructed redds were shown to fluctuate in response to flow and air temperature, but remained cool and within the optimal range for salmonid egg incubation and alevin development (4° to 12°C [39.2° to 53.6°F]) provided by Myrick and Cech (2001). For this reason, it is unlikely that intragravel water temperature conditions contribute to high rates of egg mortality of Chinook salmon on the Tuolumne River.

4.2.2 Gravel Quality Effects on Intragravel Water Quality

Variations in instream flows, water temperatures, as well as sediment transport may affect hyporheic water quality conditions such as intragravel dissolved oxygen and turbidity (e.g., Healey 1991, Williams 2006). For example, fine sediment in spawning gravel can reduce substrate permeability impede intragravel flow and thus hinder dissolved oxygen delivery as well as waste removal, which are crucial for survival of eggs and alevins (Coble 1961, Cooper 1965, Silver et al. 1963, Carter 2005). In 1987 and 1988, the Districts assessed the effects of fine sediment and sand on survival-to-emergence of fall Chinook salmon in the Tuolumne River. This assessment used two approaches: 1) predicting survival-to-emergence based on substrate composition using the model developed by Tappel and Bjornn (1983), and 2) documenting actual survival-to-emergence by trapping fry emerging from natural redds (TID/MID 1992; Appendix 8). Mean survival predicted by the Tappel-Bjornn survival-to-emergence model (which is based on substrate composition) for the riffles sampled in 1987 was 15.7 percent. Predicted mean survival from redds sampled in 1988 was 34.1 percent and survival-to-emergence documented by emergence trapping varied from one percent in 1988 to 32 percent in 1989. In addition to follow-up investigations of spawning gravel permeability (TID/MID 2001, Report 2000-7), a follow-up study was conducted during a 2001 survival-to-emergence study (TID/MID 2007, Rpt. 2006-7) which demonstrated a highly significant relationship between survival-to-emergence of Chinook salmon eggs and in-situ gravel permeability as well as a highly significant relationship between survival and intragravel flow. The delivery rate of dissolved oxygen, which affects egg survival, is a function of DO concentration and intragravel water flow. Intragravel dissolved oxygen was found to be in suitable on the Tuolumne River (7–12 mg/L) (TID/MID 2007, Report 2006-7) as well as on the nearby Stanislaus River (8–11 mg/L) (Mesick 2002). Based upon the results of the studies reviewed, although local sources of fine sediment introduced into the lower Tuolumne River may have potential impacts on egg incubation (see entombment below), gravel quality and water quality conditions on the lower Tuolumne River are not likely to be associated with high rates of egg mortality of Chinook salmon on the Tuolumne River.

4.2.3 Redd Superimposition

Egg displacement due to redd superimposition resulting from competition and exclusion of adult spawners and anthropogenically introduced hatchery fish may result in density-dependent mortality of previously deposited eggs that have been disturbed by the spawning activities of subsequently arriving females. Because of increased spawner preferences at locations nearest La Grange Dam in the Tuolumne River (Table 5-4), the effects of reduced instream flows and gravel supplies attributed to upstream dams (McBain and Trush 2000, 2004), may limit the availability of suitable spawning habitat and result in redd superimposition mortality effects upon Chinook salmon eggs.

The Districts have conducted a range of studies, examining potential egg mortality due to redd superimposition (TID/MID 1992, Appendices 6 and 7; TID/MID 1997, Report 96-7) as well as survival-to-emergence as a function of gravel quality in several studies (TID/MID 1992, Appendix 8; Report 2000-6; TID/MID 2007, Report 2006-7). On the nearby Mokelumne River, redd superimposition has been documented at rates on the order of 10% in most years of spawning surveys conducted since 1971 (Del Real and Rible 2009) and the Districts undertook intensive redd surveys during 1988 and 1989 to document rates of superimposition at 5–6 study riffles (TID/MID 1992, Appendix 6) as well as provide egg mortality estimates (TID/MID 1992, Appendix 7). These surveys documented redd superimposition at relatively low escapement levels (6,300 adults in 1988 and 1,300 adults in 1989) (TID/MID 1992, Volume 2) and the ongoing *Redd Mapping Study* (W&AR-8) will provide up-to-date data during 2012–2013 showing any evidence of redd superimposition at current spawning levels. The Districts previously used this data in the development of a redd superimposition model (TID/MID 1997, Report 96-6) and the formulation of stock production relationships for existing life-cycle population models (TID/MID 1992, Appendix 2; TID/MID 1997, Report 96-5). These studies suggest that redd superimposition has the potential to increase density dependent egg mortality at moderately high escapement levels, resulting in a net reduction of successfully emigrating smolts because later emerging fry contribute to a later fry or smolt emigration timing when water temperature conditions in the lower reaches of the Tuolumne River, San Joaquin River and Delta may have deteriorated.

Although the role of hatchery supplementation on redd superimposition has not been studied in the Central Valley, the body size of many salmonid stocks has been declining due to selective pressures, including hatchery practices, declining ocean productivity, density dependent effects of large hatchery releases, or a combination of any of these factors (e.g., Weitkamp et al. 1995). Flagg et al. (2000) suggested that since nest depth was strongly correlated with female size, eggs from smaller females under current conditions may be at increased risk from redd scour and redd superimposition by later arriving spawners.

4.2.4 Redd Scour

Redd scour from increased rates of sediment (bedload) transport during high flow events may result in displacement of eggs and alevin and may cause direct mortality due to mechanical shock, crushing or entrainment into the bedload. McBain and Trush (2000) suggest that habitat simplification and flow regulation by upstream dams on the lower Tuolumne River may result in increased vulnerability of redds to scour during flood events. However, despite losses in available riffle habitat within the primary spawning reach (RM 52.0–36.5) following the large 1997 flood event which saw peak flows near 60,000 cfs, subsequent escapement levels of the 1997 outmigration year were relatively large from 1999–2001 (Figure B-5), suggesting only moderate levels of redd scour may occur even under extreme flood events. Lapointe et al. (2000) reviewed several gravel transport studies to show that the thickness of the mobilized layer during flood-scour events is often less than the depth of normal egg pockets. For this reason, although redd scour may occur at some locations during flood conditions, redd scour is not considered to contribute to high rates of direct mortality and is not considered further in this synthesis.

4.2.5 Redd Dewatering

Redd dewatering can impair development and also cause direct mortality of salmonid eggs and alevins as a result of desiccation, insufficient oxygen, and thermal stress (Becker and Neitzel 1985). Although the current FERC spawning flow requirements are designed to protect against redd-dewatering[1], a dewatering incident of isolated redds found in the La Grange powerhouse tail-race by CDFG biologists occurred during 2008 (TID/MID 2010, Report 2009-1). Williams (2006) discusses the implications of varying reservoir releases necessary to maintain flood storage space during periods of salmonid spawning on other Central Valley Rivers, but no other incidences of redd stranding or dewatering have been documented on the lower Tuolumne River. For this reason, isolated redd dewatering incidents may potentially occur during unplanned operational outages. However, because of the low frequency of occurrence of these events, redd dewatering is not considered to contribute to high rates of direct mortality and is not considered further in this synthesis.

4.2.6 Entombment

Fine sediment from mobilized deposits may potentially result in entombment of completed redds by effectively sealing the upper layers of redds and obstruct the emergence of alevins, causing subsequent mortality. Phillips et al. (1975) and Mesick (2002) identified entombed alevins in several super-imposed redds during monitoring associated with gravel augmentation projects on the nearby Stanislaus River. Fine sediment intrusion in the Tuolumne River Chinook salmon redds has been suggested as a risk factor in successful survival to emergence (TID/MID 2001, Report 2000-7). However, excavations of artificial redds with high proportions of sand to gravel mixtures did not identify entombed alevins (TID/MID 2007, Report 2006-7) and prior redd excavations of redd superimposition studies also did not identify any entombed alevins (TID/MID 1992, Appendix 7). Gasburg, Peaslee, and Dominici Creeks provide a continuing source of fine sediments to the lower Tuolumne River (McBain and Trush 2004, Appendix E). However, because no Chinook salmon alevin entombment has been reported on the Tuolumne River and a sedimentation basin was completed in 2007 to intercept fine sediments arriving from the Gasburg Creek watershed, entombment of alevins is not considered to be a primary source of direct mortality for Chinook salmon.

4.3 Processes/Mechanisms Affecting Indirect Mortality

4.3.1 Bacterial and Fungal Infections

Although no information is available on disease incidence for incubating eggs in the Tuolumne River, bacterial presence and growth on Chinook salmon eggs has been suggested by Sauter et al. (1987) as an important causative factor in the mortality of Chinook salmon. Egg infection and subsequent diseases incidence in juvenile and adult salmonids is generally only been raised as an issue of concern in intensive fish culture practices at hatcheries (e.g., Scholz 1999). Further,

[1] Under Article 38 of the current FERC (1996) license, reductions in spawning flows below the applicable flow schedule are prohibited, and additional spawning base flows are provided to prevent dewatering based upon a 45-day averaging period established between October 15th and December 31st of each year.

because diseases incidence on incubating eggs in the wild has not been observed in the Tuolumne River or other Central Valley Rivers, bacterial and fungal infections of eggs and alevins is not expected to contribute to indirect mortality and is not considered further in this synthesis.

5.0 IN-RIVER REARING/OUTMIGRATION

As shown in Figure B-7, several processes and mechanisms may potentially affect growth, survival and smoltification of juvenile Chinook salmon in the Tuolumne River, including meteorological and instream flow effects on sediment transport, in-channel habitat availability, water temperature, water quality, food availability, as well as predation by native and introduced species.

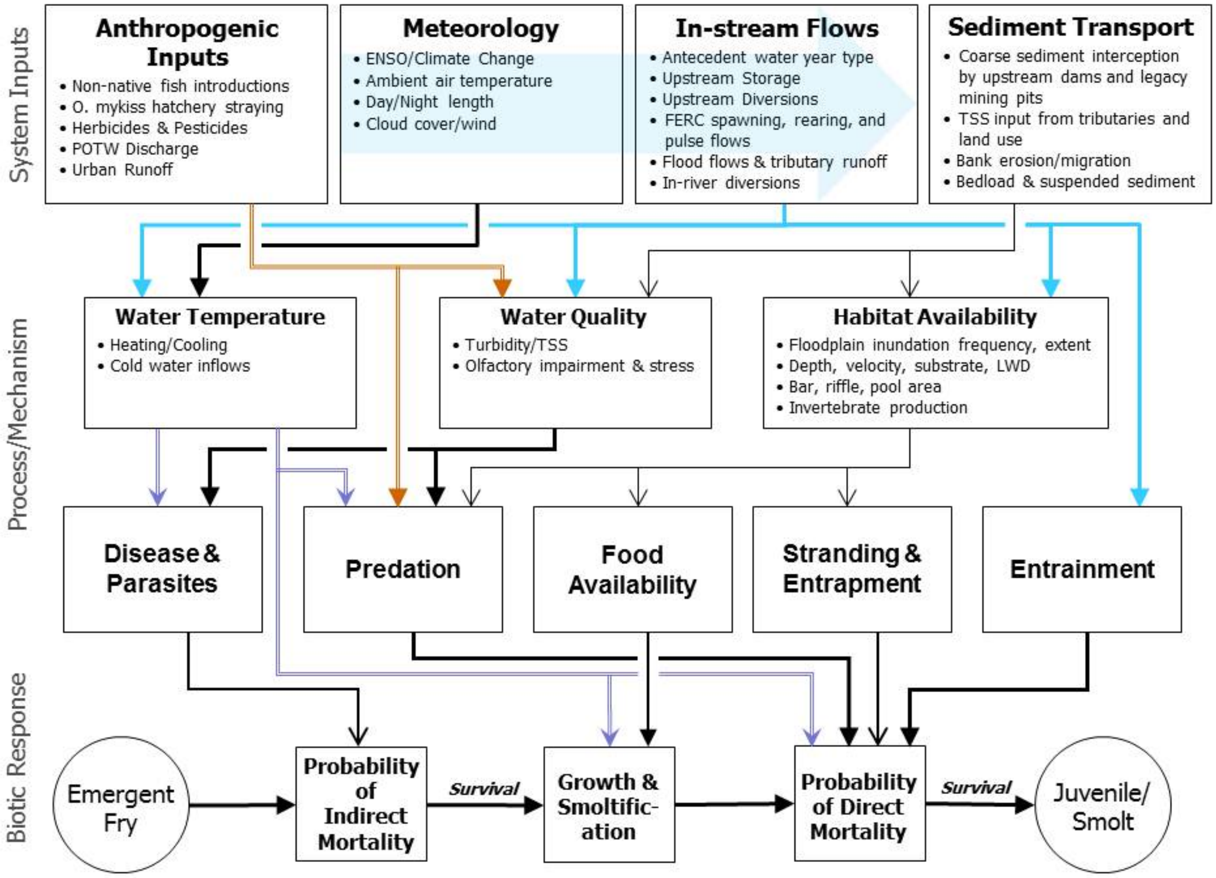

Figure B-7. Potential issues affecting in-river rearing and smolt emigration of fall-run Chinook salmon from the lower Tuolumne River.

