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

ATTACHMENT C

O. MYKISS 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 *O. mykiss* life history forms (i.e., rainbow trout or Central Valley steelhead) 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 *O. mykiss* habitat extends across local (in-river) and regional (Delta and Pacific Ocean) scales, a number of factors may affect individual life stages of either life history form within the Study Area[1] throughout their life cycle. Conceptual models for *O. mykiss* were developed in consultation with relicensing participants to identify factors that may affect different life stages throughout the species range in the Tuolumne River, lower San Joaquin River, Delta, San Francisco Bay estuary, and Pacific Ocean. Recognizing the very low occurrence of steelhead in Tuolumne River samples analyzed by Zimmerman et al. (2009), the majority of *O. mykiss* found in historical monitoring surveys are likely resident rainbow trout. For this reason, because of the Endangered Species Act (ESA) concerns regarding anadromous steelhead, the life history timing (Table C-1) and life history information for *O. mykiss* presented below is based on general Central Valley steelhead assessments (McEwan and Jackson 1996, McEwan 2001, NMFS 2009), with much of the Tuolumne-specific data representing resident rainbow trout abundance, timing, and distribution.

Table C-1. Generalized life history timing for Central Valley steelhead and rainbow trout 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+, 1+ and older)	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Smolt Outmigration (Riverine/Delta)					▒	▒	■	■	■	▒		
Ocean Rearing and Adult Residency	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒

Note: Timing adapted from Stanislaus River data in NMFS (2009) with periods of life-stage absence (no shading), potential presence (grey), and peak activity (dark grey) shown.

Recognizing that not all factors affecting Tuolumne River steelhead//*O. mykiss* may be known or well understood, the identified issues and supporting discussion in the following sections attempt to identify factors that may potentially affect individual life-stages as well as overall population levels. The discussion below refers to habitat conditions corresponding to the life-history timing (Table C-1) and seasonal residency (Figure C-1) of various *O. mykiss* life stages, and assumes the reader has some familiarity with relevant information provided in the PAD as well as

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[1] The study area includes the Tuolumne River from La Grange Dam (RM 52) downstream to the confluence with the San Joaquin River (RM 0), the lower San Joaquin River from the Tuolumne River confluence (RM 84) to Vernalis (RM 69.3), the San Francisco Bay-Delta, and the Pacific Ocean.

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 *O. mykiss*. 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.

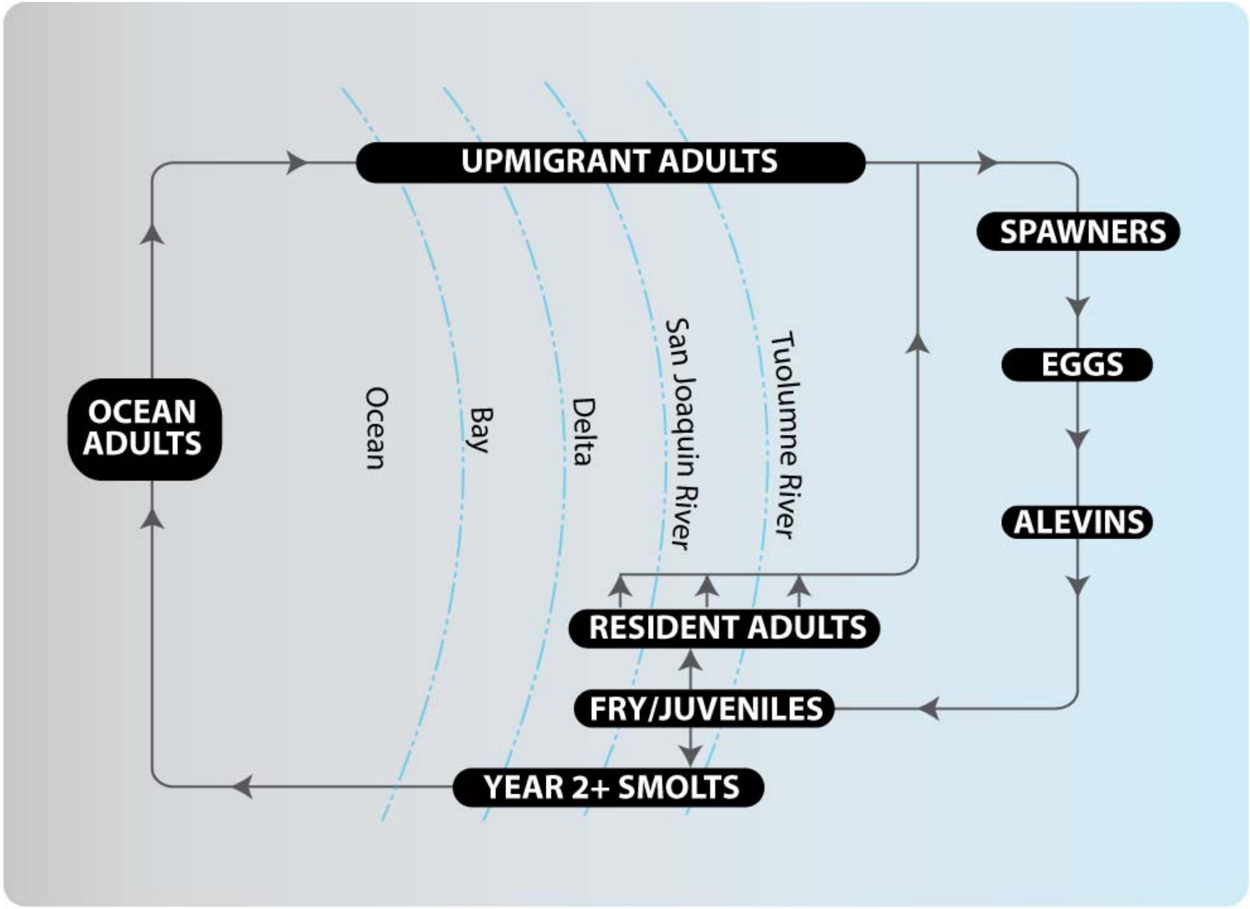

Figure C-1. **Central Valley steelhead and rainbow trout life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.**

2.0 STEELHEAD UPMIGRATION

As shown in Figure C-2, a number of factors may potentially homing fidelity, timing and potential mortality any Central Valley steelhead arriving in the lower Tuolumne River. Factors potentially affecting steelhead during upmigration through the San Francisco Bay estuary, Delta, lower San Joaquin, and Tuolumne Rivers include but are not limited to attraction flows, water quality, water temperature, as well as straying of hatchery origin fish from other river systems. Because of the limited information regarding upmigration of Central Valley steelhead as well as the low proportion of steelhead identified in otolith samples from Tuolumne River *O. mykiss*, (Zimmerman et al. 2009) the following section provides inferences regarding habitat conditions for any steelhead that may arrive in the Tuolumne River based upon data and reviews from other San Joaquin River tributaries, the Central Valley, as well as broader sources of information.

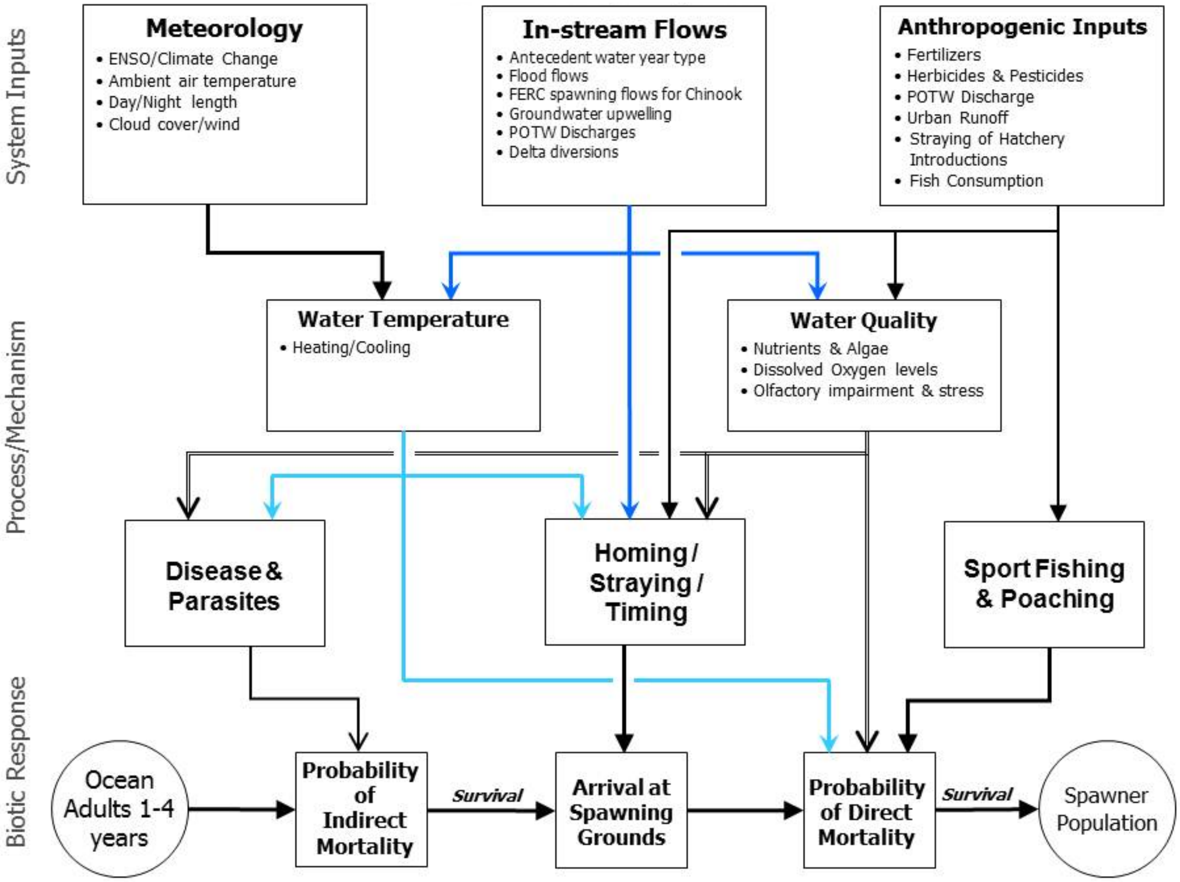

Figure C-2. Potential issues that may affect any Central Valley steelhead upmigration through the San Francisco estuary, Delta, lower San Joaquin River, and arrival in the Tuolumne River.

2.1 Processes/Mechanisms Affecting Arrival at Spawning Grounds

The only Tuolumne-specific information regarding potential steelhead arrival in the Tuolumne River are related to the examination of weir passage timing data compiled in annual FERC reports (e.g., TID/MID 2010, Report 2009-8; TID/MID 2011, Report 2010-8; TID/MID 2012, Report 2011-8) as well as historical accounts of steelhead passage by CDFG (*unpublished data*) from 1940 and 1942 at Dennet Dam (RM 16.2). Below, we discuss potential factors associated with variations in arrival timing, homing and straying of steelhead in the Tuolumne River. Because of the limited amount of information regarding steelhead timing, which is generally inferred from arrival timing in the nearby Stanislaus River (Table C-1), much of the discussion below is based upon assessment of habitat conditions in the lower San Joaquin and Tuolumne Rivers as well as studies from other river systems in California and the Pacific Northwest.

