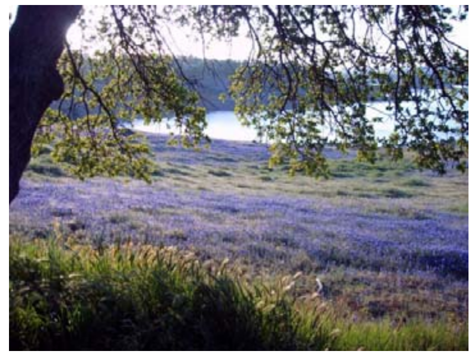
SALMONID POPULATION INFORMATION INTEGRATION AND SYNTHESIS
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299





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Modesto Irrigation District

Prepared for:
Turlock Irrigation District – Turlock, California
Modesto Irrigation District – Modesto, California

Prepared by:
Stillwater Sciences

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Salmonid Population Information Integration and Synthesis
Study Report

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List of Acronyms

ac ....acres

ACEC.........................Area of Critical Environmental Concern

AF ....acre-feet

ACOE.........................U.S. Army Corps of Engineers

ADA...........................Americans with Disabilities Act

ALJ.............................Administrative Law Judge

APE............................Area of Potential Effect

ARMR........................Archaeological Resource Management Report

BA ....Biological Assessment

BDCP ....Bay-Delta Conservation Plan

BLM...........................U.S. Department of the Interior, Bureau of Land Management

BLM-S ....Bureau of Land Management – Sensitive Species

BMI............................Benthic macroinvertebrates

BMP ....Best Management Practices

BO ....Biological Opinion

CalEPPC ....California Exotic Pest Plant Council

CalSPA.......................California Sports Fisherman Association

CAS............................California Academy of Sciences

CCC............................Criterion Continuous Concentrations

CCIC ....Central California Information Center

CCSF..........................City and County of San Francisco

CCVHJV ....California Central Valley Habitat Joint Venture

CD ....Compact Disc

CDBW........................California Department of Boating and Waterways

CDEC.........................California Data Exchange Center

CDFA.........................California Department of Food and Agriculture

CDFG.........................California Department of Fish and Game (as of January 2013, Department of Fish and Wildlife)

CDMG........................California Division of Mines and Geology

CDPR………………..California Department of Pesticide Regulation

CDWR……………….California Department of Water Resources

CDOF........................California Department of Finance
CDPH........................California Department of Public Health
CDPR........................California Department of Parks and Recreation
CDSOD......................California Division of Safety of Dams
CDWR........................California Department of Water Resources
CE ....California Endangered Species
CEII...........................Critical Energy Infrastructure Information
CEQA........................California Environmental Quality Act
CESA ....California Endangered Species Act
CFR ....Code of Federal Regulations
CFM…………………Constant Fractional Marking Program
cfs..............................cubic feet per second
CGS...........................California Geological Survey
CMAP ....California Monitoring and Assessment Program
CMC..........................Criterion Maximum Concentrations
CNDDB.....................California Natural Diversity Database
CNPS.........................California Native Plant Society
CORP ....California Outdoor Recreation Plan
CPUE ....Catch Per Unit Effort
CRAM.......................California Rapid Assessment Method
CRLF.........................California Red-Legged Frog
CRRF ....California Rivers Restoration Fund
CSAS.........................Central Sierra Audubon Society
CSBP.........................California Stream Bioassessment Procedure
CT ....California Threatened Species
CTR...........................California Toxics Rule
CTS ....California Tiger Salamander
CVP…………………Central Valley Project
CVRWQCB ....Central Valley Regional Water Quality Control Board
CWA ....Clean Water Act
CWHR.......................California Wildlife Habitat Relationship
Districts......................Turlock Irrigation District and Modesto Irrigation District
DLA ....Draft License Application