5.1 Processes/Mechanisms Affecting Juvenile Growth and Smoltification

5.1.1 In-channel and Floodplain Habitat Availability

Although no studies have directly mapped the amounts of suitable juvenile rearing habitat for Chinook salmon in the Tuolumne River, salmon fry generally occupy low-velocity, shallow areas near stream margins (Lister and Genoe 1970, Everest and Chapman 1972). Habitat conditions at particular locations (e.g., depth, velocity, distance to cover, etc.) change with river discharge as well as water temperature and McBain and Trush (2000) suggested that rearing habitat is generally associated with an alternate bar (pool-riffle) morphology that historically occurred along the length of the lower Tuolumne River. McBain and Trush (2000) summarize changes in the amounts of these habitats as well as the cumulative effects of contributing factors upon salmonid rearing conditions, primarily related to reduced areas of stream margin habitats with suitable depth/velocity profiles (See Section 5.1 of the synthesis). At lower flows in the range of the current FERC (1996) flow schedule, optimum juvenile rearing conditions on the lower Tuolumne River were found to occur at flows in the range of 100–200 cfs in two prior PHABSIM studies (TID/MID 1992, Appendices 4 and 5). The ongoing IFIM study (Stillwater Sciences 2009a) is expected to provide more up-to-date results to establish the relationship between in-channel rearing habitat and flow, including the effect of water temperature.

At river flows near bankfull discharge and above, two-dimensional (2D) hydraulic modeling was conducted in 2011 for a range of flows (1,000–5,000 cfs) at three sites in the lower Tuolumne River (RM 48.5, RM 48.0, and RM 44.5) to provide estimates of suitable salmonid rearing habitat area (Stillwater Sciences 2012b). The results of the study show increased flows are associated with increased areas of suitable juvenile rearing habitat at the study sites as flows increase above bankfull discharge, with habitat area rapidly increasing between discharges of 1,000 cfs to 3,000 cfs. It should be noted that although some overbank habitat is available for the full length of the lower Tuolumne River and the majority of floodplain habitat available at the flows studied (1,000 cfs to 5,000 cfs) is limited to several disturbed areas between RM 51.5 and RM 42 formerly overlain by dredger tailings.

Direct habitat mapping following restoration of floodplain habitat connectivity at the 7/11 Restoration Project (RM 40.3–37.7) as well as 2D modeling conducted at the SRP 9 restoration project (~RM 25.7) showed increases in suitable juvenile rearing habitat occurred at flows in excess of 1,000 cfs (TID/MID 2007, Report 2006-7). Direct sampling of juvenile habitat use has been conducted at two downstream floodplain restoration sites constructed by levee breaching, including the Big Bend Floodplain Restoration Project (RM 6.6–5.7) and the Grayson River Ranch Restoration Project (RM 5.1–3.9). At high flows ranging from 4,000–6,000 cfs occurring in the spring of 2005, juvenile salmonids were generally found at in-channel locations but only low numbers were found using the inundated floodplain habitat at the Big Bend (Stillwater Sciences 2008b) and Grayson River Ranch sites (Fuller and Simpson 2005). Stillwater Sciences (2012b) hypothesized that the restored sites lacked connectivity between the channel margin and floodplain surfaces at these sites, which were generally inundated as a backwater effect through the levee breaches included in the project designs.

Mesick and Marston (2007) previously showed that a poor correlation between smolt passage in RSTs and antecedent escapement (1998–2003) for the Stanislaus and suggested that juvenile rearing habitat may become saturated at spawner returns in excess of 500 fish in both the Stanislaus and Tuolumne Rivers. This is not well supported in long-term monitoring data collected by the Districts and provided in annual FERC reports. Although beach seines are generally unsuitable for assessing absolute juvenile production and only low numbers of smolt-sized juveniles are captured in near-shore seine sampling (e.g., TID/MID 2102, Report 2011-3) due to habitat preferences for deeper water (Lister and Genoe 1970, Everest and Chapman 1972), long term variations in peak fry density (Figure B-8) as well as average juvenile density by survey across all seine locations (Figure B-9) generally increase in winter/spring sampling following years with high spawner returns. Further, in years with moderately high escapements that could be potentially expected to result in rearing habitat limitation (1997–2003), downstream fry dispersal generally occurred earlier in years with winter-spring flood control releases (e.g., TID/MID 1999, Report 98-2; TID/MID 2000, Report 99-4; TID/MID 2001, Report 2000-3) than in years with lower flows (e.g., TID/MID 2002, Report 2001-3; TID/MID 2003, Report 2002-3; TID/MID 2004, Report 2003-2).

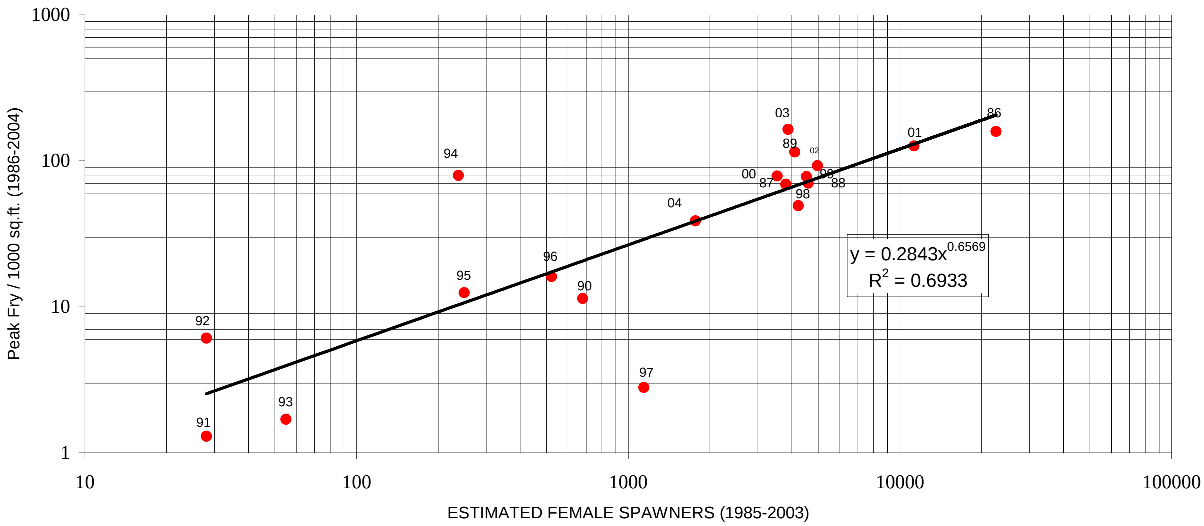

Figure B-8. **Relationship between peak salmon fry density in annual biweekly seine surveys and estimates of female spawners (1985–2003).**

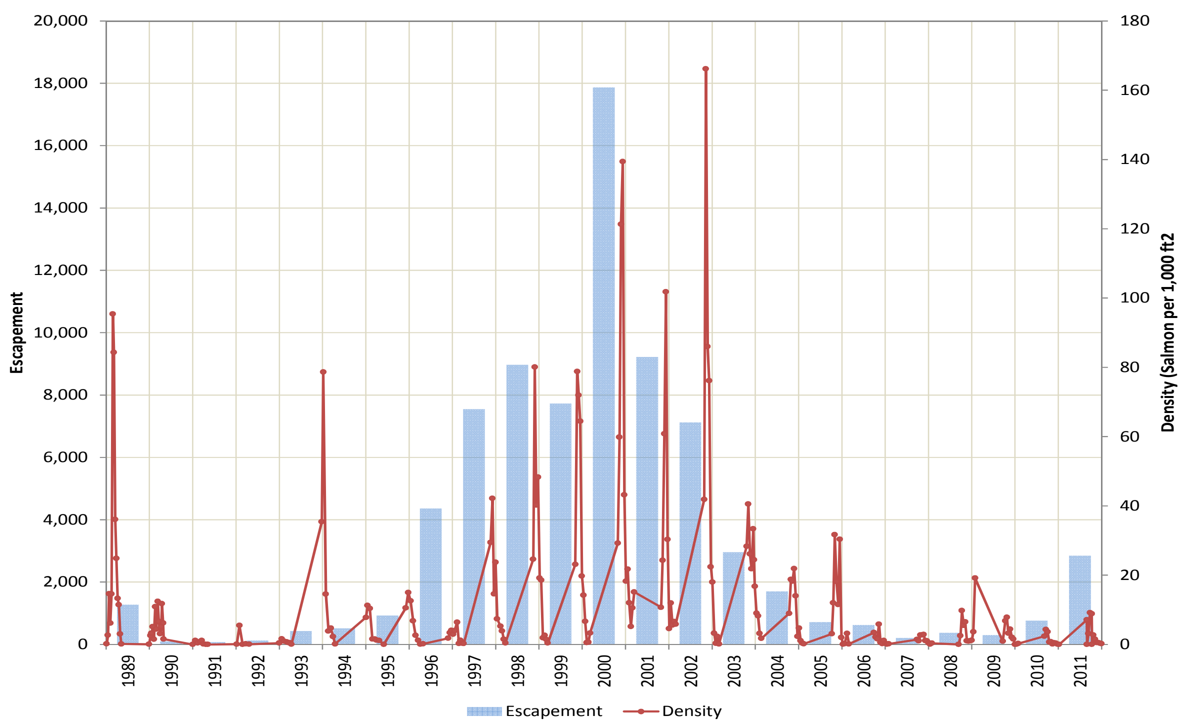

Figure B-9. **Average juvenile salmon density in all seine hauls by survey with estimated escapement (1989–2011).**

Beyond the association of higher juvenile rearing density with prior spawner abundance (Figure B-9) and increases in juvenile production estimated from RST passage during Above Normal and Wet water year types (Table B-3), additional factors affecting juvenile Chinook salmon growth and production are discussed below.