2.1.1 Flow Effects on Arrival Timing, Homing, and Straying

In addition to factors affecting instream flows and water temperatures in the San Joaquin River and Delta, anthropogenic inputs of nutrients may affect DO and result in unsuitable water temperature and water quality conditions for up-migrating steelhead during late summer periods. Although fall attraction pulse flows have been included in the current FERC (1996) license for the Tuolumne River, the low occurrences of upmigrant steelhead in the Tuolumne River (TID/MID 2012, Report 2011-8) precludes direct assessment of the relationship between arrival timing and flow. Adult steelhead are known to stray from their natal streams to spawn in nearby streams as an evolutionary adaptation to maximize reproductive opportunities and increase the likelihood of locating habitats favorable for both spawning and juvenile survival (e.g., Quinn 2005, Pearse et al. 2009). However, there are no known data describing the relationships between homing/straying of migrating adult steelhead and flows at Vernalis and SWP/CVP water exports, and the relationship between tributary homing and attraction flows remains poorly understood. Steelhead upmigration in coastal populations is generally associated with storm freshets to allow passage over barriers (e.g., Thompson 1972) and steelhead spawning in many California Rivers is generally associated with high flows (McEwan 2001). A confounding factor in the assessment of arrival timing with flow is that because the counting weir on the Tuolumne River is currently limited to flows in the range of 1,300 cfs and below (TID/MID 2012, Report 2011-8), no upstream passage estimates are available during flood control releases.

2.1.2 Water Temperature and Water Quality Effects on Homing, and Straying

Based upon arrival timing in the nearby Stanislaus River (Table C-1), steelhead may arrive in the lower Tuolumne at any time from July through March. Although WDOE (2002) demonstrated the potential for high water temperature to block upstream steelhead migration in Washington State rivers, weir passage in the Tuolumne River has been monitored since 2009 (TID/MID 2012, Report 2011-8) and few upmigrant *O. mykiss* arrived during October or late summer periods corresponding to high water temperatures in the San Joaquin River. Based upon the observation of juvenile *O. mykiss* in the Tuolumne River from February through May (Stillwater Sciences 2012a), the majority of upmigration likely occurs from November through March at a time when water temperatures are low and DO levels in the lower San Joaquin River, including the Stockton Deep Water Ship Channel, are not typically low enough to block or impede migration (Newcomb and Pierce 2010). Stillwater Sciences (2011) found only minor influences of fall pulse flows on water temperature near the San Joaquin River during summer and fall.

Because tributary homing is related to the sequence of olfactory cues imprinted during smolt emigration (Dittman and Quinn 1996), tributary homing and straying by steelhead may be affected by flow entrainment into the SWP and CVP export facilities, the relative amounts and timing of flows from San Joaquin River and east-side tributaries, as well as configurations of various barrier operations in the Delta (See Section 5.1.1 of the synthesis). Although inconclusive since no Tuolumne or San Joaquin River basin data are available to assess this issue, early life history exposure to trace metals, herbicides and pesticides may impair olfactory sensitivity (e.g., Hansen et al. 1999, Scholz et al. 2000, Tierney et al. 2010) and may potentially affect arrival of adult steelhead at Tuolumne River spawning grounds.

2.1.3 Influence of Hatchery Straying on Spawning Ground Arrival

Separate from potential instream flow, water quality, and water temperature issues discussed above, straying of hatchery-reared steelhead from other river systems may affect the numbers and timing of Tuolumne River origin fish arriving in the Tuolumne River. Straying of hatchery-reared fish is greater than their wild counter-parts in many river systems (CDFG and NMFS 2001), and this has been attributed from factors that range from hatchery practices and outplanting to non-natal rivers (Schroeder et al. 2001) to more complex factors such as the impairment of hormonal and physiological processes in hatchery settings that are associated with imprinting of olfactory cues necessary for homing (Björnsson et al. 2011). From the low numbers of steelhead documented by otolith analysis (Zimmerman et al. 2009), it is unknown whether the Tuolumne River supports a self-sustaining steelhead population or whether the observations of low numbers of anadromous *O. mykiss* were associated with instances of straying of steelhead reared in out-of-basin hatcheries. The majority of steelhead in the Central Valley are of common hatchery origin (Garza and Pearse 2008).

2.2 Processes/Mechanisms Affecting Direct Mortality

2.2.1 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 migrating adult steelhead. However, mortality of adult steelhead is unlikely to result from water quality impairments such as DO depletion from algal and bacterial respiration or from episodic toxicity events. For this reason, water quality effects on direct mortality during steelhead upmigration are not considered further in this Synthesis Study.

2.2.2 Water Temperature

Meteorology and to a minor degree, instream flows, combine to affect exposure of up-migrating adult steelhead to changes in water temperatures. However, given the general up-migration timing of adult steelhead (i.e., winter-run life history), avoidance of unsuitable water temperatures for any early arriving steelhead adult upmigrants is expected. For this reason, water temperature effects on direct mortality during steelhead upmigration are not considered further in this Synthesis Study.

2.2.3 Sportfishing and Poaching

Mortality due to bycatch of Central Valley steelhead in the commercial Chinook salmon troll fishery may potentially reduce the numbers of upmigrant adults to the Tuolumne River (Section 7.2.2). Inland sportfishing and illegal poaching may also affect the number of steelhead adults that return to their natal streams to spawn, and in turn, affect subsequent juvenile production. Sportfishing occurs mostly in the Bay and Delta, but also in the San Joaquin River system prior to the October angling closure in the tributaries (i.e., fishing is banned from November 1st through December 31st). Annual fishing report cards (Jackson 2007) do not provide sufficient data to quantitatively assess hooking mortality or other sportfishing impacts. Removal of steelhead from the wild is currently banned in the lower Tuolumne River and San Joaquin River upstream of the Delta (<http://www.dfg.ca.gov/regulations/>). Although no data are available to evaluate potential impacts of poaching, McEwan and Jackson (1996) did not believe that legal harvest in the years prior to listing Central Valley steelhead were associated with apparent population declines. For these reasons, effects of sportfishing and poaching on direct mortality during steelhead upmigration are considered to be unknown, but unlikely to affect *O. mykiss* population levels.

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. During Upmigration through the Delta and lower San Joaquin River, elevated water temperatures and adverse water quality conditions which in turn, may contribute to stress and disease (Holt et al. 1975, Wood 1979). Wild steelhead may also contract diseases which are spread through the water column (Buchanan et al. 1983), and in some cases disease may lead to mortality of adults prior to spawning, though this has not been documented in the Tuolumne River. Many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for *Renibacterium salmoninarum* (Foott 1992). However, there are no known data indicating that disease or parasites are likely to contribute to indirect mortality (e.g., via physiological stress or pre-spawn mortality) for adult steelhead during upstream migration to the Tuolumne River. Given the general up-migration timing of adult steelhead (i.e., winter-run) and because of the short exposure time to potentially adverse water quality conditions during upmigration, disease and parasite effects upon steelhead during upmigration are not considered further in this synthesis.

3.0 *O. MYKISS* SPAWNING

As shown in Figure C-3, several processes and mechanisms may potentially affect spawning success of *O. mykiss* in the lower Tuolumne River, including meteorological and instream flow effects upon sediment transport, spawning area availability, spawning gravel quality, water temperature, as well as the influence of stray hatchery fish from other systems. Although little evidence of *O. mykiss* spawning has not been observed in the Tuolumne River to date, the following section provides inferences regarding habitat conditions for any *O. mykiss* spawning that may occur in the Tuolumne River based upon assessments of local habitat conditions, data and reviews from other San Joaquin River, the Central Valley, as well as broader sources of information.

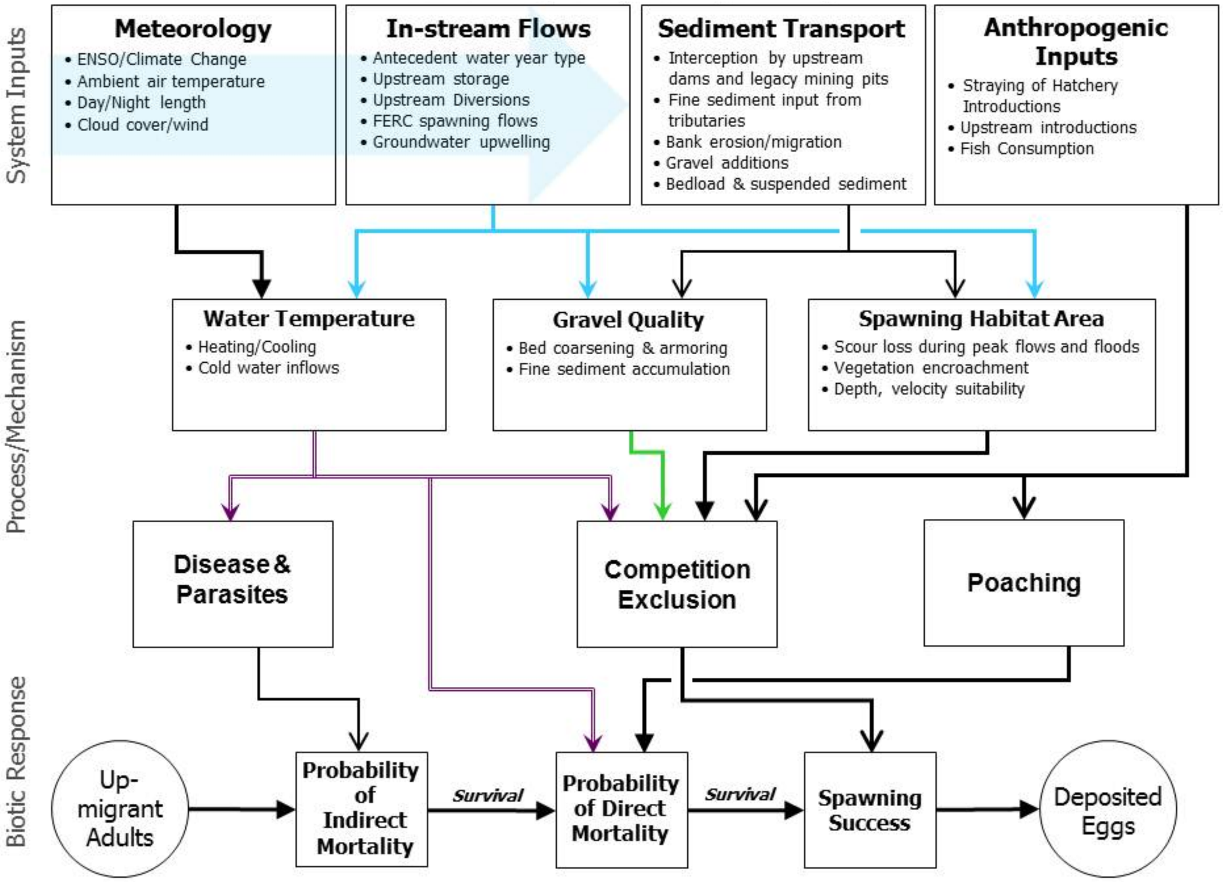

Figure C-3. Potential issues affecting *O. mykiss* spawning in the lower Tuolumne River.