DRERIP................Draft Regional Ecosystem Restoration Implementation Plan
DPRA.........................Don Pedro Recreation Agency
DPS ....Distinct Population Segment
EA ....Environmental Assessment
EC ....Electrical Conductivity
EFH ....Essential Fish Habitat
EIR ....Environmental Impact Report
EIS.............................Environmental Impact Statement
EPA ...........................U.S. Environmental Protection Agency
ESA ....Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU ....Evolutionary Significant Unit
EWUA........................Effective Weighted Useable Area
FERC..........................Federal Energy Regulatory Commission
FFS ....Foothills Fault System
FL ....Fork length
FMU ....Fire Management Unit
FOT ....Friends of the Tuolumne
FPC ....Federal Power Commission
ft/mi...........................feet per mile
FWCA ....Fish and Wildlife Coordination Act
FYLF..........................Foothill Yellow-Legged Frog
g.................................grams
GIS ....Geographic Information System
GLO ....General Land Office
GPS ....Global Positioning System
HCP ....Habitat Conservation Plan
HHWP........................Hetch Hetchy Water and Power
HORB ....Head of Old River Barrier
HPMP.........................Historic Properties Management Plan
ILP.............................Integrated Licensing Process
ISAB.....................Independent Scientific Advisory Board
ISR ....Initial Study Report

ITA............................Indian Trust Assets
JHRC……………….Joint Hatchery Review Committee
kV..............................kilovolt
m ....meters
M&I...........................Municipal and Industrial
MCL..........................Maximum Contaminant Level
mg/kg ....milligrams/kilogram
mg/L..........................milligrams per liter
mgd ....million gallons per day
mi ....miles
mi^2 ....square miles
MID...........................Modesto Irrigation District
MOU ....Memorandum of Understanding
MRFF……………….Merced River Fish Facility
MSCS........................Multi-Species Conservation Strategy
msl.............................mean sea level
MVA ....Megavolt Ampere
MW ....megawatt
MWh ....megawatt hour
mya............................million years ago
NAE ....National Academy of Engineering
NAHC ....Native American Heritage Commission
NAS...........................National Academy of Sciences
NAVD 88..................North American Vertical Datum of 1988
NAWQA ....National Water Quality Assessment
NCCP ....Natural Community Conservation Plan
NEPA ....National Environmental Policy Act
ng/g ....nanograms per gram
NGOs ....Non-Governmental Organizations
NHI ....Natural Heritage Institute
NHPA........................National Historic Preservation Act
NISC ....National Invasive Species Council
NMFS........................National Marine Fisheries Service

NOAA........................National Oceanic and Atmospheric Administration

NOI ....Notice of Intent

NPS ............................U.S. Department of the Interior, National Park Service