Table B-3. Estimated rotary screw trap passage of juvenile Chinook salmon by water year and type at Waterford and Shiloh/Grayson (1995–2011).

Water Year and (Type)[1]	Sampling Period	Fry (<50 mm)		Parr (50-69 mm)		Smolt (≥ 70 mm)		Total
		Est. Passage	%	Est. Passage	%	Est. Passage	%	
Upstream RST operated at Waterford (RM 29.8)								
2006 (W)	winter-spring	163,805	54.0	6,550	2.2	133,127	43.9	303,482
2007 (C)	winter-spring	20,633	35.7	7,614	13.2	29,554	51.1	57,801
2008 (C)	winter-spring	15,259	61.3	1,102	4.4	8,534	34.3	24,894
2009 (BN)	winter-spring	13,399	36.0	4,562	12.3	19,213	51.7	37,174
2010 (AN) [2]	winter-spring	10,735	25.9	1,030	2.5	29,728	71.6	41,493
2011 (W) [2]	winter-spring	400,478	95.1	4,884	1.2	15,608	3.7	420,971
Downstream RST operated at Shiloh Rd. (RM 3.5) and Grayson (RM 5.2)								
1995 (W)	spring only[3]	--	--	--	--	22,067	100	22,067
1996 (W)	spring only[3]	--	--	--	--	16,533	100	16,533
1997 (W)	spring only[3]	--	--	--	--	1,280	100	1,280
1998 (W)	winter-spring	1,196,625	74.1	327,422	20.3	91,626	5.7	1,615,673
1999 (AN)	winter-spring	830,064	95.4	14,379	1.7	25,193	2.9	869,636
2000 (AN)	winter-spring	55,309	51.4	21,396	19.9	30,912	28.7	107,617
2001 (D)	winter-spring	65,845	61.8	26,620	25.0	14,115	13.2	106,580
2002 (D)	winter-spring	75	0.5	5,705	41.0	8,147	58.5	13,928
2003 (BN)	spring only[3]	26	0.3	128	1.4	8,920	98.3	9,074
2004 (D)	spring only[3]	155	0.9	727	4.1	16,718	95.0	17,600
2005 (W)	spring only[3]	--	--	442	0.2	254,539	99.8	254,981
2006 (W)	winter-spring	35,204	19.4	17,550	9.7	128,937	71.0	181,691
2007 (C)	spring only[3]	--	--	--	--	905	100	905
2008 (C)	winter-spring	981	29.9	15	0.5	2,291	69.7	3,287
2009 (BN)	winter-spring	139	3.0	162	3.5	4,047	88.0	4,598
2010 (AN)	winter-spring	173	4.1	0	0	4,060	95.9	4,060
2011 (W)	winter-spring	45,781	52.5	1,654	1.9	39,737	45.6	87,172

1 DWR Bulletin 120 Water Year Types for the San Joaquin River basin (C=Critical, D=Dry, BN=Below Normal, AN=Above Normal, W=Wet).
2 For 2010 and 2011, the estimated passage values used in this table for Waterford (RM 29.8) are the median values of the estimated range.
3 Because only partial season sampling occurred in some years (1995–1997, 2003–2005, 2007), passage estimates may not be suitable for estimating juvenile production.

5.1.2 Water Temperature Effects on Growth and Smoltification

As shown in Figure B-7, suitable water temperatures are required for growth and subsequent smoltification of juvenile Chinook salmon. Like other salmonids, juvenile growth rates of Chinook salmon increase with increasing temperature up to an optimal temperature that maximizes the fish's efficiency in converting food into tissue (Reiser and Bjornn 1979). As temperatures rise above the optimum levels, growth may slow or cease because fish cannot eat or metabolize enough calories to meet their increased energy demands. Although no Tuolumne specific data are available to assess growth rates as a function of water temperature, Williams (2006) reports upon three studies that have evaluated temperature vs. growth relationships in Central Valley Chinook salmon (Rich 1987; Marine 1997, Marine and Cech 2004, Cech and Myrick 1999) as well as growth ration models in theses by Stauffer (1973) and McLean (1979). As reported by Williams (2006) most early estimates of the growth of juvenile Chinook salmon in the Central Valley were developed from the size distributions from sequential field observations rather than from otolith studies (e.g., Limm and Marchetti 2009). In the Tuolumne River, growth rate estimated from sequential measurements of maximum fork length in multiple seine surveys typically range from 0.5–0.8 mm/day with a long-term (1986–2011) average of 0.6 mm/day (TID/MID 2012, Report 2011-4), within the range reported by Williams (2006).

For larger juveniles, depending on growth rates and water temperatures, the parr-smolt transformation, or smoltification process, involves changes in behavior and physiology of juvenile anadromous salmonids to prepare for survival in the brackish portions of the Bay and Delta as well as the open ocean. Although growth rates of juvenile Chinook salmon may be high at temperatures approaching 19°C (66°F), cooler temperatures may be required for Chinook to successfully complete the physiological transformation from parr to smolt. In addition to body size and growth rates, water temperature, photoperiod, lunar phasing, and other environmental cues are associated with the onset of smoltification (Clarke and Hirano 1995, Wedemeyer et al. 1980). Smoltification in juvenile Sacramento River fall-run Chinook was studied by Marine (1997, as cited in Myrick and Cech 2001), who found that juveniles reared under a high temperature regime of 21–24°C (70–75°F) exhibited altered and impaired smoltification patterns relative to those reared at low 13–16°C (55–61°F) and moderate 17–20°C (63–68°F) temperatures. In the Tuolumne River, as well as other San Joaquin River tributaries, smoltification begins during April and May (Rich and Loudermilk 1991) with smolts entering San Francisco Bay in May and June (MacFarlane and Norton 2002). Smolt-sized fish are captured at the lower RST at Grayson River Ranch from April to mid-June in most years (e.g., TID/MID 2012, Report 2011-4). Depending upon water year type and fry emergence timing, suitable temperature conditions for smoltification may be limited to upstream locations in the Tuolumne River by late spring. Routine RST monitoring indicates a drop in passage of smolt-sized Chinook salmon extending into June during years with flood control releases such as 2011 (TID/MID 2012, Report 2011-4), with shorter emigration periods ending by late May in years when no flood control releases occurred (e.g., TID/MID 2010, Report 2009-4).

5.1.3 Food Availability

Food availability and growth rates of juvenile Chinook salmon are affected by allochthonous sources of organic matter (e.g., leaf litter, LWD decomposition, soil runoff) as well as autochthonous sources (e.g., algae and diatoms) that provide the base of the aquatic food web. The availability of these particulate organic matter sources and the physical habitat availability for benthic macroinvertebrates (BMI) and invertebrate drift are in turn affected by instream flows and factors contributing to alterations in sediment transport processes. Evaluation of the food resources available and assessment of whether the food supply is limiting requires sampling of invertebrates in both the rearing habitat (benthic and drift samples) and in the diet of the fish (stomach samples). Using juvenile Chinook salmon collected during 1983–1987, gastric irrigation was conducted and stomach contents analyzed to examine prey items and to provide a daily ration estimates for the Tuolumne River (TID/MID 1992, Appendix 16). This assessment concluded that food supplies for juvenile salmon were more than adequate to support the population. Overall Chinook salmon diet composition was found to be similar to studies on the Mokelumne and American Rivers and calculated metrics suggested no food limitation for Chinook salmon. Longer term monitoring of BMI (TID/MID 1997, Report 1996-4; TID/MID 2003, Report 2002-8; TID/MID 2005, Report 2004-9; TID/MID 2009, Report 2008-7) has shown consistent densities of primary salmonid prey organisms and metrics suggestive of ecosystem "health" and adequate food supply. Although Mesick (2009) suggested that in-river food availability was insufficient to support high levels of fry and juvenile production, the high lipid content in Tuolumne River Chinook salmon smolts sampled in 2001 by Nichols and Foott (2002) suggest adequate food resources for rearing and smoltification of Chinook salmon. Further, the winter and spring flows occurring in 2001 were not sufficient to provide extended periods of floodplain inundation and were also accompanied by moderate levels of juvenile production, presumably relying upon in-river food supplies exclusively. Based upon available information, food availability is not likely to limit juvenile Chinook salmon rearing success in the lower Tuolumne River and is not considered further in this synthesis.

5.2 Processes/Mechanisms Affecting Direct Mortality

Predation and elevated water temperature are considered to be the primary mortality factors explaining reduced levels of juvenile production from the Tuolumne River in some years, with low levels of mortality potentially associated with stranding and entrainment. Predation is influenced by the abundance and distribution of native and introduced species, changes in habitat that affect predator distribution, flow and water temperature effects on predation rate, and the effects of water temperature and water quality on the ability of salmon to avoid predators.

5.2.1 Water Temperature

Meteorology and to a minor degree instream flows combine to affect exposure of rearing juvenile Chinook salmon to changes in water temperatures, with varying probabilities of direct mortality. Since 1988, the Districts have conducted model predictions of water temperature with flow (TID/MID 1992, Appendices 18–19; Stillwater Sciences 2011) and the current *Lower Tuolumne River Temperature Model Study* (W&AR-16) provides current estimates of the relationships between flow and water temperature. The Districts have also documented river-wide distribution of Chinook salmon, native and non-native fish distribution with water temperatures in surveys during spring, summer and fall in various years (TID/MID 1992, Appendix 27; TID/MID 1997, Report 96-3). The effects of water temperature on fry and juvenile salmon were directly assessed based on sampling (using seine hauls) in areas of potentially high temperature, analysis of data from several thermograph stations in the Tuolumne River and the San Joaquin River near the Tuolumne River confluence, and literature review (TID/MID 1992, Appendices 17, 19, and 21). Although temperatures in the San Joaquin River during Chinook salmon outmigration were relatively high and transiently exceeded the probable upper incipient lethal temperature, salmon captured in these higher temperature areas exhibited no signs of acute stress. In a water temperature review by Myrick and Cech (2001), juvenile Chinook salmon thermal tolerances are shown to be a function of acclimation temperature and exposure time and fish acclimated to high temperatures tend to show greater heat tolerance than those acclimated to cooler temperatures. Once temperatures reach a chronically lethal level (approximately 25°C [77°F]), the time to death decreases with increasing temperature. Higher temperatures (up to 29°C [84°F]) may be tolerated for short periods of time. Although low rates of mortality due to water temperature are suggested by reduced numbers of over-summering juvenile Chinook salmon during mid-summer and fall snorkel surveys (e.g., TID/MID 2011, Report 2010-5), no mortality events have been observed and water temperature mortality of juveniles is unlikely to occur during springtime rearing and emigration periods (April-May). Water temperature effects upon indirect mortality due to predation are discussed further below and comparisons of relevant water temperature criteria and water temperature conditions is provided in the current *Temperature Criteria Assessment (Chinook salmon and O. mykiss) Study* (W&AR-14). Based upon review of available information, water temperature conditions are not expected to contribute to high rates of mortality for juvenile Chinook salmon during in-river rearing and emigration.