3.1 Processes/Mechanisms affecting Spawning Success

3.1.1 Effects of Spawning Habitat Availability

As with the corresponding discussion for Chinook salmon above, Figure C-3 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). Other than isolated observations of *O. mykiss* carcasses in annual spawning reports (e.g., TID/MID 2001, Report 2001), spawning locations used by *O. mykiss* has not been well documented in spawning surveys extending from mid-October to mid-January in most years (e.g., TID/MID 2012, Report 2011-2). Roelofs (1983) suggested that steelhead may use smaller tributary streams for spawning to reduce mortality risks due to redd scour as well as lower predator densities. The current *Redd Mapping Study* (Study W&AR-8) will document locations of any *O. mykiss* spawning occurring in 2013 and the current *Spawning Gravel Study* (W&AR-4) provides an estimate of gravel availability and the river-wide distribution of suitable spawning habitat.

Assuming that the area required per spawning pair is approximately four times the average redd size (Burner 1951) and a representative average *O. mykiss* redd size is 47 ft^2 based on studies conducted in Washington and Idaho (Hunter 1973, Reiser and White 1981), the average area required per spawning pair is on the order of 200 ft^2. Adult steelhead are typically larger than resident *O. mykiss* and resident fish require less space for spawning. For this reason, potential competition by resident *O. mykiss* and steelhead for spawning habitat and subsequent exclusion would only be likely under very high resident population levels and/or high anadromous escapements. The current *Redd Mapping Study* (W&AR-8) will provide information on spawning habitat availability for *O. mykiss* and the number and locations of redds in the lower Tuolumne River. Although spawning gravel area availability documented in the current *Spawning Gravel Study* (W&AR-4) is adequate to support a large number of spawning *O. mykiss* without space limitation, the ongoing IFIM study (Stillwater Sciences 2009) will provide estimates of habitat maximizing flows for *O. mykiss* spawning.

3.1.2 Effects of Spawning Gravel Quality

The spawning area estimates included in the *Spawning Gravel Study* (W&AR-4) is based on a wide gravel size range of 6–102 mm (median diameter, or D_{50}) which includes gravel suitable for spawning both by Chinook salmon and *O. mykiss*. The size range of suitable spawning gravel for *O. mykiss* includes smaller gravel than the range of suitable spawning gravel for Chinook salmon. As reported by Kondolf and Wolman (1993) the average D_{50} of *O. mykiss* spawning gravel is 25 mm, with a range of 10–46 mm. Recent gravel additions at Bobcat Flat (RM 43) were selected at sizes that allow spawning by both *O. mykiss* and Chinook salmon, gravel that is too large and thus unsuitable for spawning by *O. mykiss* may result in competition for suitable spawning sites and reduced spawning success. The large gravel area estimates in the current Spawning Gravel Study (W&AR-4) suggest that suitable gravel areas are available river-wide. The current *Redd Mapping Study* (W&AR-8) will provide additional information on the influence of gravel quality upon spawning site selection by *O. mykiss*.

3.1.3 Effects of Water Temperature

Water temperature may affect the suitability and use of available spawning habitat by *O. mykiss* (e.g., Reiser and Bjornn 1979). The ongoing IFIM Study (Stillwater Sciences 2009) will integrate PHABSIM results with modeled water temperature to evaluate effects of water temperature on habitat suitability for spawning *O. mykiss*. Previous HEC-5Q water temperature modeling based on 1980–2007 meteorology (Stillwater Sciences 2011) indicates that an average flow of 50 cfs or less would be required to maintain a maximum weekly average temperature (MWAT) of 13ºC (55.4ºF) from La Grange Dam downstream to Roberts Ferry Bridge (RM 39.5) from late November–early February, which corresponds with the first half of the *O. mykiss* spawning period (Table C-1). Higher flows would be required to meet these conditions during the February–March peak *O. mykiss* spawning period, but these criteria have not been modeled.

Given that the majority of *O. mykiss* spawning occurs in winter and early spring (Table C-1) when water temperature is naturally lowest, water temperature is not expected to reduce the suitability and use of spawning habitat under most meteorological and flow conditions. For this reason, water temperature effects on *O. mykiss* spawning success are not considered further in this Synthesis Study.

3.1.4 Effects of Hatchery Straying

Competition for suitable spawning sites between introduced hatchery fish and resident *O. mykiss* may potentially limit spawning success of any wild steelhead arriving in the Tuolumne River. Because hatchery fish generally stray at higher rates than wild fish (Björnsson et al. 2011) and are typically smaller at return than their wild counter parts at return (Flagg et al. 2000), hatchery straying may result in reduced fecundity of any spawning females in the Tuolumne River as well as reductions in subsequent juvenile production. However, from the low numbers of steelhead vs. resident *O. mykiss* that were documented in otolith analyses by Zimmerman et al. (2009), it is likely that the majority of any spawning observed will be of resident *O. mykiss* origin. For these reasons, although hatchery straying likely affects the amounts of steelhead spawning in the lower Tuolumne River, because of the absence of any basin-specific data on spawning or straying from out-of-basin hatcheries, available data are insufficient to determine the proportion of hatchery-origin steelhead that may potentially spawn in the lower Tuolumne River. Further compounding this uncertainty is the fact that most steelhead in the Central Valley are genetically similar (Pearse et al. 2009) and are of common hatchery origin (Garza and Pearse 2008) due to historical planting operations and straying.

3.2 Processes/Mechanisms Affecting Direct Mortality

3.2.1 Sportfishing and Poaching

Illegal poaching of adult *O. mykiss* in the lower Tuolumne River during the spawning period has not been quantified, but potentially reduces the number of adults that successfully spawn. Annual fishing report cards (e.g., Jackson 2007) do not provide sufficient data to quantitatively assess hooking mortality or other sportfishing impacts. Although no data are available to evaluate potential impacts of poaching, McEwan and Jackson (1996) did not believe that legal harvest in the years prior to listing Central Valley steelhead were associated with apparent population declines. For these reasons, effects of sportfishing and poaching on direct mortality during and following *O. mykiss* spawning are considered to be unknown, but unlikely to affect overall population levels.

3.2.2 Water Temperature

Meteorology and instream flows combine to affect exposure of spawning adults to changes in water temperatures. No information is available regarding pre-spawning mortality of steelhead. Given the general up-migration timing of adult steelhead (i.e., winter-run), water temperature effects on pre-spawn mortality are unlikely. Previous HEC-5Q water temperature modeling based on 1980–2007 meteorology (Stillwater Sciences 2011) indicates that an average flow of 50 cfs or less would be required to maintain a maximum weekly average temperature (MWAT) of 13ºC (55.4ºF) from La Grange Dam downstream to Roberts Ferry Bridge (RM 39.5) from late November through early February, which corresponds with the first half of the *O. mykiss* spawning period (Table 5-3). For this reason, effects of water temperature on direct mortality during steelhead spawning are not considered further in this Synthesis Study.

3.3 Processes/Mechanisms Affecting Indirect Mortality

3.3.1 Disease and Parasites

Meteorology and instream flows in the lower Tuolumne River combine to affect exposure of pre-spawning adults to changes in water temperatures, which in turn, may contribute to stress and disease (Holt et al. 1975, Wood 1979). Disease incidence may be also related to prior exposure to unsuitable water temperatures and water quality in the Delta and exposure to water-borne pathogens or interactions with other infected/infested fish (Fryer and Sanders 1981; Evelyn et al. 1984). Wild steelhead may also contract diseases which are spread through the water column (Buchanan et al. 1983), and in some cases disease may lead to mortality of adult *O. mykiss* prior to spawning, though this has not been documented in the Tuolumne River. Increased incidence of disease and parasites due to unsuitably high water temperature is not expected because adult steelhead can generally tolerate higher water temperatures during upstream migration than any other life stage (Myrick and Cech 2001), and the typical winter and spring migration of adult steelhead (Table C-1) coincides with the period of lowest water temperatures. For these reasons, disease and parasites are considered unlikely to reduce *O. mykiss* spawning success and are not considered further in this Synthesis Study.

4.0 EGG INCUBATION

As shown in Figure C-4, several processes and mechanisms may potentially affect egg incubation and fry emergence of *O. mykiss* 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 *O. mykiss* spawning has not been well documented in the Tuolumne River to date, the following section provides inferences regarding habitat conditions for any *O. mykiss* spawning that may occur in the Tuolumne River based upon assessments of local habitat conditions, data from juvenile monitoring, as well as inferences from reviews of other information sources from the San Joaquin River, the Central Valley, and the Pacific Northwest.

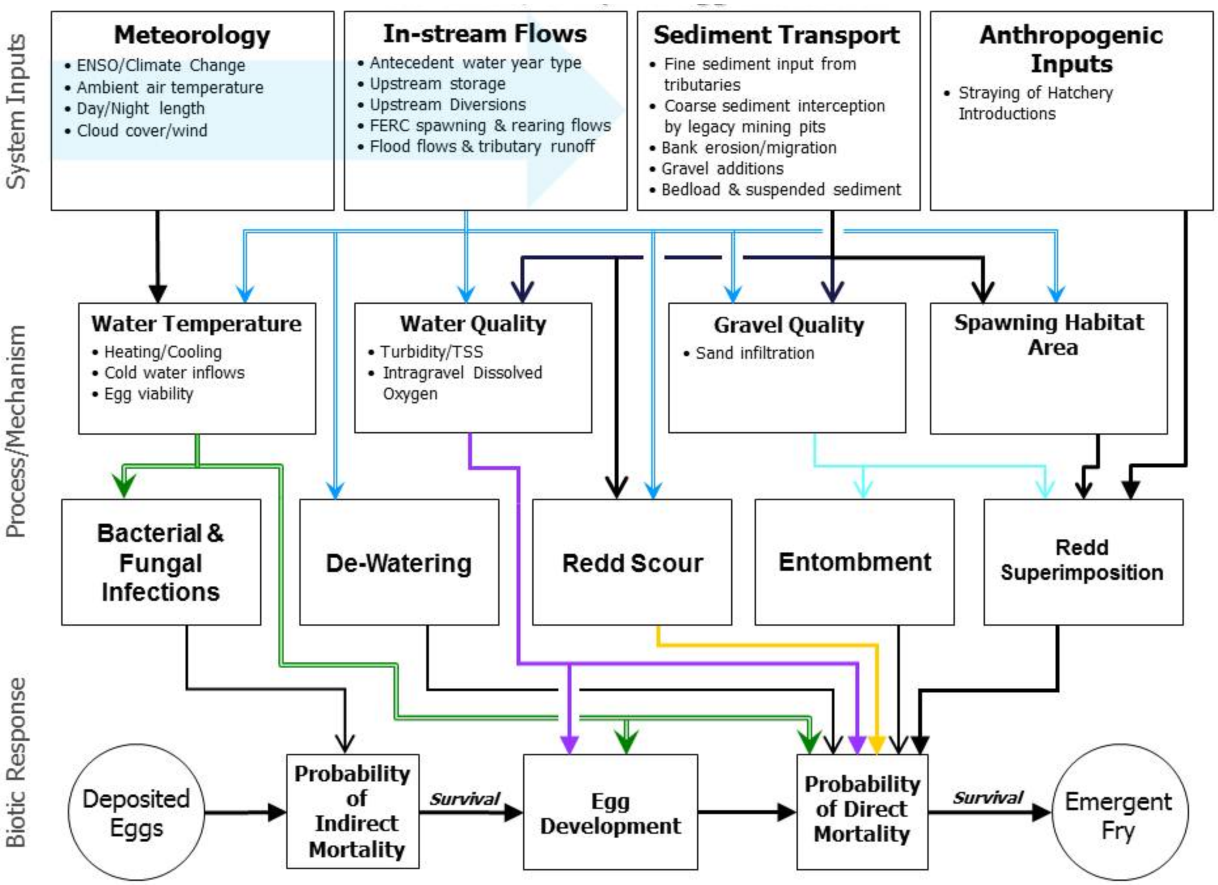

Figure C-4. Potential issues affecting *O. mykiss* egg incubation, alevin development, and fry emergence in the lower Tuolumne River.