NRCS ....National Resource Conservation Service

NRHP.........................National Register of Historic Places

NRI.............................Nationwide Rivers Inventory

NTU ....Nephelometric Turbidity Unit

NWI............................National Wetland Inventory

NWIS ....National Water Information System

NWR ....National Wildlife Refuge

NGVD 29...................National Geodetic Vertical Datum of 1929

O&M..........................operation and maintenance

OEHHA......................Office of Environmental Health Hazard Assessment

ORV ....Outstanding Remarkable Value

PAD............................Pre-Application Document

PDO............................Pacific Decadal Oscillation

PEIR...........................Program Environmental Impact Report

PGA............................Peak Ground Acceleration

PHG............................Public Health Goal

PM&E ....Protection, Mitigation and Enhancement

PMF............................Probable Maximum Flood

POAOR......................Public Opinions and Attitudes in Outdoor Recreation

POTW……………….publicly owned water treatment works

ppb.............................parts per billion

ppm ....parts per million

PSFMC………………Pacific State Marine Fisheries Council

PSP.............................Proposed Study Plan

QA..............................Quality Assurance

QC..............................Quality Control

RA..............................Recreation Area

RBP............................Rapid Bioassessment Protocol

Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation

RM ....River Mile

RMP ....Resource Management Plan

RP..............................Relicensing Participant

RSP ....Revised Study Plan

RST ....Rotary Screw Trap

RWF ....Resource-Specific Work Groups

RWG ....Resource Work Group

RWQCB ....Regional Water Quality Control Board

SC..............................State candidate for listing under CESA

SCD...........................State candidate for delisting under CESA

SCE ....State candidate for listing as endangered under CESA

SCT ....State candidate for listing as threatened under CESA

SD1 ....Scoping Document 1

SD2 ....Scoping Document 2

SE..............................State Endangered Species under the CESA

SFP............................State Fully Protected Species under CESA

SFPUC ....San Francisco Public Utilities Commission

SHPO ....State Historic Preservation Office

SJRA ....San Joaquin River Agreement

SJRGA ....San Joaquin River Group Authority

SJTA ....San Joaquin River Tributaries Authority

SPD ....Study Plan Determination

SRA...........................State Recreation Area

SRMA ....Special Recreation Management Area or Sierra Resource Management Area (as per use)

SRMP........................Sierra Resource Management Plan

SRP ....Special Run Pools

SSC ....State species of special concern

ST..............................California Threatened Species under the CESA

STORET ....Storage and Retrieval

SWAMP....................Surface Water Ambient Monitoring Program

SWE ....Snow-Water Equivalent

SWP…………………State Water Project

SWRCB.....................State Water Resources Control Board

TAC............................Technical Advisory Committee
TAF............................thousand acre-feet
TCP............................Traditional Cultural Properties
TDS............................Total Dissolved Solids
TID............................Turlock Irrigation District
TMDL........................Total Maximum Daily Load
TOC............................Total Organic Carbon
TRT............................Tuolumne River Trust
TRTAC......................Tuolumne River Technical Advisory Committee
UC..............................University of California
USDA.........................U.S. Department of Agriculture
USDOC......................U.S. Department of Commerce
USDOI.......................U.S. Department of the Interior
USFS..........................U.S. Department of Agriculture, Forest Service
USFWS......................U.S. Department of the Interior, Fish and Wildlife Service
USGS.........................U.S. Department of the Interior, Geological Survey
USR............................Updated Study Report
UTM...........................Universal Transverse Mercator
VAMP........................Vernalis Adaptive Management Plan
VELB.........................Valley Elderberry Longhorn Beetle
VRM..........................Visual Resource Management
WPT...........................Western Pond Turtle
WSA...........................Wilderness Study Area
WSIP..........................Water System Improvement Program
WWTP.......................Wastewater Treatment Plant
WY.............................water year
µS/cm.........................micro-Siemens per centimeter

Adipose fin	A small fleshy fin with no rays, located between the dorsal and caudal fins. Clipping of adipose fins is used to identify hatchery-raised salmonids.
Age	The number of years of life completed, here indicated by an arabic numeral, followed by a plus sign if there is any possibility of ambiguity (e.g., age 1, age 1+).
Age-class	A group of individuals of a certain species that have the same age.
Age composition	Proportion of individuals of different ages in a stock or in the catches.
Alevin	Newly hatched salmon or *O. mykiss* that have not completely absorbed their yolk sacs and usually have not yet emerged from the gravel.
Alluvial	Originating from the transport and deposition of sediment by running water.
Anadromous	Fish such as salmon and steelhead trout that migrate up rivers from the sea to spawn in fresh water.
Coded-wire tag (CWT)	A small (0.25mm diameter x 1 mm length) wire etched with a distinctive binary code and implanted in the snout of salmon or steelhead, which, when retrieved, allows for the identification of the origin of the fish bearing the tag.
Cohort	Members of a life-stage that were spawned in the same year.
Delta	An alluvial landform composed of sediment at a river mouth that is shaped by river discharge, sediment load, tidal energy, land subsidence, and sea-level changes. The Sacramento and San Joaquin River Delta refers to a complex network of channels east of Suisun Bay (an upper arm of the San Francisco Bay estuary).
Density-dependent	Factors affecting the population that are dependent on the population size, such as spawning habitat area or juvenile rearing area at higher population sizes.
Density Independence	Factors affecting the population regardless of population size, such as temperature, disease, or stranding.
Dispersal	A process by which animals move away from their natal population
El Niño	A climactic event that begins as a warming episode in the tropical Pacific zone that can result in large scale intrusions of anomalously warm marine water northward along the Pacific coastline of North America.
Escapement	The number of sexually mature adult salmon or steelhead that successfully pass through an ocean fishery to reach the spawning