5.2.2 Predation by Native and Introduced Species

Comparison of recovery data and estimated passage at RSTs located downstream of the spawning reach indicates substantial mortality of juvenile Chinook salmon (fry, parr, and smolt) in the approximately 25–26 miles between the upper (RM 29.8) and lower (RM 3.5 and RM 5.2) traps. In 2008–2011, the most recent years for which data are available from the upstream and downstream traps during the entire season, the estimated number of juvenile salmon passing the lower traps was 79–90% lower than the estimated number of salmon passing the upper traps (Table 5-3). The most probable explanation for the drastically lower numbers at the lower traps is predation in the intervening reach, which contains large numbers of in-channel mining pits that provide suitable habitat for predatory fish species (McBain and Trush 2000). Although avian predation has not been assessed on the lower Tuolumne River, predation by piscivorous fish species has long been identified as a factor potentially limiting the survival and production of juvenile Chinook salmon in the lower Tuolumne River.

In 1987, CDFG documented almost 70% mortality of 90,000 coded-wire-tagged juvenile Chinook salmon in the three days it took the fish to travel downstream from just below La Grange Dam to the San Joaquin River confluence (TID/MID 1992, Appendix 22). Because water temperatures were considered optimal during this period for outmigrating juvenile salmon, predation was the most plausible explanation for the high mortality. Subsequent studies in the early 1990s concluded that predation by non-native largemouth bass (*Micropterus salmoides*) was a significant factor limiting Chinook salmon outmigrant survival, particularly during drier years (TID/MID 1992, Appendix 22). Smallmouth bass (*M. dolomieu*), another non-native piscivore, were also found to prey on juvenile Chinook salmon and identified as a potentially important Chinook salmon predator. In addition to these “black bass” species, annual summer and fall snorkel surveys conducted in the lower Tuolumne River from near La Grange Dam (RM 52.2) downstream to near Waterford (RM 31.5) have documented Sacramento pikeminnow (*Ptychocheilus grandis)* every year from 1986 through 2011 as well as recent observations of Striped bass (*Morone saxitalis*) (TID/MID 2011, Report 2011-5). Largemouth and smallmouth bass have been observed in most years. However, the distribution of these predator species has changed, apparently in response to increased minimum flows provided by the 1996 SA. Prior to 1996, introduced fish species were commonly seen at most snorkel sites. After 1996 these species were often absent at upstream sites or observed in lower numbers. Striped bass have been observed during recent snorkel surveys in 2010 and 2011, and were documented as far upstream as RM 49.9 in 2011 (TID/MID 2011, Report 2011-5). Whereas striped bass and Sacramento pikeminnow are tolerant of a wide range of water temperatures (Bain and Bain 1982, Baltz et al. 1987) and may occur throughout the river during the salmon outmigration period, spatial distribution of warmwater predators (largemouth and smallmouth bass) in the lower Tuolumne River is seasonally restricted by water temperature (Brown and Ford 2002).

Both native and introduced piscivorous fish species inhabit the lower Tuolumne River (Ford and Brown 2001). Only introduced species have been identified as predators of juvenile Chinook salmon (TID/MID 1992, Appendix 22). The current *Predation Study* (Study W&AR-7) captured four potential predator species—non-native largemouth bass, smallmouth bass, striped bass, and native Sacramento pikeminnow—and examined their stomach contents to determine prey composition. Only largemouth, smallmouth, and striped bass were found to have consumed juvenile Chinook salmon. Likewise, stomach content analysis of 12 potential predator species (n = 356) conducted in the lower Tuolumne River in the early 1990s documented salmon predation only by largemouth and smallmouth bass (TID/MID 1992, Appendix 22). Although native predators such as Sacramento pikeminnow are known to prey on juvenile salmonids in other rivers (Tucker et al. 1998), there is no evidence from the current study or prior studies that native piscivores are important predators on juvenile Chinook salmon in the lower Tuolumne River. Nevertheless, the presence of predatory species as well as occurrence of juvenile salmon in stomach samples of predator species collected from the Tuolumne River suggests that predation is a primary mortality factor affecting Chinook salmon population levels.

5.2.3 Effects of Habitat Changes on Predator Distribution

As discussed in the synthesis (Section 5.1), historical changes in instream flows with dam construction along with in-channel mining have created an abundance of suitable predator habitat in the lower Tuolumne River (McBain and Trush 2000). Largemouth bass and smallmouth bass, the primary salmon predators in the lower Tuolumne River (TID/MID 1992, Appendix 22; W&AR-7) prefer habitat conditions found predominantly in downstream reaches (Ford and Brown 2001). Largemouth and smallmouth bass have been documented in the Tuolumne River from Old La Grange Bridge (RM 50.5) to Shiloh (RM 3.4), but largemouth bass are typically most abundant downstream of Hickman Bridge (RM 31.6) and smallmouth bass are most abundant downstream of RM 37 (Ford and Brown 2001, Brown and Ford 2002). Downstream of approximately RM 31 most of the introduced species, including largemouth and smallmouth bass, reach their maximum frequency of occurrence (Ford and Brown 2001). This portion of the lower Tuolumne River has been significantly affected by gravel mining and provides optimal habitat conditions for these predatory fish species (Ford and Brown 2001, McBain and Trush and Stillwater Sciences 2006).

Largemouth bass is a warm-water species that prefers low-velocity habitats. Optimal riverine habitat for largemouth bass includes fine-grained (sand or mud) substrates, some aquatic vegetation, and relatively clear water (Trautman 1957, Larimore and Smith 1963, Scott and Crossman 1973, all as cited in Stuber et al. 1982). The SRPs provide extensive low-velocity areas with abundant vegetation cover suitable for largemouth bass foraging and reproduction. Restoration of SRP 9 reduced depth and increased water velocity at the site, thus reducing largemouth bass habitat by 68–95% (weighted usable area) over the range of flows modeled (i.e., 75–5,000 cfs) compared to pre-restoration conditions (McBain and Trush and Stillwater Sciences 2006). Predator monitoring in 1998, 1999 and 2003 associated with the SRP 9 habitat restoration project (McBain and Trush and Stillwater Sciences 2006) found that smallmouth bass were most abundant in riffles and largemouth bass most abundant in the in-channel mining pits (SRPs). Based upon available information, habitat changes in the Tuolumne River have increased the presence of predatory species, with effects upon juvenile production discussed further below.

5.2.4 Flow and Water Temperature Effects on Predation

As shown in Table 5-3, the estimated number of outmigrating Chinook salmon fry, parr, and smolts is substantially greater in years with high spring flows (e.g., Wet water year types occurring in 1998, 2005, 2006, and 2011). As shown by Mesick et al. (2008) and TID/MID (2005, Report 2004-7) there is a significant positive relationship between Chinook salmon outmigrant survival and basin outflow during the outmigration period. Using critical analyses of CWT data from paired release smolt survival studies conducted in the Tuolumne River (data from 1987, 1990, 1994–2002), the TRTAC Monitoring Subcommittee conducted a multi-year review of the CWT experiments to allow the development of a smolt survival relationship with flow (TID/MID 2002, Report 2001-5; TID/MID 2003, Report 2002-4; TID/MID 2005, Report 2004-7). Although the resulting smolt survival relationship provides a broad estimate of survival at specific flows (Figure B-10), the analyses support the hypothesis that flow reduces predation related mortality in the lower Tuolumne River.

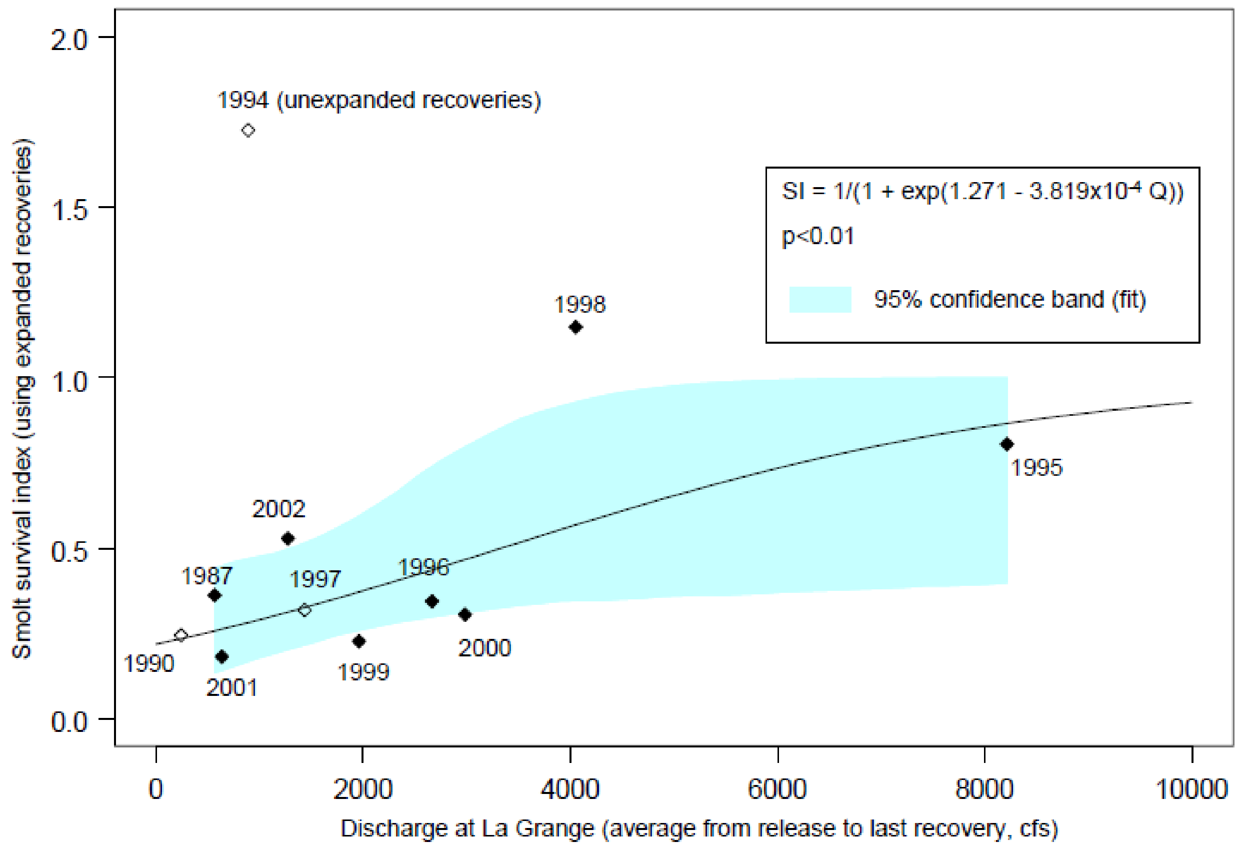

Figure B-10. Logistic regression of validated smolt survival indices by the recovery-weighted flow (cfs) at La Grange from release to last recapture at Mossdale Trawl.

As discussed further in TID/MID (2005a), a key, but uncertain assumption in the resulting flow vs. survival relationship is that flow is considered in these studies as a surrogate for all other factors that may affect relative CWT smolt survival. Factors evaluated in this synthesis, include predator populations, predation rates, food availability, smolt condition and behavior, temperature, turbidity, entrainment into riparian diversions, as well as the effects of water quality contaminants such as herbicides and pesticides. Other than the known effects of water temperatures upon predator avoidance (e.g., Marine 2007, Marine and Cech 2004), the effects of these factors are generally unknown, but obviously vary from year to year and often independently from flow, further complicating the assessment of study results in regards to the relative survival of CWT hatchery salmon related to flow.