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 *O. mykiss* embryo development (Myrick and Cech 2001, Wales 1941), suitable water temperatures are required for proper *O. mykiss* embryo and alevin development and emergence. Alterations in instream flow magnitude and timing, as well as inter-annual and decadal changes in climate and meteorology (Section 5.2.1.4) affect water temperature or incubating *O. mykiss* in the Tuolumne River. Myrick and Cech (2004) report there are no published peer-reviewed studies on the effects of temperature on the development and survival of Central Valley steelhead egg/alevin life stage and no direct spawning observations of *O. mykiss* on the Tuolumne River are available to gain inferences on incubating *O. mykiss* eggs. Although the current *Redd Mapping Study* (W&AR-8) will provide additional information on water temperature conditions at any identified spawning redds, available relationships (e.g., Wales 1941, Velsen 1987) allow the estimation of incubation rates and emergence timing with water temperature.

4.1.2 Water Quality

As with water temperature discussed above, successful *O. mykiss* 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) and in prior assessments during spring 2004 (TID/MID 2005b, Report 2004-10). Intragravel dissolved oxygen conditions measured in artificial redds during February 2001 were in the range of 7–12 mg/L (TID/MID 2007, Report 2006-7) and it is unlikely that dissolved oxygen levels are adversely affecting egg incubation or alevin development.

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. No studies were identified examining reduced egg viability due to antecedent water temperatures in the Tuolumne River or other San Joaquin River tributaries. Myrick and Cech (2001) report steelhead eggs can survive at water temperatures of up to 15ºC (59ºF). Intragravel water temperatures were measured during February and March 1991 at several locations in the lower Tuolumne River, generally fluctuating between 11–15°C (51–58°F)(TID/MID 1997, Report 96-11). Given that the majority of *O. mykiss* spawning occurs in winter and early spring (Table C-1) when water temperature is naturally lowest, water temperature is not expected to result in high rates of egg mortality under most meteorological and flow conditions. Although the current *Redd Mapping Study* (W&AR-8) will provide additional information on the locations of any spawning redds, it is likely that any potentially unsuitable water temperatures would be restricted to spawning locations farther downstream and for spawning occurring later in the spring (e.g., late March or April).

4.2.2 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). Intragravel dissolved oxygen measurements were found in the range of 7–12 mg/L on the Tuolumne River (TID/MID 2007, Report 2006-7) and intragravel dissolved oxygen conditions measured in Chinook salmon incubation studies on the nearby Stanislaus River also generally ranged near 8–11 mg/L (Mesick 2002). Based upon these studies, although no *O. mykiss* spawning has been documented to date, it is unlikely that intragravel water quality conditions contribute to high rates of egg mortality on the Tuolumne River.

4.2.3 Redd Superimposition

Although evidence of competition by Chinook salmon for suitable spawning areas and Chinook salmon egg mortality from redd superimposition was documented in the Tuolumne River in 1988 and 1989 (TID/MID 1992, Appendix 6), no similar evidence of competition for space exists for spawning *O. mykiss* in the Tuolumne River. Very low levels of redd superimposition (1 of 51 redds, or 2%) by steelhead in the Mokelumne River were recently documented by Del Real and Rible (2009). The current *Redd Mapping Study* (W&AR-8) will provide information on *O. mykiss* spawning and any observations of redd superimposition. However, the likelihood of direct *O. mykiss* egg mortality due to redd superimposition in the lower Tuolumne River is low.

4.2.4 Redd Scour

McBain and Trush (2000) suggested 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. The depth of egg pockets for *O. mykiss* redds is generally lower than for Chinook salmon (Devries 1997). 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, and the current *Redd Mapping Study* (W&AR-8) may identify redd locations particularly vulnerable to scour, redd scour is not considered to contribute to high rates of direct egg mortality of *O. mykiss* 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, because *O. mykiss* spawning may occur later during the winter spring there is an increased likelihood of *O. mykiss* spawning at locations more vulnerable to dewatering during extended flood control releases. 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 incidences of *O. mykiss* stranding or dewatering were identified during literature reviews for this Synthesis. For this reason, only isolated redd dewatering incidents may potentially occur during flow reductions following flood control releases as well as during unplanned operational outages. Although the current *Redd Mapping Study* (W&AR-8) may identify redd locations particularly vulnerable to dewatering, redd dewatering is not considered to contribute to high rates of egg mortality and is not considered further in this Synthesis.

4.2.6 Entombment

Fine sediment intrusion was suggested to contribute to Chinook salmon egg and alevin mortality in prior survival-to-emergence modeling (TID/MID 1992, Appendix 8; TID/MID 2001, Report 2000-7), and fine sediment 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, Barnhart 1986). The current *Redd Mapping Study* (W&AR-8) may identify redd locations vulnerable to entombment from fine sediment intrusion, such as at the mouths of Gasburg, Peaslee, and Dominici Creeks that have been shown to provide a continuing source of fine sediments to the lower Tuolumne River (McBain and Trush 2004, Appendix E). However, based upon suitable intra-gravel dissolved oxygen and the absence of entombment in Chinook salmon survival-to-emergence studies (TID/MID 2001, Report 2000-7), *O. mykiss* egg/alevin entombment mortality is unlikely.

4.3 Processes/Mechanisms Affecting Indirect Mortality

4.3.1 Bacterial and Fungal Infections

No information has been identified on disease incidence for incubating *O. mykiss* eggs in the Central Valley or in broader studies. 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, 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 of steelhead/*O mykiss* and is not considered further in this Synthesis.

5.0 IN-RIVER REARING/OUTMIGRATION

As shown in Figure C-5, several processes and mechanisms may potentially affect growth and survival of juvenile *O. mykiss* in the Tuolumne River, including meteorological and instream flow effects on sediment transport, in-channel habitat availability, water temperature, water quality, food availability, predation, entrainment, and mortality related to any sportfishing or illegal poaching that may occur.

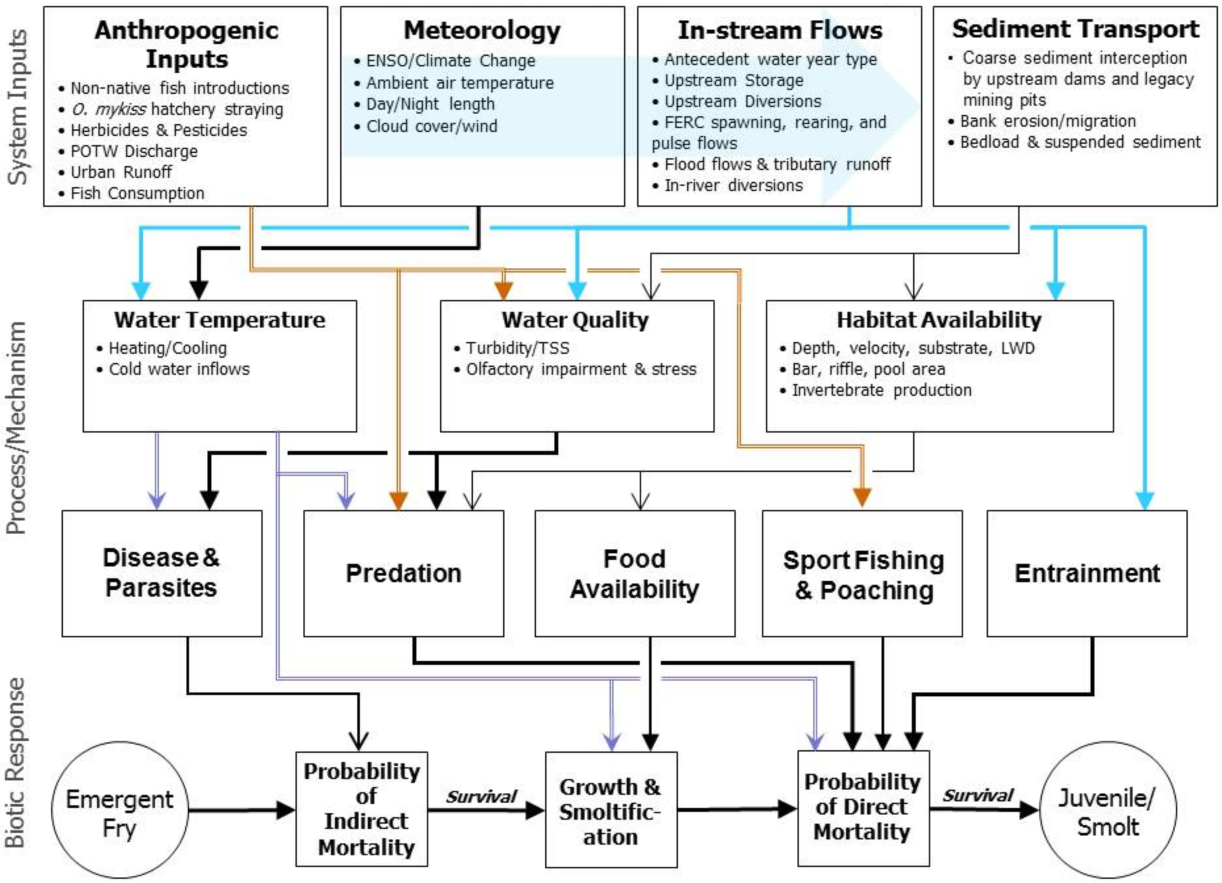

Figure C-5. Potential issues affecting in-river rearing of juvenile *O. mykiss* and smolt emigration of any Central Valley steelhead from the lower Tuolumne River.