	grounds. This amount reflects losses resulting from harvest, and does not reflect natural mortality during upmigration such as pre-spawn mortality. Thus, escaped fish do not necessarily spawn successfully.
Estuary	A region where salt water from the ocean is mixed with fresh water from a river or stream (also see Delta). The greater San Francisco Bay estuary includes brackish and salt water habitats from the Golden Gate Bridge in San Francisco Bay and includes Suisun, San Pablo, Honker, Richardson, San Rafael, San Leandro, and Grizzly bays.
Floodplain	The part of a river valley composed of unconsolidated river deposits that periodically floods. Sediment is deposited on the floodplain during floods and through the lateral migration of the river channel across the floodplain.
Fry	Salmonid life stage between the alevin and parr stages. Functionally defined as a size <50–69 mm, fry generally occupy stream margin habitats, feeding on available insect larvae.
Homing	The ability of a salmon or steelhead to correctly identify and return to their natal stream, following maturation at sea.
Hydroelectric	Generation of electricity by conversion of the energy of running water into electric power.
Irrigation	The application of water to land by means of pumps, pipes, and ditches in order to help crops grow.
Kelts	A spent or exhausted salmon or steelhead after spawning. All species of Pacific salmon, except some steelhead and sea-run cutthroat, die at this stage.
Life history	The events that make up the life cycle of an animal including migration, spawning, incubation, and rearing. There is typically a diversity of life history patterns both within and between populations. Life history can refer to one such pattern, or collectively refer to a stylized description of the 'typical' life history of a population.
Life-stage	Temporal stages (or intervals) of a fish's life that have distinct anatomical, physiological, and/or functional characteristics that contribute to potential differences in use of available habitats.
Macroinvertebrate	Invertebrates visible to the naked eye, such as insect larvae and crayfish.
Osmoregulation	Refers to the physical changes that take place in salmonids as their gills and kidneys adjust from fresh water to salt water as they enter the ocean, and from salt water to fresh water upon their return.

Pacific Decadal Oscillation	A pattern of Pacific climate variability associated with sea surface warming and changes in ocean circulation that shifts phases on at least inter-decadal time scale, usually about 20 to 30 years.
Parr	Life stage of salmon or *O. mykiss* between the fry and smolt stages. Functionally defined as a size of 50–69 mm at this stage, juvenile fish have distinctive vertical parr marks and are actively feeding in fresh water.
Predator	An animal which feeds on other living animals.
Production	Output from a stock-production model at a particular life-step.
Proximate factor	Stimuli or conditions responsible for animal behavior at ecological time scales (i.e., immediate or short-term responses).
Recruitment	Addition of new fish to a defined life history stage by growth from among smaller size categories. Often used in context of management, where the stage is the point where individuals become vulnerable to fishing gear.
Redd	A nest of fish eggs consisting of gravel, typically formed by digging motion performed by an adult female salmon or *O. mykiss*.
Riffle	A shallow gravel area of a stream that is characterized by increased velocities and gradients, and is the predominant stream area used by salmonids for spawning.
Riparian	Referring to the transition area between aquatic and terrestrial ecosystems. The riparian zone includes the channel migration zone and the vegetation directly adjacent to the water body that influence channel habitat through alteration of microclimate or input of LWD.
River mile	A statute mile measured along the center line of a river. River mile measurements start at the stream mouth (RM 0.0).
Riverine	Referring to the entire river network, including tributaries, side channels, sloughs, intermittent streams, etc.
Smolt	Salmonid life stage between the parr and adult stages. Functionally defined as a size ≥70 mm at this stage, juvenile salmon and steelhead actively outmigrate from freshwater habitats and take on the appearance of silver adult fish.
Smoltification	Refers to the physiological changes to allow tolerance to saltwater conditions in the ocean.
Spawn	The act of producing a new generation of fish. The female digs a redd in the river bottom and deposits her eggs into it. The male then covers the eggs with milt to fertilize them.
Spawning grounds	Areas where fish spawn.
Stock	Input value required by the stock-production models. It is the first required value entered into the population dynamics model