In examining more specific mechanisms underlying the observed relationships between juvenile production (Table B-3) and smolt survival (Figure B-10), high flows reduce water temperatures and increase in-channel water velocity, both of which reduce habitat suitability for non-native piscivorous fish such as largemouth and smallmouth bass. These may be the primary factors influencing the longitudinal distribution and relative abundance of native and non-native fishes in the lower Tuolumne River. As shown by Brown and Ford (2002), during years with high winter-spring flows and lower water temperatures, non-native species occurred in greatest abundance at downstream locations. River wide abundance of non-native species increases and distribution extends farther upstream during low-flow years. Largemouth bass prey consumption generally peaks at water temperatures of 79–81°F (26–27°C) (Coutant 1975, Zweifel et al. 1999) and maximum prey consumption rate for smallmouth bass peaks at approximately 72°F (22°C) (Zweifel et al. 1999). While water temperatures in the lower Tuolumne River during the Chinook salmon rearing and outmigration period are never low enough to preclude bass predation, flow increases (e.g., natural floods, managed pulse flows) may reduce water temperature sufficiently to depress predator foraging rates (McBain and Trush and Stillwater Sciences 2006) as well as spawning activity. Moyle (2002) reports spawning begins when water temperature reaches 59–61°F (15–16°C) for largemouth bass and 55–61°F (13–16°C) for smallmouth bass, conditions occurring during March and April in the Tuolumne River. Predator monitoring in 1998 associated with restoration of SRP 9 documented relatively low largemouth and smallmouth bass populations and few young-of-the year bass in the lower Tuolumne River, indicating poor bass recruitment following the 1997 flood (McBain and Trush and Stillwater Sciences 2006). In 1999, after two seasons of relatively low flows and warm water temperatures in the lower Tuolumne River, juvenile largemouth bass were abundant. In 2003, bass populations had rebounded and a variety of age classes were documented (McBain and Trush and Stillwater Sciences 2006). Although high flows can effectively displace juvenile predators from the River during flood conditions, a sufficient number of adults can typically find shelter in flooded areas to repopulate the stream during lower flow conditions (Moyle 2002). For this reason, although predation may potentially still occur due to cold water adapted non-native species such as striped bass (*Morone saxitalis*) or rainbow trout adults, it is likely that reduced water temperatures associated with flood control releases may affect year-class success of many non-native predator species.

In addition to flow and water temperature effects upon predator distribution and activity, high flows may reduce predation efficiency of non-native piscivores due to reduced prey exposure time, as well as spatial separation of predators and prey. Hydraulic modeling in the lower Tuolumne River has indicated that higher water velocities reduce the amount of suitable predator habitat in riffles and in the thalweg of some pools (McBain and Trush and Stillwater Sciences 2006, Stillwater Sciences 2012) and may create "safe velocity corridors" in mid-channel areas where higher water velocities exclude largemouth and smallmouth bass and segregate outmigrant salmon from these non-native predators and reduce bass predation efficiency (McBain and Trush and Stillwater Sciences 2006). Tracking studies in the current *Predation Study* (W&AR-7) as well as radio-tracking conducted in 2005 (Stillwater Sciences and McBain and Trush 2006) provide some indication that largemouth and smallmouth bass use channel edge habitat and inundated floodplains during high flows.

When flows are sufficiently high to inundate floodplains, 2D hydraulic modeling (based on depth and velocity criteria) shows that floodplains are highly suitable for juvenile salmonid but provide little suitable habitat for all modeled predator species except for Sacramento pikeminnow (Stillwater Sciences 2012). Although there is no data on predation rate on inundated floodplains, the large amount of available habitat for predators and prey likely reduces the frequency with which predators encounter prey and predation rate is expected to be low. Stillwater Sciences and McBain and Trush (2006) documented the presence of both salmon and bass on inundated Tuolumne River floodplains in May, 2006, yet the salmon predation rate by captured largemouth and smallmouth bass was zero. These results suggest that predation by bass on salmon may be negligible even in areas where bass and salmon co-occur, although reduced predator feeding rates may have also been greatly reduced due to the floodplain water temperatures during the study (10.7–12.8°C [51–55°F]).

Based upon a large body of information collected for the Tuolumne River, apparent variations in juvenile Chinook salmon production with flow are consistent with predation as a primary direct mortality source, with effects upon juvenile production and population levels. Factors affecting predation range from historical introductions of non-native predatory species, historical habitat modifications along the lower Tuolumne River channel, as well as inter-annual variations in water flows and temperatures that affect predator population levels, predator distribution, and activity.

5.2.5 Water Quality Effects on Predator Avoidance

Anthropogenic inputs of contaminants may affect water quality and the susceptibility of juvenile Chinook salmon to predation. For example, the lower Tuolumne River is currently included in California 2010 Section 303(d) List of Water Quality Limited Segments for pesticides (CVRWQCB 2009) that have been shown to inhibit olfactory-mediated alarm responses, potentially making juvenile Chinook more vulnerable to predation (Scholz et al. 2000). Predation efficiency has also been shown to be influenced by turbidity (TID/MID 1992, Appendix 23), which may be affected by surrounding land use practices, instream flows, and factors that alter sediment transport processes (See Section 5.1 of the synthesis). It is currently unknown, the degree to which water quality conditions are affecting predation rates or juvenile production of Tuolumne River Chinook salmon.

5.2.6 Stranding and Entrapment

Rapid reductions in instream flows, particularly during flood flow conditions, may eliminate access to available habitat and cause stranding and entrapment of fry and juvenile salmon on gravel bars and floodplains and in off-channel habitats that may become cut off when flows are reduced. Although stranding is a natural process on unregulated rivers in association with flow changes resulting from runoff events, mortality of juveniles by several mechanisms often results, including desiccation, temperature shock, asphyxiation, as well as predation by birds and mammals. Because of concerns regarding rapid river stage changes when power peaking during the first years following completion of the New Don Pedro Project, flow fluctuation assessments were completed as part of the 1986 study plan (TID/MID 1992, Appendix 14; TID/MID 1997, Report 96-2). Surveys conducted during 1999–2002 under the FERC (1996) Order, and including analysis of historical data, confirmed higher stranding risk on low gradient sand and gravel substrates in the primary spawning reach (RM 51.5 to RM 47.8) when flows decreased from near 3,000 cfs down to 1,500 cfs (TID/MID 2001, Report 2000-6). At the lower end of this flow range, which approximates bankfull flow conditions in this reach of the Tuolumne River (McBain and Trush 2004, Stillwater Sciences 2012), low levels of stranding may continue to occur during flood control operations as flows recede from the floodplain. Nevertheless, the Districts have not had daily hydropower peaking releases to the river in the past 20 years, and flood management flow reduction rates are at or below the 1995 SA ramping rate limits (TID/MID 2005a), further reducing the magnitude of stranding events. For these reasons, low levels of juvenile mortality due to stranding are not considered further in this synthesis.

5.2.7 Entrainment into Unscreened Riparian Diversions

Depending on instream flows and agricultural operations, entrainment of rearing or migrating juvenile Chinook salmon into unscreened pumps may occur, resulting in mechanical damage and mortality. CDFG has developed an inventory of riparian pumps along the Tuolumne River that are used, primarily for irrigation during late spring and summer, although some may also be used for frost protection for tree crops during periods of juvenile rearing. In earlier surveys conducted by CDFG, some thirty-six small riparian diversions were located on the lower Tuolumne River (Reynolds et al. 1993). In a literature review of agricultural diversion effects on Central Valley fishes, Moyle and White (2002) showed that almost no studies have examined fish losses at smaller diversions, and no data exists for the Tuolumne River. Based upon review of available information, entrainment mortality of juvenile Chinook salmon is unknown, although mortality risks would relate to weather conditions associated with riparian diversion in the Tuolumne (e.g., frost protection, or crop irrigation during warm weather).

5.3 Processes/Mechanisms Affecting Indirect Mortality

5.3.1 Diseases and Parasites

Meteorology and instream flows combine to affect exposure of rearing juvenile Chinook salmon to varying water temperatures, which in turn, may contribute to stress and disease incidence in some fish (Myrick and Cech 2001, Holt et al. 1975, Wood 1979) and contribute to subsequent mortality. A literature review by Myrick and Cech (2001) summarized the results of several studies (Arkoosh et al. 1998, Foott and Hedrick 1987) on the range of temperatures at which a wide variety of pathogens may be found to infect Chinook salmon in the Central Valley. No clinical levels of infection were identified in health surveys of juvenile Chinook from the Tuolumne River during the spring of 2000 and 2001 (Nichols and Foott 2002). Although, water quality factors such as low DO (Wedemeyer 1974) and chemical contaminants (Arkoosh et al. 1998) are sometimes associated with stress and disease incidence, the relatively low incidence of disease in juvenile Chinook salmon from the Tuolumne River suggests that there is a low risk of indirect mortality due to disease. For this reason, the effects of disease and parasites on juvenile Chinook salmon are not considered further in this synthesis.

6.0 DELTA REARING/OUTMIGRATION

As shown in Figure B-11, a number of factors affect growth and survival of juvenile Chinook salmon in the Delta, including meteorological and instream flow effects upon sediment transport, in-channel and floodplain habitat availability, water temperature and food availability. Historically, the Sacramento-San Joaquin Delta provided high quality rearing habitat for juvenile Chinook salmon. Modification of the Delta, however, has degraded this once favorable environment. Today, poor water quality, channel modifications, loss of shallow marsh habitats, hydraulic changes (e.g., flow reversals) caused by operation of the State and Federal pumps, entrainment of juvenile fish in the pumps, abundance of introduced predators, and other factors reduce the survival of Chinook salmon migrating through the Delta and greater San Francisco Bay estuary. Specific information related to Tuolumne River origin salmon is related to information collected from recovery locations and numbers of fish from various coded-wire-tag (CWT) release groups used in smolt survival studies since the late 1980s. However, broader information sources from the San Joaquin River Group Authority annual reports, as well as Central Valley salmon assessments provide relevant information on habitat conditions for rearing Chinook salmon in the Delta.