5.1 Processes/Mechanisms affecting Juvenile Growth and Smoltification

5.1.1 In-channel and Floodplain Habitat Availability

Following emergence in winter and spring, *O. mykiss* fry generally occupy shallow, low-velocity areas near the stream margin and may use interstitial spaces among cobble substrates for resting and cover habitat (Bustard and Narver 1975). Juvenile *O. mykiss* (<150-mm) as well as Age 1+ and older adult fish (>150 mm) have been routinely documented during summer snorkel surveys since the 1980s (Ford and Kirihara 2010). Recent river-wide snorkel survey observations since 2001 are shown in Table C-2, which shows both Age 0+ and older age classes documented in snorkel surveys at one or more sites upstream of Roberts Ferry Bridge (RM 39.5) in summer (July-September). Habitat suitability for juvenile *O. mykiss* is highly influenced by water temperature which, in the lower Tuolumne River like many regulated rivers, is highly dependent on flow. Using previous models of water temperature (TID/MID 1992, Appendix 18) and habitat suitability with flow from a 1992 IFIM evaluation (USFWS 1995), Stillwater Sciences (2003) estimated the effective weighted usable area (EWUA) based on suitable depths, velocities, and temperatures at several periods during late summer and early fall (August 2-6, September 1-5, and October 1-5). For example, results for juvenile *O. mykiss* indicate that in most years, flows of approximately 150–200 cfs would generally meet a 21°C (70°F) temperature objective in early August as far downstream as Roberts Ferry Bridge (RM 39.5). For adults, habitat maximizing flows at this threshold were found to occur in the range of 300–350 cfs, but due to the associated velocity increases these flows would result in reduced usable habitat area for juveniles. The results suggest a trade-off may exist between the downstream extent of cool water habitat and the potential for unsuitable high velocities for over-summering Age 0+ *O. mykiss* at higher discharge. Although Table C-2 shows increased numbers of *O. mykiss* were observed in snorkel surveys during recent years with higher summer flows (e.g., 2005, 2006, 2010, 2011), the ongoing IFIM study (Stillwater Sciences 2009a) is expected to provide more up-to-date results on the relationship between in-channel rearing habitat and flow, as well as water temperature.

Table C-2. River-wide distribution and number of *O. mykiss* observed (all sizes combined) in Tuolumne River snorkel surveys, 2001–2011.

Location	River Mile	2001		2002		2003		2004			2005	2006	2007		2008	2009	2010		2011	
		June	September	June	September	June	September	June	August	September	September	September	June	September	June	June	August	November	September	November
Riffle A3/A4	51.6								5											
Riffle A7	50.7	7	3	5	1	66	16	12	6	11	10	115	106	75	76	80	35	33	249	6
Riffle 1A	50.4								4											
Riffle 2	49.9	3	3	1	4	8	2	23	2	7	7	15	34	16	9	12	58	67	203	27
Riffle 3B	49.1	8	1	11	1	5	21	22	5	7	6	66	45	12	78	27	73	67	261	8
Riffle 4B	48.4								8											
Riffle 5B	48.0	4	2	3	0	6	10	11	15	6	36	54	92	10	21	11	26	16	149	41
Riffle 7	46.9	4	0	5	2	14	9	13	5	2	2	106	22	7	13	6	25	6	88	9
Riffle 9	46.4								3											
Riffle 13A–B	45.6	3	0	2	4	1	6	5	13	0	46	103	15	57	24	4	33	14	129	8
Riffle 21	42.9	2	3	1	0	0	6	5	9	7	15	32	10	10	11	0	8	2	33	8
Riffle 23B–C	42.3	0	0	0	0	1	1	0	1	0	14	27	5	7	0	2	9	10	52	32
Riffle 30B	38.5			0	0															
Riffle 31	38.1	0	0			0	0	0	0	0	1	21	12	4	0	0	1	0	10	2
Riffle 35A	37.0			0	0	0	0	0	0	0	2		0	0	0	0	0	0	3	0
Riffle 36A	36.7											4								
Riffle 37	36.2	0	0																	
Riffle 41A	35.3	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	3	2	6
Riffle 57–58	31.5	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	1
Total *O. mykiss*		**31**	**12**	**28**	**12**	**101**	**71**	**91**	**76**	**40**	**139**	**543**	**343**	**198**	**232**	**142**	**268**	**218**	**1179**	**148**

At river flows near bankfull discharge and above, two-dimensional (2D) hydraulic modeling was conducted by in 2011 conducted 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 at the study sites (Stillwater Sciences 2012b). Although juvenile *O. mykiss* are generally not found using floodplain habitats in the Tuolumne River or in floodplain studies in the Cosumnes River (Moyle et al. 2007), the results of the study show increased flows are associated with increased areas of suitable juvenile rearing habitat on floodplains 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 the majority of floodplain habitat available at the flows studied (1,000–5,000 cfs) is limited to several disturbed areas between RM 51.5 and RM 42 formerly overlain by dredger tailings (Stillwater Sciences 2012).

During intensive summer snorkel surveys conducted from 2008–2011, juvenile *O. mykiss* (<150-mm) were found primarily in riffle habitats, whereas adult-sized fish (>150 mm) were found primarily in run and pool heads at riffle tailouts (Stillwater Sciences 2008, 2009; TID/MID 2011, Report 2010-6; TID/MID 2012, Report 2011-6). Adult fish have also been documented to use these run and pool head habitats by local anglers, extending from La Grange Dam (RM 52) downstream to near Roberts Ferry Bridge in some years (CRRF 2004). In the recent snorkel surveys, where In the recent snorkel surveys, where juvenile and adult-sized fish co-occurred, juveniles were typically found at 2–10 times greater densities than adult-sized fish. Similar relationships in typical rearing densities of Age 0+ and Age 1+ fish has been found in other studies (Grant and Kramer 1990). Figure C-6 also shows some density-dependent effects within the upstream portions of pool habitats near riffle tailouts that were sampled between 2008–2001. Increasing Age 1+ densities generally correspond to lower Age 0+ densities in these habitats, whereas Figure C-6 shows little density dependence is apparent in in pool body habitats and none in runs or riffles. Interestingly, the density relationship for riffle/run transitions ("Run Head") was more similar to riffles than the corresponding patterns for riffle/pool transitions ("Pool Head"), suggesting depths and hydraulics may provide markedly differing habitat conditions for rearing *O. mykiss*. As discussed further in the current *O. mykiss Habitat Survey Study* (W&AR-12), other than riffle/pool transitions, few structural elements such as instream wood or boulders are available for juvenile and adult *O. mykiss*. Although increased structure has been shown to reduce defended territory size (Imre et al. 2002) and improve steelhead feeding opportunities (Fausch 1993), it is unlikely that the alluvial portions of the Tuolumne River downstream of La Grange dam historically supported large wood or boulder features that are more typically found in high gradient streams of the Central Valley and along the coasts of California and Oregon.

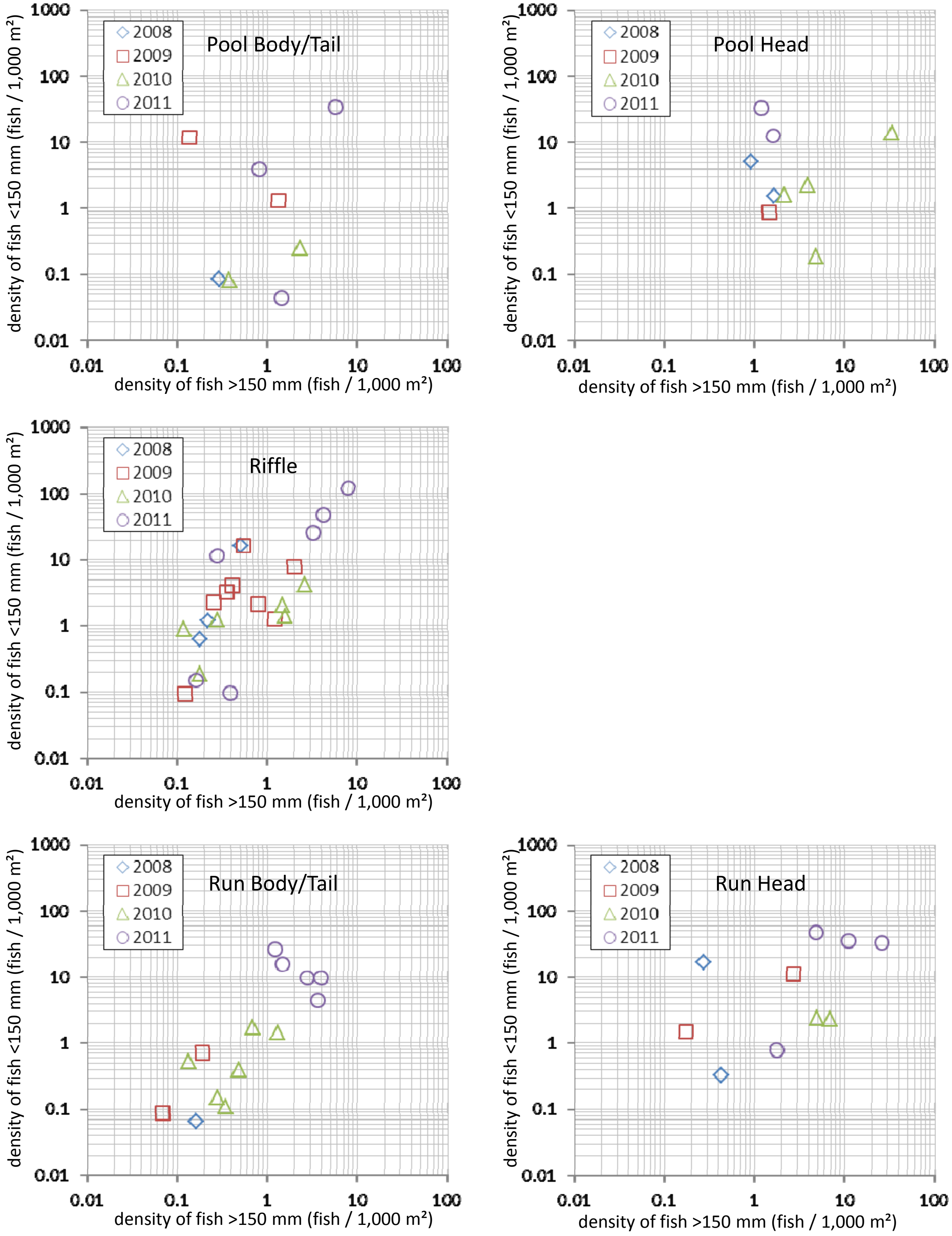

Figure C-6. **Comparison of Age 0+ vs. Age 1+ *O. mykiss* density in various habitat types sampled by snorkeling in the Tuolumne River (2008-2011).**

5.1.2 Water Temperature Effects on Growth and Smoltification

Potential direct mortality effects of water temperature on juvenile *O. mykiss* survival are discussed separately below. Juvenile steelhead rear for at least one full summer in fresh water and they must necessarily be present in streams when seasonal water temperatures are at their highest. Whereas *O. mykiss* that exhibit an anadromous life history strategy typically spend 1–3 years in their natal stream before moving downstream to the estuary and the ocean (McEwan 2001), resident *O. mykiss* are subject to summer water temperatures annually for the duration of their lifespan.