	spreadsheets; for example, stock would be the number of fry, for a fry-to-juvenile step.
Straying	A natural phenomena of adult spawners not returning to their natal stream, but entering and spawning in some other stream.
Wild	Salmon or *O. mykiss* produced by natural spawning in fish habitat from parents that were spawned and reared in fish habitat.
Woody debris	Logs, branches, or sticks that fall or hang into rivers. This debris gives salmonids places to hide and provides food for insects and plants which these fish feed upon.
Yolk sac	A small sac connected to alevin which provides them with protein, sugar, minerals, and vitamins. Alevin live on the yolk sac for a month or so before emerging from the gravel and beginning to forage food for themselves.

1.0 INTRODUCTION

1.1 General Description of the Don Pedro Project

Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir formed by the dam extends 24-miles upstream at the normal maximum water surface elevation of 830 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi^2).

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The Project serves many purposes including providing water storage for the beneficial use of irrigation of over 200,000 ac of prime Central Valley farmland and for the use of M&I customers in the City of Modesto (population 210,000). Consistent with the requirements of the Raker Act passed by Congress in 1913 and agreements between the Districts and City and County of San Francisco (CCSF), the Project reservoir also includes a "water bank" of up to 570,000 AF of storage. CCSF may use the water bank to more efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. CCSF's "water bank" within Don Pedro Reservoir provides significant benefits for its 2.6 million customers in the San Francisco Bay Area.

The Project also provides storage for flood management purposes in the Tuolumne and San Joaquin rivers in coordination with the U.S. Army Corps of Engineers (ACOE). Other important uses supported by the Project are recreation, protection of the anadromous fisheries in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from approximately one mile downstream of the dam to approximately RM 79 upstream of the dam. Upstream of the dam, the Project Boundary runs generally along the 855 ft contour interval which corresponds to the top of the Don Pedro Dam. The Project Boundary encompasses approximately 18,370 ac with 78 percent of the lands owned jointly by the Districts and the remaining 22 percent (approximately 4,000 ac) is owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

The primary Project facilities include the 580-foot-high Don Pedro Dam and Reservoir completed in 1971; a four-unit powerhouse situated at the base of the dam; related facilities including the Project spillway, outlet works, and switchyard; four dikes (Gasburg Creek Dike and Dikes A, B, and C); and three developed recreational facilities (Fleming Meadows, Blue Oaks, and Moccasin Point Recreation Areas). The location of the Project and its primary facilities is shown in Figure 1.1-1.