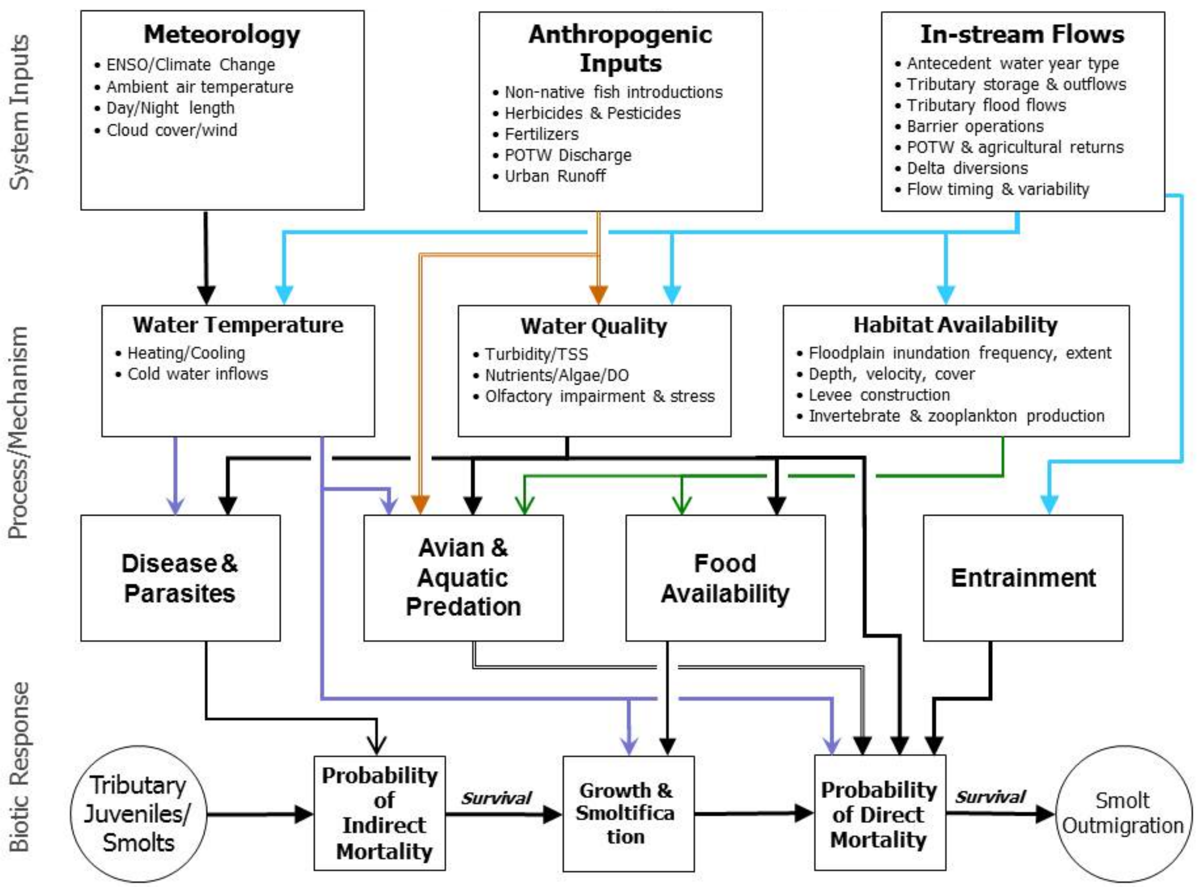

Figure B-11. Potential issues affecting Tuolumne River fall-run Chinook salmon juvenile rearing and smolt emigration from the Delta.

6.1 Processes/Mechanisms Affecting Juvenile Growth and Smoltification

6.1.1 In-channel and Floodplain Habitat Availability

No studies have directly mapped the amounts of suitable rearing habitat for juvenile Chinook salmon in the lower San Joaquin River and Delta. Extensive juvenile rearing may occur in the Delta during high-flow years when fry or young juveniles are displaced downstream into the Delta during major storms and flood conditions. Table 5-1 shows juvenile Chinook salmon may be found in the Delta from February through early June, with smaller size classes (<70 mm) found from February to April in most years (MacFarlane and Norton 2002). Chinook salmon rear along the shallow vegetated edges of Delta channels (Grimaldo et al. 2000). Although marsh and floodplains may have been extensive enough in the Delta under historical conditions (Atwater et al. 1979) to support high juvenile production in an environment where there were fewer predators, Delta marsh habitats and native fish communities have undergone such extreme changes from historical conditions (Kimmerer et al. 2008) that few locations in the eastern and central Delta provide suitable habitat for rearing Chinook salmon.

As discussed in the synthesis (Section 5.1), although much of the historical floodplain habitat in the Central Valley has been lost, Chinook salmon have been documented to utilize the floodplain habitat in the Sutter Bypass, Yolo Bypass, and in the Cosumnes River during extended periods of floodplain inundation in high flow years (Feyrer et al. 2006, Sommer et al. 2001, Sommer et al. 2005, Moyle 2007). A pilot study of the Ecosystem Flow Model (EFM) developed during the Sacramento and San Joaquin Rivers Comprehensive Study conducted in a 13-mile (21 km) reach on the lower San Joaquin River, downstream of the Stanislaus River confluence, indicated that there is a “natural terrace” inside of the levee on one side of the river that would be inundated and provide floodplain habitat beneficial to native fishes at flows above approximately 15,000 cfs in winter and spring (ACOE 2002). More recently, the extent of inundated floodplain in the SJR between the confluence of the Stanislaus River (RM 74.8) and Mossdale (RM 56) was shown to exceed 2,000 acres at flows near 25,000 cfs (cbec 2010). In comparison, flood flows can inundate large expanses of the 59,000 acre Yolo Bypass (Sommer et. al 2005). Because extended periods of floodplain inundation in the lower San Joaquin River and Delta are not expected except those accompanying large flood control releases from the tributaries, it is likely that historical changes in Delta habitats affect growth opportunities and survival of rearing Chinook salmon with subsequent effects upon the numbers of smolts entering the ocean fishery as well as early ocean survival.

6.1.2 Water Temperature Effects on Growth and Smoltification

As shown in Figure B-11, suitable water temperatures are required for growth and subsequent smoltification of juvenile Chinook salmon rearing in the Delta. Meteorology and to a minor degree instream flows combine to affect water temperature of both in-channel habitats in the San Joaquin River and Delta as well as water temperatures of off-channel habitats (e.g., sloughs, marshes, as well as seasonally inundated floodplains). Seasonal variations in water temperatures, in turn have a strong influence on growth and feeding rates of rearing juvenile Chinook salmon and studies of Chinook salmon growth and water temperatures are review by several authors (Myrick and Cech 2004, Williams 2006). Travel times for smolt-sized fish through the lower San

Joaquin River and Delta range from 2–21 days based on CWT recoveries (Baker and Morhardt 2001) and acoustic tracking (Holbrook et al. 2009). Smaller juveniles may rear for extended periods of up to two months in the Delta where increased water temperatures and higher growth rates are generally observed as compared to fish reared in upstream tributaries (e.g., Healey 1991, Kjelson et al. 1982). Although high growth rates were also observed on inundated floodplains due to increased water temperatures and abundant food supplies (Sommer et al. 2001), as discussed above, floodplain rearing opportunities are limited in the South Delta.

For juvenile Chinook salmon rearing in the Delta, water temperatures may impair smoltification under some circumstances. As with smoltification occurring in upstream rearing habitats, in addition to body size and growth rates, water temperature, photoperiod, lunar phasing, and other environmental cues are associated with the onset of smoltification (Clarke and Hirano 1995, Wedemeyer et al. 1980). Myrick and Cech (2001) report that Chinook salmon can smolt at temperatures as high as 20°C (68°F), but smoltification is impaired at higher water temperatures (21–24°F). Water temperatures in the San Joaquin River near Vernalis (USGS 11303500) generally range from below 18–21°C (65–70°F) from mid-April to mid-May across a wide range of water years. For these reasons, although outmigration of upstream smolts passing through the Delta may occur as late as June in most years, it is unlikely that smoltification of juveniles reared in the Delta occurs much after May. Although water temperature has a strong influence upon Chinook salmon life history timing, separate from direct and indirect mortality effects, both the degree to which water temperature affects smoltification in the Delta as well as long term population levels is unknown.

6.1.3 Food Availability

Like in other estuaries, the availability of phytoplankton and fine particulate organic matter sources to zooplankton in the Delta is affected by freshwater flows, nutrient supplies, water exports (Arthur et al. 1996, Jassby et al. 1996), as well as the presence of non-native species (e.g., *Corbula*) (Kimmerer et al. 2008). Although the diet of Chinook salmon varies among estuaries (Williams 2006), Kjelson et al. (1982) found the diet of fry and juvenile Chinook salmon in the San Francisco Estuary consisted of dipterans and cladocerans, while in brackish San Pablo and San Francisco Bay, the consumption of copepods, amphipods, and fish larvae of other species increased. The Interagency Ecological Program (IEP), a consortium of nine state and federal agencies, has been monitoring fish populations in the San Francisco Bay Estuary and Delta for decades, and based upon changes in the fish assemblage documented in the midwater trawl at locations throughout the Delta, documented a long-term Pelagic Organism Decline (POD) strongly related to delta exports among other factors (Baxter et al. 2008). While the mechanisms responsible for long-term and POD-era declines of Delta species vary by species, the consistent declines across species and trophic levels suggests that the mechanisms may have a common linkages (e.g., inflows, exports, intra-specific competition, etc.). Durand et al. (2008) provides a recent conceptual model of the Delta food web, but based upon habitat and food web changes in the Delta, food resources may limit juvenile salmonids under some conditions. For example, as discussed in Williams (2006), MacFarlane and Norton (2002) found that compared to upstream locations, juvenile Chinook moving through the bays grew more slowly in the Delta and San Francisco Bay estuary (0.18 mm d^{-1} on average) until they reached the Gulf of the Farallones. Further, Kjelson et al. (1982) noted that the scales of fish from the Sacramento-San

Joaquin system did not show the pattern of intermediate circuli spacing on scale samples indicative of enhanced growth in brackish water. Although Sommer et al. (2001) found the greater abundance of drift invertebrates and warmer temperatures were associated with high growth rates in the inundated Yolo bypass during flood conditions, it is likely that food resources in the Delta may be limiting the growth opportunity for juvenile Chinook salmon under drier water year types, with affects upon early ocean survival and long-term population levels.

6.2 Processes/Mechanisms Affecting Direct Mortality

As shown in Appendix B, water temperature related mortality, temperature effects upon predation as well as predation related mortality due to entrainment are primary factors that may result in direct mortality of rearing juvenile Chinook salmon in the lower San Joaquin River, Delta, and the greater San Francisco Bay estuary. As discussed further below, avian and aquatic predation during Delta rearing and outmigration is affected by the abundance and distribution of native and introduced species, changes in habitat that affect predator distribution, flow and water temperature effects on predator activity, as well as water temperature and water quality effects upon the ability of salmon to avoid predators.

6.2.1 Water Temperature

Seasonal and inter-annual changes in meteorology, air temperatures, and to a minor degree instream flows combine to affect exposure of rearing juvenile Chinook salmon to periods of elevated water temperatures in the lower San Joaquin as well as increased rates of mortality. As discussed in the synthesis (Section 5.1) water temperatures in the lower San Joaquin River and south Delta can be warm, generally ranging between 8 and 27°C (46–82ºF) on an annual basis. Although water temperatures generally range from 18–21°C (65–70°F) from mid-April to mid-May across a wide range of water years, temperatures rapidly increase above these levels in May. Because water temperatures in excess of 25°C (77°F) are associated with increased mortality incidence (Myrick and Cech 2001), water temperature related mortality may occur during warmer meteorological conditions. However, prior analyses (e.g., Mesick 2010; TID/MID 1992, Appendix 21) showed only broad relationships of water temperature and flood flows at Mossdale between May 1 and May 15, suggesting that ambient air temperatures have a stronger influence upon water temperatures than upstream flows entering the Delta. Nevertheless, it is likely that water temperature related mortality occurs to some degree by early June in most years without extended flood conditions, with effects upon the numbers of adult recruits to the ocean fishery.

6.2.2 Predation by Native and Introduced Species

Non-native fish introductions in California date back to European settlement and present-day fish communities in the lower reaches of the San Joaquin River tributaries and Delta are dominated by non-native taxa, many of which prey upon juvenile salmonids or compete for food resources (See Section 5.1 of the synthesis). Delta fish species in the area that may potentially prey upon juvenile Chinook salmon include striped bass, largemouth and smallmouth bass, Sacramento pikeminnow, channel catfish (*Ictalurus punctatus*), black and white crappies (*Pomoxis nigromaculatus and P. annularis*), green sunfish, (*Lepomis cyanellus*), warmouth (*Lepomis* *gulosus*), as well as adult life stages of *O. mykiss*. Of these, only pikeminnow and *O. mykiss* are native to the system. Predation may have the greatest impact on salmon populations when juveniles and smolts outmigrate in large concentrations during the spring through the lower mainstems of rivers and estuaries on their way to the ocean (Mather 1998). The potential for predation is highest when habitats of juvenile and smolt salmonids overlap with preferred habitats of predaceous fish (e.g., during the earlier rearing period, juvenile Chinook may tend to be found in lower-velocity nearshore areas used by ambush predators such as smallmouth bass (Nobriga and Feyrer 2007, Grimaldo et al. 2000), while during smolt outmigration they may travel in open water habitats further from shore and be more vulnerable to predation by striped bass (Thomas 1967, Lindley and Mohr 2003). Although all of the species listed above may potentially contribute to predation mortality of Chinook salmon in the Delta, striped bass in particular are considered a top predator in the Delta and has been implicated in the declines of many native species (Moyle 2002). Based upon review of available information, predation in the Delta has strong effects upon the numbers of adult recruits to the ocean fishery.