Water temperature in the lower Tuolumne River is highest during summer and early fall, during which time the effects of high water temperature on the amount of suitable rearing habitat are likely to be most pronounced. Flows of 300–500 cfs were estimated to be required to meet a MWAT temperature objective of 18ºC (64.4ºF) in July (Stillwater Sciences 2011), which is generally the hottest month of the year. Mean annual air temperatures are expected to increase by as much as 2.2–5.8°C (4.0–10.4ºF) statewide under a range of climate change scenarios over the next century (Loarie et al. 2008), with accompanying increases in water temperatures expected (Wagner et al. 2011). The potential for summer water temperature to limit juvenile *O. mykiss* rearing success may likewise increase. Annual *O. mykiss* reference surveys from 2001–2011 indicate that juvenile abundance in the lower Tuolumne River is consistently lower in fall than in summer (Table C-2), suggesting a summer rearing habitat limitation. The maximum densities of oversummering *O. mykiss* that a given habitat area can support are determined by territorial/agonistic behavior, both intraspecific and interspecific with other salmonids when they are present (Everest and Chapman 1972). This behavior results in density-dependent emigration or mortality of juveniles that do not successfully establish and defend territories.[2] For larger adults tracked as part of a FERC-Ordered acoustic-tagging study, preliminary results indicate that all acoustically tagged *O. mykiss* remained within the Tuolumne River during the study, with only two of fourteen fish showing upstream or downstream movements of a few miles (TID/MID 2012, Report 2011-7).

Water temperature also affects fish metabolism, with higher temperatures increasing metabolism and thus requiring greater food intake to support growth. Growth of juvenile steelhead during their freshwater rearing period is believed to be critical to their attaining a size that will promote survival during outmigration and ocean phases. Growth rates of steelhead with ration and water temperature have been estimated in the laboratory (Wurtsbaugh and Davis 1977, Myrick and Cech 2005) and increased water temperatures have been shown to increase the metabolic rate of juvenile steelhead, thereby increasing energy requirements beyond that which can be met by available food resources and effectively curtailing growth. Although only low numbers of *O. mykiss* are captured in biweekly seine surveys to allow estimation of growth rates for Age 0+ fish, depending on assumptions regarding spawning and emergence timing, size at capture data

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[2] The physical habitat requirements for different age classes of *O. mykiss* are relatively similar, except that as the fish age and grow their requirements for space tend to become more restrictive. Age 0+ juveniles can use shallower habitats and finer substrates (e.g., gravels) than age 1+ adult fish, which, because of their larger size, need coarser cobble/boulder substrate for velocity cover while feeding and escape cover from predators. Because age 0+ *O. mykiss* can generally utilize the habitats suitable for age 1+ adults, but age 1+ fish cannot use shallower and/or finer substrate habitats suitable for age 0+ juveniles, it is unlikely that summer habitat will be in shorter supply for age 0+ than age 1+ *O. mykiss*.

for Age 0+ *O. mykiss* is within the broad range predicted by growth rates 0.2–0.9 mm/day found in coastal watersheds (Moyle et al. 2008) as well as the Mokelumne River (Merz 2002). Annual growth rate estimates for Tuolumne River *O. mykiss* between Age 1 and Age 4 are provided in the current *O. Mykiss Scale Collection and Age Determination Study* (W&AR-20).

In addition to growth rates, steelhead smoltification is affected by water temperatures (Myrick and Cech 2001), growth rates, as well as genetic influences. Several studies have shown strong relationship between the size at which a steelhead smolt migrates to the ocean and the probability that it returns to freshwater to spawn (Kabel and German 1967, Hume and Parkinson 1988). Beakes et al. (2010) conducted a recent laboratory study of hatchery steelhead from the Scott Creek (Central California Coast ESU) and from Battle Creek (Central Valley ESU), demonstrating that higher temperatures and food levels contributed to higher growth rates, fish size, and greater survival rates through the transformation to smolts. However, the study also showed differing growth trajectories of the two populations that were evident even before the experimental treatments were initiated. This suggests a genetic factor may explain early life history "decisions" regarding anadromy that is not well explained. In a literature review by T.R. Payne and Assoc, and S.P. Cramer and Assoc, (2005), greater extremes in environmental conditions such as the effect of water temperature variability on smoltification (e.g. Clarke and Hirano 1995) appears to affect the degree of anadromy expressed in local *O. mykiss* populations. As seems to have occurred for *O. mykiss* in the upper mainstem Sacramento River below Keswick Dam (McEwan 2001), stable flows and water temperatures in tailwater fisheries may select for a largely residential life history.

5.1.3 Food Availability Effects on Growth and Smoltification

As with Chinook salmon juveniles, food availability and growth rates of juvenile *O. mykiss* are affected by BMI, terrestrial and aquatic insect drift. No direct studies of *O. mykiss* feeding or diet have been conducted on the Tuolumne River. General steelhead diet information is well documented in the literature (Shapolov and Taft 1954, Bilby et al. 1998), and the diets of sub-yearling steelhead have been described for the American River (Merz and Vanicek 1996). As summarized by Merz (2002) for a Mokelumne River study, the diet of Age 0+ steelhead on the lower Mokelumne River was comprised of larval insects; similar to that reported by other studies. Long-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 for juvenile salmonids. For older age classes (Age 1+ and above), opportunistic feeding of upon other prey items as well as attached algae was observed on the Mokelumne River, and stomach content analysis also revealed the presence of Chinook salmon eggs and newly emerged fry in their diets during fall and winter 1998 (Merz 2002). Although no data are available to assess the condition of *O. mykiss* juveniles in the lower Tuolumne River, the high lipid content in Tuolumne River Chinook salmon smolts studied by Nichols and Foott (2002) suggest adequate food resources for rearing and potential smoltification of steelhead. However, because Tipping and Byrne (1996) found that artificial food limitation and lower condition factor in *O. mykiss* promoted a greater tendency for smoltification and outmigration than smolts that had higher food levels and higher condition factor, it is unknown whether the relatively high food availability in the Tuolumne River may currently select for a greater proportion resident *O. mykiss* rather than anadromous steelhead.

5.2 Processes/Mechanisms Affecting Direct Mortality

5.2.1 Water Temperature

Meteorology and to a minor degree instream flows combine to affect exposure of rearing juvenile *O. mykiss* trout 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. In a water temperature review by Myrick and Cech (2001), juvenile Central Valley steelhead 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. Using a critical thermal maxima of 25°C (77°F) identified by Myrick and Cech (2001) associated with the increased probability of water temperature related mortality, water temperatures may exceed this threshold by July and August in some summers in the vicinity of Robert's Ferry Bridge (RM 39.5), with temperatures in excess of this level routinely found during summer at locations downstream of RM 23.6 (TID/MID 2005a). Although low rates of mortality due to water temperature are suggested by reduced numbers of over-summering juvenile *O. mykiss* (Table C-2), direct temperature mortality of juveniles is unlikely to occur during springtime rearing and emigration. 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, low rates of water temperature related mortality are likely to occur for over-summering juvenile *O. mykiss* excluded from preferred cold water rearing habitats nearest La Grange Dam (RM 52).

5.2.2 Predation

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 (e.g., TID/MID 1992, Appendix 22). Many of the same mechanisms may potentially limit Age 0+ *O. mykiss* survival in habitats preferred by predatory fish species. Non-native largemouth and smallmouth bass have been found to prey on juvenile Chinook salmon in the lower Tuolumne River (TID/MID 1992, Appendix 22) and are believed to be a significant factor limiting Chinook salmon outmigrant survival, particularly during drier years. Sacramento pikeminnow and striped bass have also been documented in the lower Tuolumne River (TID/MID 2011, Report 2011-5) and may also be important salmon predators. Despite the lack of data, it can be reasonably assumed that juvenile *O. mykiss* are also subject to predation by these predator species. However, predation rates on *O. mykiss* are likely lower than for Chinook due to several factors related to juvenile life history and habitat preferences.

The restricted distribution of *O. mykiss* in the lower Tuolumne River may result in a lower risk of predation compared to Chinook salmon, due to a more restricted spatial and temporal overlap with predators. Juvenile *O. mykiss* are found primarily upstream of Roberts Ferry Bridge (RM 39.5) where water temperature and other habitat conditions are most suitable (Ford and Kirihara 2010). Lower water temperatures and occasional winter-spring high flows keep abundance of non-native predators relatively low in this reach (Brown and Ford 2002) and likely depress predator feeding rates, thus reducing predation pressure on juvenile *O. mykiss*. In addition, because *O. mykiss* have a fusiform body shape that is well adapted to holding and feeding in swift currents, they often occupy areas of high water velocity where habitat suitability for most predators is poor but feeding opportunities are high (Reedy 1995, Everest and Chapman 1972).

Outmigrating steelhead smolts are rarely documented in lower river reaches by outmigrant trapping (TID/MID 2012, Report 2011-4) or other sampling methods (e.g., seine: TID/MID 2012, Report 2011-3), indicating that the density of outmigrating steelhead in downstream reaches where non-native predators are abundant is very low relative to other potential prey such as juvenile Chinook salmon and other fishes. Furthermore, any outmigrant smolts would typically be Age 1+ or 2+ sized fish (McEwan 2001) and are therefore larger than outmigrating fall-run Chinook salmon, which typically outmigrate at Age 0+. The majority of *O. mykiss* captured in Tuolumne River rotary screw traps from 2000–2011 have been ≥ 150 mm (TID/MID 2012, Report 2011-4). Because swimming ability increases with size, Age 1+ and older *O. mykiss* can be assumed to avoid predators more successfully than salmonids of smaller size classes. These fish are also less susceptible to predation because they are too large to be eaten by smaller predators. As prey fish increase in size, their vulnerability to smaller predators decreases. Because the size of the prey that can be eaten is determined in large part by mouth size (gape) (Hoyle and Keast 1987, 1988; both as cited in Mittelbach and Persson 1998), prey are vulnerable to an increasingly narrow size range of predators (i.e., only larger predators) as they grow.

Thus predation on juvenile *O. mykiss* is likely restricted largely to the reach upstream of Roberts Ferry Bridge (RM 39.5), and can be expected to occur primarily in low flow years when summertime water temperatures are conducive to predator foraging farther upstream. The potential for predation to limit juvenile *O. mykiss* rearing and outmigration success remains unknown, but the above evidence suggests that population-level effects are likely minor as compared with Chinook salmon.

5.2.3 Stranding and Entrapment

Rapid reductions in instream flows, particularly following flood flow conditions, may cause stranding and entrapment of fry and juvenile *O. mykiss* on gravel bars, floodplains, and in off-channel habitats; resulting in potential mortality. Although analysis of historical Chinook stranding data (TID/MID 2001, Report 2000-6) suggests a higher stranding risk for Age 0+ *O. mykiss* during rapid flow reductions following flood control releases, juvenile and larger size-classes of *O. mykiss* are generally not found using floodplain habitats in the Tuolumne River or in floodplain studies in the Cosumnes River (Moyle et al. 2007). As stated above, the cessation of hydropower peaking releases to the river by the Districts and inclusion of reduced ramping rates under the FERC (1996) Order reduces the risk stranding (TID/MID 2005a). For these reason, although low levels of *O. mykiss* stranding may potentially occur during flood control operations as flows recede from the floodplain, high rates of mortality due to stranding are unlikely and stranding is not considered further in this Synthesis.