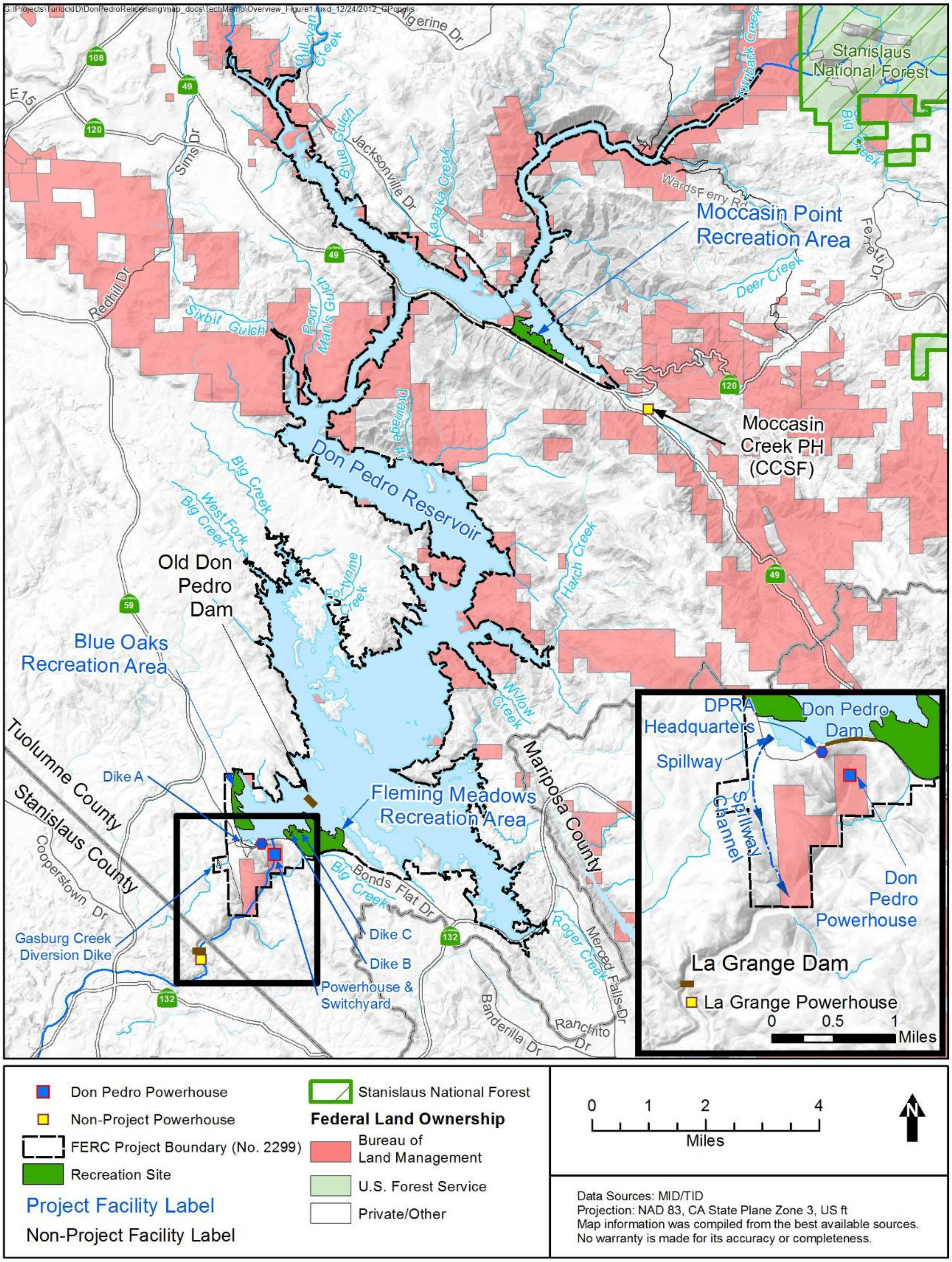

Figure 1.1-1. Don Pedro Project location.

1.2 Relicensing Process

The current FERC license for the Project expires on April 30, 2016, and the Districts will apply for a new license no later than April 30, 2014. The Districts began the relicensing process by filing a Notice of Intent and Pre-Application Document (PAD) with FERC on February 10, 2011, following the regulations governing the Integrated Licensing Process (ILP). The Districts' PAD included descriptions of the Project facilities, operations, license requirements, and Project lands as well as a summary of the extensive existing information available on Project area resources. The PAD also included ten draft study plans describing a subset of the Districts' proposed relicensing studies. The Districts then convened a series of Resource Work Group meetings, engaging agencies and other relicensing participants in a collaborative study plan development process culminating in the Districts' Proposed Study Plan (PSP) and Revised Study Plan (RSP) filings to FERC on July 25, 2011 and November 22, 2011, respectively.