6.2.3 Effects of Habitat Changes on Predator Distribution

Although anadromous salmonids evolved with native fish predators such as Sacramento pikeminnow, introduced species may be better able to prey on juvenile salmonids and other native fish species, or may put additional strain on populations already weakened by multiple stressors. For example, many native fish species are well-adapted to the seasonal and annual flow fluctuations that were characteristic of the region under historical conditions, including multi-year periods of flooding and drought (Moyle 2002). At the same time, many non-native species have expanded in population and distribution with the more stable flow conditions and altered flow patterns associated with water exports from the SWP and CVP in the South Delta under current conditions. Feyrer and Healey (2003) discuss a combination of influences such as degraded physical habitat such as channelization, altered hydrodynamics (Nichols et al. 1986), and negative interactions with non-native species such as intra-specific competition (Marchetti 1999) as well as predation (Turner and Kelley 1966, Bennett and Moyle 1996). Hydrology in the Delta is highly altered and only resembles historic conditions during seasonal extreme flow and high turbidity conditions that typically occur during spring flood conditions. For these and other reasons, several species native to the Delta are threatened or endangered, and populations of many non-native species are flourishing under present-day conditions (Lund et al. 2007). Based upon review of available information, habitat changes in the Delta may be attributed to current rates of predation, with strong effects upon the numbers of adult recruits to the ocean fishery.

6.2.4 Flow and Water Temperature Effects on Predation

Although Chinook salmon fry and smolt survival have been extensively studied in the Delta (Brandes and McLain 2001, Kjelson et al. 1989), relatively weak relationships with flow have been documented in some studies of Sacramento River Chinook salmon (e.g., Newman and Rice 2003, Newman 2008). For the Sacramento River study fish, the studies generally demonstrated a substantial negative effect of the Delta Cross Channel and water exports on survival of juvenile salmon. In 2001, the first multi-year analyses of smolt survival data from mark-recapture studies was conducted to estimate salmon survival relative to flow at Vernalis (Baker and Morhardt 2001; Brandes and McLain 2001). While Brandes and McLain (2001) identified a statistically significant relationship between smolt survival from Dos Reis to Chipps Island and river flow at Stockton, Baker and Morhardt (2001) noted several weaknesses in the available data including low recapture numbers which generated imprecise estimates of survival, a lack of control of flow and export conditions during individual experiments, and lack of a statistical design in combinations of flows and exports.

The Vernalis Adaptive Management Plan (VAMP) was initiated in 2000 as part of SWRCB Decision 1641 to evaluate variations in smolt survival change in response to alterations in San Joaquin River flows SWP/CVP exports as well as with the installation of the Head of Old River Barrier (HORB) near Lathrop, CA at RM 48 (SJRGA 2011). Although smolt survival experiments during the 1990s and early 2000s suggested increasing survival with flow, survival through the South Delta has been very low since 2003 (e.g., SJRGA 2007), and high flow events have failed to increase survival to levels observed when flows ranged between 5,000 and 6,000 cfs, despite flood flows of up to 25,000 cfs during the juvenile emigration period. This is in part due to the installation of the HORB, which is limited to flows below 7,000 cfs at Vernalis (RM 69.3). In his re-analysis of the VAMP studies, Newman (2008) shows a significant relationship between Vernalis flow and smolt survival from Dos Reis to Jersey Point but shows only weak relationships between export levels and smolt survival. However, results of the Newman (2008) reanalysis of two studies ("Interior" and "Delta Action 8") suggests that export levels have a significant effect upon outmigrant survival, with the VAMP and "Delta Cross Channel" studies showing significant relationships between smolt survival and barrier operations. The results of the studies to date indicate that installation of the HORB improves salmon smolt survival through the Delta by 16-61%, whereas in the absence of the physical (rock) HORB, a statistically significant relationship between flow and survival does not exist (Newman 2008).

In examining a relationship between water temperature in the Delta and predation-related mortality, Williams (2006) discusses statistical analyses used to relate smolt survival to water temperature from data associated with CWT smolt-survival releases (Baker et al. 1995, Newman and Rice 2002, Newman 2003) and it is clear that high water temperatures reduce juvenile Chinook salmon survival in the Delta. For example, Baker et al. (1995) showed that, depending upon release location, water temperature explained much of the variation in observed smolt survival, with a fitted estimate of temperatures associated with a 50% probability mortality of 23°C (73°F). Based upon review of available information, water temperature related mortality has a strong influence upon juvenile Chinook salmon survival as well as juvenile life history timing.

Chronic exposure to high temperatures may also result in greater vulnerability to predation (Marine 1997, Myrick and Cech 2004). In a study by Marine (1997), Sacramento River fall-run Chinook salmon reared at the highest temperatures (21–24°C [70–75°F]) were preyed upon by striped bass more often than those reared at low or moderate temperatures. Consumption rates of piscivorous fish such as Sacramento pikeminnow, striped bass, and largemouth bass increase with temperature, which may compound the effects of high temperature on juvenile and smolt predation mortality. Juvenile growth rates are an important influence on survival because juvenile salmon are gape-limited predators that are themselves subject to gape-limited predation by larger fish. Faster growth thus both increases the range of food items available to them and decreases their vulnerability to predation (Myrick and Cech 2004). Based upon review of available information, flow and water temperature in the Delta is likely to have effects upon predation mortality of juvenile Chinook salmon during later months (e.g., May and June) with effects upon the numbers of adult recruits to the ocean fishery.

6.2.5 Entrainment Effects on Juvenile Salmon Mortality

Depending on tributary instream flows to the San Joaquin River and Delta, entrainment of rearing or migrating juvenile Chinook salmon into unscreened pumps may occur, resulting in mechanical damage and mortality. For the protection of outmigrating Fall-run Chinook salmon in years when spring flow in the San Joaquin River is less than 5,000 cfs, a temporary barrier has been typically placed at the head of Old River from April 15th to May 15th in most years without to prevent drawing these fish towards the pumps near Tracy. Nevertheless, entrainment into the SWP and CVP export facilities in the South Delta may result in increased rates of predation, physical damage and stress during salvage operations, as well as subsequent predation at release points for salvaged fish near the western (downstream) edge of the Delta. As discussed in the synthesis (Section 5.1), combined SWP and CVP exports from the San Joaquin and Sacramento rivers and their tributaries have increased dramatically since 1971 The export rates routinely far exceed the flow of the San Joaquin River at Vernalis except during the limited April-May period and in wet Water Year Types with extended flood control releases (e.g., 1998, 2005, 2011). To examine the influence of water exports on fish survival and movement in the Delta, numerous studies have employed mark recapture techniques, acoustic and radio telemetry, and fish salvage data in an effort to examine the importance of various management alternatives and varying environmental conditions (Kjelson and Brandes 1989, Brandes and McClain 2001, Newman and Rice 2002. Along with predation and water temperature related mortality, entrainment into the CVP/SWP facilities has been considered to a primary sources of mortality of smolts outmigrating from the Tuolumne River, resulting in an estimated loss of 35–44% of juveniles migrating through the San Joaquin River in water years 1973–1988 (TID/MID 1992, Appendix 26). Kimmerer (2008) showed the direct losses of Chinook salmon to salvage at the SWP and CVP generally increased with increasing export flows. For salmon entrained into the forebay, paired releases of CWT fish at the entry to the Clifton Court forebay and at the trash racks upstream of the fish screen louvers provide an estimate of pre-screen mortality on the order of 63–99% of all fish entrained into the forebay (Gingras 1997). Predation on salmon by striped bass and pikeminnow at salvage release sites in the Delta and lower Sacramento River has been documented (Orsi 1967); however, accurate predation rates at these sites are difficult to determine.

In addition to entrainment losses of juvenile Chinook salmon at the SWP and CVP export facilities, juveniles are also susceptible to entrainment at many unscreened agricultural irrigation diversions located throughout the Delta and within the Central Valley rivers and tributaries. Although Herren and Kawasaki (2001) provide a relatively recent inventory of agricultural diversion in the Delta water diversions, Moyle and White (2002) indicate that of several hundred studies reviewed related to diversion screens, almost no studies have examined fish losses at smaller diversions. In a prior review of fish screen mortality, entrainment rates were measured at the Banta-Carbona Irrigation District pumps (RM 82.0) in 1955 at about 12 fish per hour (Hallock and Van Woert 1959). In summer 2002, fish screens were installed at Banta-Carbona that appear to be effective at protecting juvenile salmon (TID/MID 2005a). Hallock and Van

Woert (1959) reviewed entrainment rates at other sites and suggested that 1) more fish were lost to large diversions than small ones, 2) total numbers of salmon lost in the diversions was surprisingly small and was attributed to low overlap with the irrigation season and the main periods of salmon outmigration, 3) numbers of fish lost to individual diversions was highly variable but most abundant were Chinook salmon, common carp, Sacramento sucker, white catfish, and small centrarchids.

Based upon review of available information, although entrainment in smaller irrigation diversion has not been well quantified, entrainment related mortality in the CVP/SWP export facilities is considered to be a major source of mortality for rearing and outmigrating Chinook salmon juveniles with strong effects upon the numbers of adult recruits to the ocean fishery.

6.2.6 Water Quality Effects on Direct Mortality and Predator Susceptibility

Variations in dissolved oxygen at Stockton were not shown to be well correlated with VAMP smolt survival study results (e.g., SJRGA 2002 and 2003). Separate from dissolved oxygen issues, anthropogenic inputs of contaminants in the lower San Joaquin River and Delta may lead unsuitable water quality conditions and exposure of juvenile Chinook salmon to contaminants which may potentially result in both direct mortality as well as increased susceptibility to predation. Brown (1996) inventoried over 350 pesticides used across the San Joaquin River basin and found that significant loads of pesticides are primarily released 1) in December and January when dormant orchards are sprayed for insect control and when subsequent rainfall flushes the pesticides into surface water, and 2) in March and April, when alfalfa fields are treated to control insects. Although direct exposure of agricultural tile drainage was shown to cause high rates of juvenile Chinook salmon mortality (Saiki et al. 1992), no studies have directly assessed contaminant-related mortality in the Delta and direct mortality is likely uncommon. NMFS (2006) and Scott and Sloman (2004) provide reviews of potential effects of early life history exposure to anthropogenic inputs of trace metals, herbicides and pesticides which may affect susceptibility of salmonids to piscine, avian, and mammalian predation over an extended period of time after exposure. For example, many chemicals that are applied to control aquatic weeds in the Delta contain ingredients that have been shown to cause behavioral and physical changes, including loss of equilibrium, erratic swimming patterns, prolonged resting, surfacing behaviors, and narcosis (NMFS 2006). Scholz et al. (2000) conducted a study on the neurological effects of Diazinon, an organophosphate (OP) insecticide, on Chinook salmon and found short-term, nominal exposure inhibited olfactory-mediated alarm responses, which may reduce survival, subsequent homing, as well as reproductive success. Based upon review of available information, water quality effects upon predation of juvenile Chinook salmon is considered unknown.