5.2.4 Entrainment into unscreened riparian diversions

Although entrainment of rearing *O. mykiss* or migrating steelhead into unscreened diversions may potentially occur depending on instream flows and agricultural operations, very few studies have examined fish losses of any kind as a result of diversion in the Central Valley (Moyle and White 2002). Approximately thirty-six small riparian diversions were located on the lower Tuolumne River in the early 1990s (Reynolds et al. 1993). Based upon review of available information, entrainment mortality of juvenile *O. mykiss* remains unknown, with any potential mortality associated with weather conditions that affect riparian diversions within the Tuolumne (e.g., crop irrigation during warm weather).

5.2.5 Sportfishing and Poaching

In-river sportfishing and illegal poaching of adult steelhead potentially reduce the number of *O. mykiss* smolts produced in the Tuolumne River and affects long-term population levels. As mentioned previously, removal of steelhead from the wild is currently banned in the San Joaquin River tributaries upstream of the Delta, with catch and release fishing allowed from January 1st through October 31st in each year (<http://www.dfg.ca.gov/regulations/>). Neither illegal poaching of *O. mykiss* in the lower Tuolumne River nor angler hooking mortality have been quantified, but may potentially contribute to direct mortality of adult life stages of *O. mykiss*. McEwan and Jackson (1996) did not believe that legal harvest in the years prior to listing Central Valley steelhead were associated with apparent population declines. For these reasons, effects of sportfishing and poaching on direct mortality during in-river rearing of *O. mykiss* are considered to be unknown, but unlikely to affect overall population levels.

5.3 Processes/Mechanisms Affecting Indirect Mortality

5.3.1 Diseases and Parasites

Meteorology and instream flows combine to affect exposure of rearing juvenile *O. mykiss* 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 or good growth and survival. Wild steelhead may contract diseases which are spread through the water column (Buchanan et al. 1983) and many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), but no information regarding disease incidence was identified for *O. mykiss* in the Tuolumne River or other San Joaquin River tributaries. Although steelhead may potentially rear in the lower Tuolumne River for 1–3 years and because steelhead are presumed to be susceptible to the same diseases as Chinook salmon, the low disease incidence in Chinook salmon smolts (Nichols and Foott 2002) suggests a low risk of indirect mortality due to disease.

6.0 DELTA OUTMIGRATION

As shown in Figure C-7, although only limited data exists supporting the presence of low numbers of smolt-sized *O. mykiss* recovered in Tuolumne River RST monitoring in some years (e.g., Ford and Kirihara 2010, TID/MID 2012, Report 2011-4), a number of factors may potentially affect the survival and growth of any outmigrating steelhead smolts from the Tuolumne River as they pass through the Delta, including meteorological and instream flow effects upon in-channel and floodplain habitat availability, water temperature and food availability. The following section provides a discussion of habitat conditions and survival of steelhead smolts that may potentially emigrate from the Tuolumne River based upon relevant information from other Delta and Central Valley monitoring.

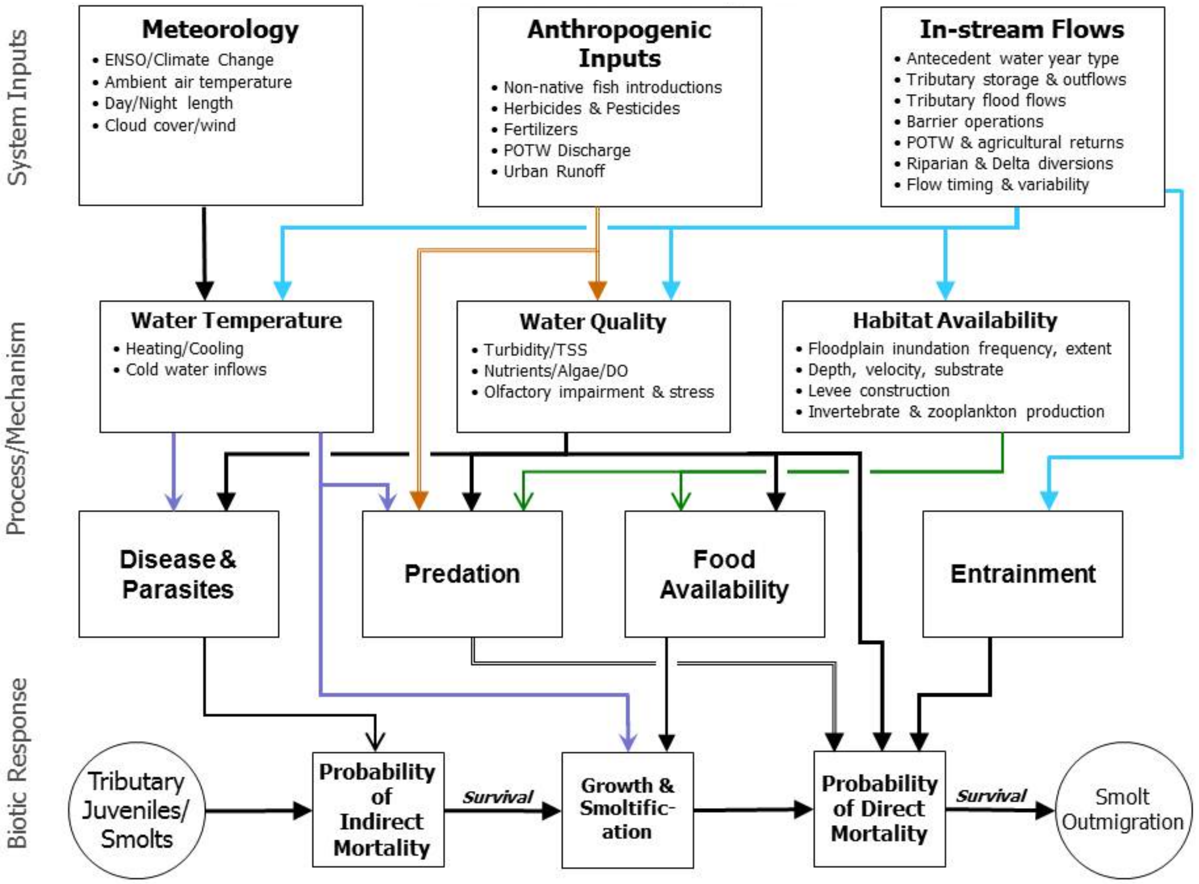

Figure C-7. Potential issues affecting any Central Valley steelhead smolts emigrating from the Tuolumne River through the lower San Joaquin River, Delta, and San Francisco Estuary.

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 steelhead in the lower San Joaquin River and Delta. Smolt-sized steelhead are routinely captured in the Delta at the Mossdale trawl (RM 56.7) downstream of Vernalis (RM 69.3) (SJRGA 2011) as well as at the CVP fish salvage, with peak recoveries typically occurring in February and March (USBR 2008). Although data regarding habitat use of the Delta by rearing steelhead is limited, juvenile steelhead were documented to use the Yolo bypass during flood conditions in 1988 with some evidence of active feeding by stomach content analysis (USBR 2008). For these reasons, historical habitat losses of floodplain habitat (See Section 5.1 of the synthesis) may potentially affect the growth and survival of juvenile steelhead. 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 habitat changes in Delta habitats affect 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 C-7, suitable water temperatures are required for growth and survival for steelhead and may limit the times of year for successful smolt outmigration from upstream tributaries to winter and spring, typically February through May. 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). As summarized above for in-river rearing (Section 5.1), steelhead smoltification is affected by water temperatures, growth rates, as well as genetic influences that may affect behavioral “decisions” regarding adoption of resident or anadromous life histories within riverine habitats. Although water temperature clearly has a strong influence upon steelhead life history timing, separate from direct and indirect mortality effects, both the degree to which water temperature affects smoltification (or desmoltification) in the Delta as well as long term population levels is unknown. Because fairly low temperatures are required for smoltification of Central Valley steelhead (Myrick and Cech 2001), it is unlikely that smoltification occurs within Delta habitats during late spring. For any Central Valley steelhead smolt emigrants from the Tuolumne River, Myrick and Cech (2004) would suggest that optimal growth conditions would be at temperatures below 19°C (66°F). Steelhead juveniles can survive temperatures as high as 27–29 °C (80–84°F) for short periods of time. Because 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, it is likely that Delta conditions are suitable for smolt emigration as late as June in some years.

6.1.3 Food Availability

Although steelhead feeding in the Delta has not been well documented in the literature, active feeding of steelhead smolts has been documented in studies by DWR during 1998 (USBR 2008). In other estuaries, gammarid amphipod invertebrates (e.g., *Gammarus, Corophium,* *Eogammarus, Anisogammarus spp.*) have been found to make up a large proportion of the diet of steelhead (Needham 1939), but the larger mouth gape of Age 1+ and older steelhead smolts suggests they may potentially feed upon small fish up to 50% of their size as found in studies of Central Valley and other Pacific salmonids (Martin et al. 1993, Sholes and Hallock 1979, Damsgard 1995). Potential prey fishes available to steelhead smolts in the Delta include larval fishes as well as Chinook salmon juveniles and smolts. Although little is known regarding prey items eaten by steelhead in the Delta, because extensive predation of steelhead upon Chinook salmon fry has been documented in Sacramento River tributaries (e.g., Sholes and Hallock 1979; Menchen 1981), it is likely that steelhead feed upon these fishes in the Delta as well. Because of evidence of poor Chinook salmon growth conditions in the Delta by MacFarlane and Norton (2002) and apparent declines in pelagic prey species (Baxter et al. 2008), it is likely that food resources in the Delta may potentially limit the growth opportunity for steelhead smolts under non-flood conditions occurring in 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 Figure C-7, 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 emigrating steelhead smolts in the lower San Joaquin River, Delta, and the greater San Francisco Bay estuary. Although Age 1+ and older steelhead are typically large enough to reduce predation risk, 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 steelhead smolts to avoid potential 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 emigrating steelhead smolts to periods of elevated water temperatures in the lower San Joaquin as well as increased rates of mortality. Water temperatures in the lower San Joaquin River at Vernalis (USGS 11303500) typically rise above 25°C (77°F) by mid-June in most years. Because water temperatures in excess of 25°C (77°F) are associated with increased mortality incidence (Myrick and Cech 2001), it is likely that water temperature related mortality occurs to some degree by mid-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

As summarized in the accompanying synthesis (Section 5.1), non-native fish introductions, habitat alterations in the Delta, as well as alterations in hydrology and flows in the Delta have resulted in increased risk of predation upon juvenile salmonids, including steelhead smolts. Because steelhead recoveries from the Chipps Island Trawl operated by USFWS indicate an extremely small percentage of steelhead emigrate as Age 0+ fry, it is expected that most steelhead predation occurs upstream of the Delta (USBR 2008). Although steelhead predation has been documented in 2007 at the Clifton Court forebay to the SWP export facilities (Clark et al. 2009), the general absence of steelhead in the stomachs suggests predation pressure on the relatively large steelhead smolts migrating through the Delta may typically be low. For example, in an IEP funded study on Delta predation between 2001–2003 no steelhead were found in any of the 570 striped bass stomachs, 320 largemouth bass stomachs, or 282 Sacramento pikeminnow foreguts examined (Nobriga and Feyrer 2007). Based upon available information, low levels of predation upon emigrating steelhead smolts may potentially occur in the Delta, although it is unlikely that predation has strong effects upon the numbers of adult recruits to the ocean fishery.