6.3 Processes/Mechanisms Affecting Indirect Mortality

6.3.1 Diseases and Parasites

Variations in meteorology and instream flows as well as various anthropogenic sources of contamination may contribute to stress and disease incidence (Myrick and Cech 2001, Holt et al. 1975, Wood 1979) which may contribute to subsequent mortality of rearing or emigrating juvenile Chinook salmon. A literature review by Myrick and Cech (2001) summarized the results of several studies (Arkoosh et al. 1998, Foott and Hedrick 1987) on the range of temperatures at which a wide variety of pathogens may be found to infect Chinook salmon in the Central Valley and some studies have suggested that suppressed immune systems in young salmon from chemical contamination could make the fish more susceptible to disease as they move further into the marine environment (Arkoosh et al. 1998, 2001). Despite some evidence of impaired water quality and temperature conditions in the Delta, Nichols et al. (2001) identified no clinical signs of disease, virus, or obligate bacterial pathogens were detected in any of the 242 juvenile fall-run Chinook salmon examined from the San Joaquin River and Delta with only light infections of the PKX myxosporean (the causative agent of Proliferative Kidney Disease) detected in a few hatchery and natural fish. Nichols and Foott (2002) found only low levels of infection of Tuolumne River juvenile Chinook salmon in 2001 but found increased levels of clinical infection in the lower San Joaquin River in 2002. Based upon review of available information, other than potential infections of hatchery-reared fish, potential effects of disease incidence on Tuolumne River Chinook salmon rearing in the Delta are considered unlikely.

7.0 OCEAN REARING AND ADULT RESIDENCY

As shown in Figure B-12, a number of factors affect growth and survival of juvenile and adult Chinook salmon during ocean residency, including meteorological effects upon ocean circulation and sea surface temperatures, exposure to adverse water quality and growth conditions during riverine and Delta rearing, as well as the influences of predation and harvest related mortality. Although limited information related to Tuolumne River origin salmon may be found from the ocean recovery of CWT release groups used in upstream smolt survival studies, the information presented in this section draws upon broader information sources from California and the Pacific Northwest.

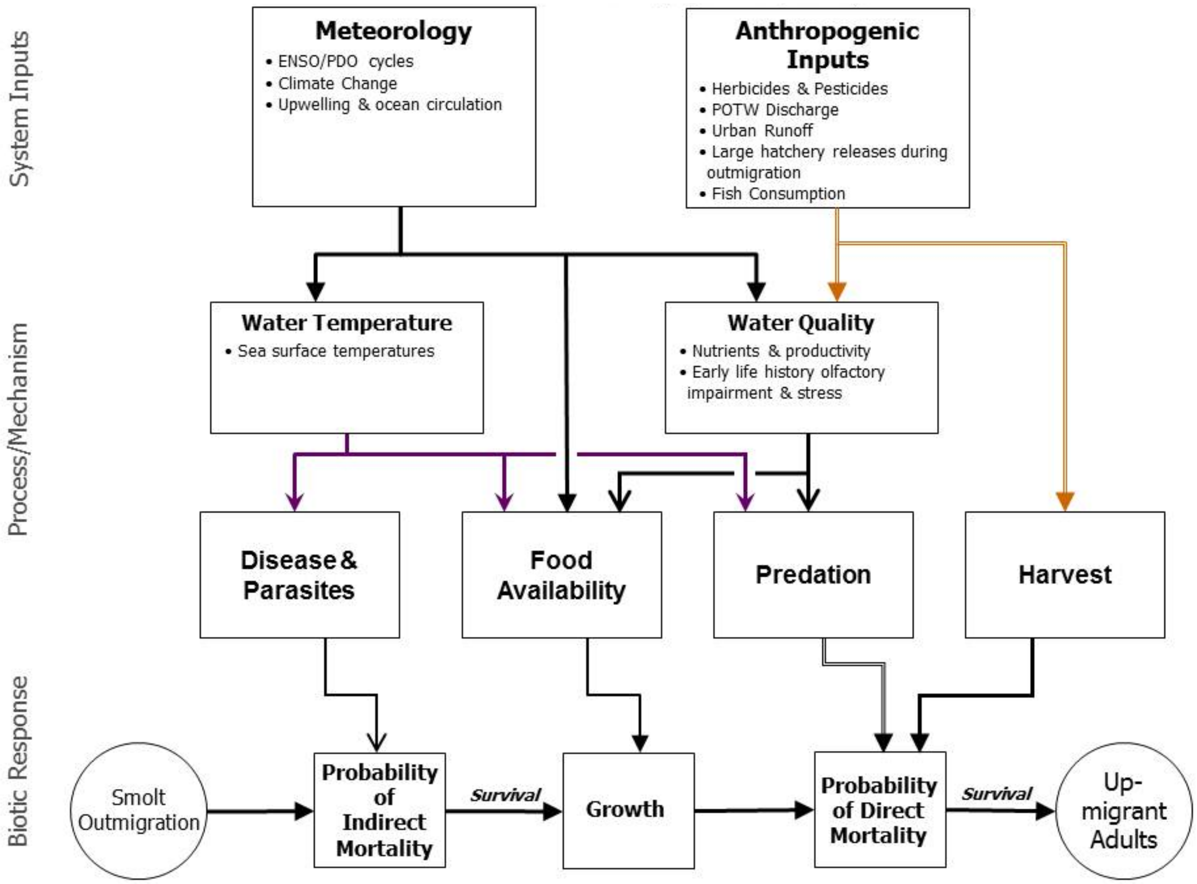

Figure B-12. Potential issues affecting Tuolumne River fall-run Chinook salmon during adult rearing in the Pacific Ocean.

7.1 Processes/Mechanisms Affecting Adult Growth

7.1.1 Food Availability

As discussed in the synthesis (Section 5.1), both the Pacific Decadal Oscillation (PDO) and shorter-term El Niño/Southern Oscillation (ENSO) influence water temperature and ocean circulation patterns that, in turn, influence coastal productivity through a series of complex interactions. Mantua and Hare (2007) provide a historical review of the PDO that suggests large changes in ocean productivity and salmon harvest, with peaks in abundance off the California and Oregon coasts occurring during periods of low abundance off the coast of Alaska. Cooler, more-productive cycles generally prevailed from 1947–1976 and in the late 1990s, with lower productivity associated with warm conditions and changes in circulation in the ocean from 1977 to 1997 (Mantua et al. 1997), as well as during the 2000s (Lindley et al. 2007). In contrast, the ENSO occurs approximately every five years and is also associated with changes in ocean currents and productivity off of the California coast (MacFarlane et al. 2005). Chinook salmon smolts originating from the Central Valley appear to be particularly dependent on prevailing coastal conditions for growth during early ocean residency, potentially the result of habitat simplification throughout the San Francisco Estuary (MacFarlane and Norton 2002, MacFarlane, 2010, Lindley et al. 2009). As an example of this dependence, the proximate cause of the recent Sacramento River salmon fisheries collapse of the early 2000s has been attributed to unusually weak upwelling, warm sea temperatures, and low densities of prey items in the coastal ocean (Lindley et al. 2009). Wells et al. (2007) found that favorable meteorological and oceanic conditions which result in faster growth during the year prior to upmigration led to earlier maturation and larger sizes at return in the Smith River, CA. Potential density-dependent effects of large hatchery releases on wild salmon populations include competition for food resources during early ocean rearing. Ruggerone et al. (2010) estimated the relative abundances of wild and hatchery origin salmon for pink, chum, and sockeye salmon populations in the northern Pacific Ocean and suggested that density-dependent effects may occur due to the timing and magnitude of hatchery releases relative to wild salmonid populations. Based upon review of available information ocean conditions have a strong effect upon food availability, year class strength, and size at return of Chinook salmon escaping the ocean troll fishery.

7.2 Processes/Mechanisms Affecting Direct Mortality

7.2.1 Estuarine and Marine Sources of Predation

Predation of Chinook salmon smolts following ocean entry potentially reduces subsequent escapement, although population level impacts are not well documented. In studies of northern Pacific salmonids outside of California, high rates of mortality within the 1st year of ocean residency may be related to size-dependent effects, with smaller individuals more susceptible to size-selective predation (Willette et al. 1999). Caspian tern predation on juvenile salmonid originating from the Sacramento and San Joaquin rivers was estimated based on coded wire tags recovery on Brooks Island (Evans et al. 2011). The results of the study indicated that an estimated 27,000 to 80,000 juvenile salmon were consumed by the entire tern colony during 2008. The numeric codes on the tags revealed that 98% of the salmon consumed were fall-run Chinook salmon, and 99.7% were from Chinook salmon trucked and released in San Pablo Bay.

Early life history exposure to anthropogenic inputs of contaminants during outmigration and Delta rearing may also affect susceptibility of salmonids to both piscivory and avian predation in the Bay and ocean (Scholz et al. 2000, NMFS 2006).

For adult salmon rearing in the Pacific Ocean, as part of the West Coast Pinniped Program, Scordino (2010) reviewed monitoring results of pinniped predation on Pacific coast salmonids and found that predation by Pacific harbor seals and California sea lions can adversely affect the recovery of ESA-listed salmonid populations, but conceded that more research is needed to better estimate this impact.

7.2.2 Ocean Harvest

Ocean harvest of adult Chinook salmon affects the age structure and number of spawning adults that return to their natal streams. The Central Valley Harvest Index is tracked in various reports of the Pacific Marine Fisheries Council (e.g., PFMC 2011), showing relative changes in harvest and escapement for Central Valley rivers. The Central Valley Harvest Rate Index has been in excess of 70% in many years and recent fishing bans (2009–2010) have been imposed to increase adult population levels. Fishery management errors have led to over-estimations of escapement and subsequent lack of ocean harvest constraints when they were needed (Lindley et al. 2009). Information provided by Myers et al. (1998) shows that Central Valley Chinook stocks have been exploited at average rates of more than 60 percent for many years (Lindley et al. 2009). Such high harvest rates that are targeted toward larger (older) fish may decrease genetic diversity and cause selection toward younger and smaller spawners that reproduce earlier in the year, both reducing overall fitness of the population (Lindley et al. 2009).

7.3 Processes/Mechanisms Affecting Indirect Mortality

7.3.1 Diseases and Parasites

Meteorology and instream flow effects upon water temperature in upstream habitats may affect early life history disease incidence and subsequent mortality of adult Chinook salmon. Prior exposure to poor water quality, contaminants, pathogens and parasites during juvenile rearing and outmigration may also contribute to increased disease incidence in the adult Chinook salmon population. For example, Arkoosh et al. (2001) showed that Chinook salmon smolts exposed to aromatic and chlorinated organic compounds found in sediments suffered a higher pathogen-related mortality and that this immune response may extend into their early ocean life (NMFS, 2006). However, Nichols et al. (2001) identified no clinical signs of disease, virus, or obligate bacterial pathogens in juvenile Chinook salmon collected in the lower San Joaquin River and Delta, and Nichols and Foott (2002) found only low levels of infection of Tuolumne River juvenile Chinook salmon in 2001. Based upon available monitoring data, potential impacts of disease on juvenile Chinook salmon upon early ocean entry are considered unlikely.

8.0 REFERENCES

References for this information review are provided in the accompanying synthesis document.