6.2.3 Flow and Water Temperature Effects on Predation

Information regarding predation of juvenile steelhead in the Delta is sparse. The large body size and greater swimming ability of Age 1+ and older steelhead smolts as compared to Age 0+ Chinook salmon smolts suggests that steelhead are less susceptible to predation risks in the Delta. However, given the findings of Newman (2008) showing a significant relationship between Vernalis flow and Chinook salmon smolt survival from Dos Reis to Jersey Point, as well as the routine recovery of steelhead smolts at the SWP/CVP salvage facilities (USBR 2008), it is likely that steelhead smolt survival is affected by river flows and barrier (i.e., HORB) placement. With regards to temperature effects upon predation, although no direct studies were identified to examine this issue for Central Valley steelhead, because increased water temperature has been found to result in reduced predator avoidance by Chinook salmon (e.g., Marine 1997, Marine and Cech 2004), low levels of water temperature related predation mortality of steelhead smolts may potentially occur during later months (e.g., May and June) but is unlikely to affect overall population levels.

6.2.4 Entrainment Effects on Juvenile Salmon Mortality

Depending on tributary instream flows to the San Joaquin River and Delta, entrainment of migrating steelhead smolts into unscreened pumps may occur, resulting in mechanical damage and mortality. Although steelhead have been routinely documented by CDFG in trawls at Mossdale (RM 56) since 1988 (SJRGA 2011), it is unknown whether large numbers of steelhead emigrate outside of the seasonal installation of the barrier at the head of Old River (i.e., HORB), typically placed from April 15th to May 15th in most years. Based upon routine recoveries of smolt sized steelhead at the CVP fish protection facilities (USBR 2008), entrainment into the Clifton Court forebay of the SWP is occurring and may result increased rates of predation (Clark et al 2009), physical damage and stress during salvage operations. Using a combination of passive integrated transponder (PIT) tag studies, as well as acoustic tag tracking studies, Clark et al. (2009) estimated pre-screening mortality of steelhead in the Clifton Court forebay was on the order of 78–82% during studies conducted in 2007. Based upon review of available information, entrainment in smaller irrigation diversion has not been well quantified, but is not considered to contribute to high rates of mortality of steelhead smolts in the Delta. However, entrainment related mortality in the CVP/SWP export facilities is considered to be a potential source of mortality for outmigrating steelhead smolts with effects upon the numbers of adult recruits to the ocean fishery.

6.2.5 Water Quality Effects on Direct Mortality and Predator Susceptibility

As with Chinook salmon juveniles rearing in the Delta, although no studies have assessed contaminant-related mortality of steelhead smolts in the Delta, direct mortality is likely uncommon. NMFS (2006) as well as Scott and Sloman (2004) provide reviews of potential effects of early life history exposure of salmonids 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). Based upon review of available information, water quality effects upon predation of steelhead smolts in the Delta is considered unknown but unlikely due to the episodic nature of potential contaminant releases and short residency of steelhead smolts in the Delta.

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 emigrating juvenile steelhead. Many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), but no information regarding disease incidence was identified for steelhead in the lower San Joaquin River and Delta. Wild steelhead may contract diseases which are spread through the water column (Buchanan et al. 1983). However, concerns regarding disease incidence in steelhead are generally related to hatchery management practices (Wood 1979). Although there is some evidence of impaired water quality and temperature conditions in the Delta, steelhead temperatures tolerances are generally higher than that of Chinook salmon (Myrick and Cech 2004). Assuming steelhead are susceptible to the same diseases as Chinook salmon, because no reports of clinical levels of infection were found in rearing Chinook salmon in the lower San Joaquin River and Delta in 2000 (Nichols et al. 2001) and only low rates were identified in the lower San Joaquin River in 2001 (Nichols and Foott 2002), it is unlikely that disease and parasites contribute to high rate of mortality of emigrating steelhead smolts in the Delta.

7.0 OCEAN REARING

As shown in Figure C-8, a number of factors affect growth and survival of adult steelhead during ocean residency, including meteorological effects upon ocean circulation and sea surface temperatures, exposure to adverse water quality and growth conditions during riverine rearing and Delta passage, as well as the influences of predation and harvest related mortality. Only limited data exists supporting the presence of low numbers of smolt-sized *O. mykiss* recovered in Tuolumne River RST monitoring in some years (e.g., Ford and Kirihara 2010, TID/MID 2012, Report 2011-4) and very little information exists regarding Central Valley steelhead ocean rearing. The information presented in this section draws upon broader information sources regarding ocean conditions for steelhead off of the California coast as well as in the Pacific Northwest.

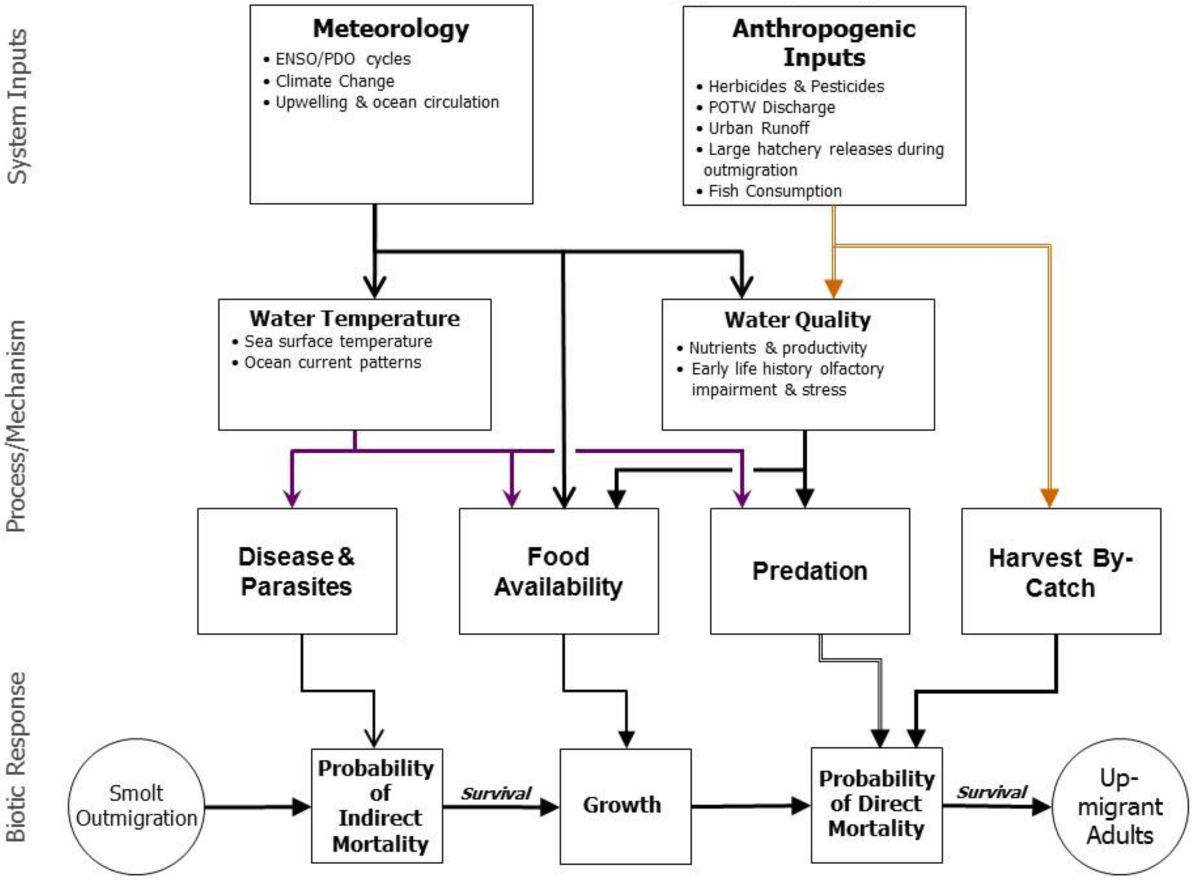

Figure C-8. Potential issues affecting any Central Valley steelhead adults from the Tuolumne River during adult rearing in the Pacific Ocean.

7.1 Processes/Mechanisms Affecting Adult Growth

7.1.1 Food Availability

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 Chinook salmon harvest, with peaks in abundance off the California and Oregon coasts occurring during periods of low abundance off the coast of Alaska. Less is known about how steelhead respond to ocean productivity patterns. Steelhead are thought to migrate quickly to the open ocean upon smoltification (Burgner et al. 1992 as cited by Quinn et al. 2012) where they feed primarily on fish and squid (Atcheson 2010). For North Pacific ecosystems, Atcheson (2010) identified age-dependent factors influencing growth of the steelhead at sea. Using a bioenergetic model, Atcheson (2010) further concluded that food consumption and interannual changes in sea surface temperatures are limiting factors on steelhead growth at sea and that hatchery sourced steelhead were consistently smaller in size than naturally produced steelhead.

7.2 Processes/Mechanisms Affecting Direct Mortality

7.2.1 Predation

Predation of steelhead smolts following ocean entry has not been well documented, but could present potential population level impacts. Since steelhead are capable of spending years in freshwater and brackish habitats before migrating to the ocean as smolts, they tend to be larger than Chinook smolts and, as a result, not likely avian prey. 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 Harvest By-catch

Low levels of incidental mortality of adult steelhead in by-catch of ocean salmon fisheries may potentially occur. There is no longer a commercial ocean fishery for steelhead (McEwan and Jackson 1996) and USBR (2008) suggests that steelhead may be caught in either unauthorized drift net fisheries, or as bycatch in other authorized fisheries such as salmon troll fisheries. Based on very limited data collected when drift net fishing was legal, the combined mortality estimates of adult steelhead in these fisheries were between 5 and 30 percent (USBR 2008). Although current harvest-related mortality is unknown, the lack of reports of high rates of steelhead in ocean harvests suggests by-catch mortality is relatively low and unlikely to affect overall population levels.

7.3 Processes/Mechanisms Affecting Indirect Mortality

7.3.1 Disease and Parasites

Meteorology and instream flow effects upon water temperature and water quality in upstream habitats may affect early life history disease incidence and subsequent mortality of adult any Central Valley steelhead originating in the Tuolumne River. As stated above, many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for bacterial infection (Foott 1992). Just like those effects for Chinook salmon, prior exposure to unsuitable water temperatures, contaminants, and pathogens during juvenile rearing and outmigration may also contribute to increased disease incidence in the adult Central Valley steelhead originating in the Tuolumne River. Although there is some evidence of impaired water quality and temperature conditions in the Delta, steelhead temperatures tolerances are generally higher than that of Chinook salmon (Myrick and Cech 2004). Assuming steelhead are susceptible to the same diseases as Chinook salmon, because no reports of clinical levels of infection were found in rearing Chinook salmon in the lower San Joaquin River and Delta in 2000 (Nichols et al. 2001) and only low rates were identified in the lower San Joaquin River in 2001 (Nichols and Foott 2002), it is unlikely that disease and parasites contribute to high rate of mortality of emigrating steelhead smolts upon ocean entry.

8.0 REFERENCES

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