On December 22, 2011, FERC issued its Study Plan Determination (SPD) for the Project, approving, or approving with modifications, 34 studies proposed in the RSP that addressed Cultural and Historical Resources, Recreational Resources, Terrestrial Resources, and Water and Aquatic Resources. In addition, as required by the SPD, the Districts filed three new study plans (W&AR-18, W&AR-19, and W&AR-20) on February 28, 2012 and one modified study plan (W&AR-12) on April 6, 2012. Prior to filing these plans with FERC, the Districts consulted with relicensing participants on drafts of the plans. FERC approved or approved with modifications these four studies on July 25, 2012.

Following the SPD, a total of seven studies (and associated study elements) that were either not adopted in the SPD, or were adopted with modifications, formed the basis of Study Dispute proceedings. In accordance with the ILP, FERC convened a Dispute Resolution Panel on April 17, 2012 and the Panel issued its findings on May 4, 2012. On May 24, 2012, the Director of FERC issued his Formal Study Dispute Determination, with additional clarifications related to the Formal Study Dispute Determination issued on August 17, 2012.

This study report describes the objectives, methods, and results of the Salmonid Population Information Integration and Synthesis Study (W&AR-05) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

As proposed in the *Salmonid Populations Information Integration and Synthesis Study Plan* (W&AR-5) as modified and approved by FERC in its December 22, 2011 Study Plan Determination, a workshop consultation process was distributed to relicensing participants on March 20, 2012 including adoption of communication process recommendations in the June 2011 *Integrated Life Cycle Models Workshop Report* (Rose et al. 2011), methods for achieving consensus on key issues between interested participants and the Districts, providing materials on electronic media in advance of scheduled workshops, and convening additional workshops as necessary. The Districts held two relicensing participant meetings on April 10, 2012 (Workshop No. 1) and on June 26, 2012 (Workshop No. 2).

Workshop No. 1 was held to summarize and update existing salmonid information originally provided to relicensing participants on January 17, 2012 and to provide an opportunity for relicensing participants to propose additional literature and data sources for use in this *Salmonid Populations Information Integration and Synthesis Study* ("synthesis"). Materials for the workshop, which included an updated reference list, PowerPoint slides, and glossary, were provided to relicensing participants on April 2, 2012 in advance of the workshop and in accordance with the March 20, 2011 Consultation Protocol. Draft workshop notes were prepared and distributed to relicensing participants on April 20, 2012 and comments were received from CDFG, USFWS, and the Conservation Groups[1] as well as recommendations for additional data sources to be considered. In their filing of the final workshop notes on June 18, 2012, the Districts responded to comments and agreed to review and consider all of the materials provided by relicensing participants for use in this synthesis.

Workshop No. 2 was held to present and refine preliminary conceptual models of the biology and ecology of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) as well as resident and anadromous *O. mykiss* occurring within the Tuolumne River, lower San Joaquin River, Sacramento-San Joaquin River delta [Delta], and the Pacific Ocean. Materials for the workshop—preliminary conceptual models and an accompanying narrative—were provided to relicensing participants on June 15, 2012. In addition to discussing models of ecosystem inputs and other factors affecting salmonid ecology, relicensing participants at the workshop were asked to provide input and assistance in narrowing the amount of existing information needing to be incorporated/reviewed and identifying the most important factors affecting salmonid populations and individual life stages. In addition to draft workshop notes provided to relicensing participants on July 25, 2012, revised conceptual models and a preliminary summary of key factors affecting salmonid life stages were provided (with citations) as attachments to the notes. Comments were received from CDFG, USFWS, SWRCB, as well as a combined filing by the Tuolumne River Trust and the California Sportfishing Protection Alliance. Comments addressed the draft workshop notes, workshop consultation process, revisions to preliminary conceptual models, as well as the process used to identify key factors affecting various salmonid life stages. In their filing of the final workshop notes on November 15, 2012, the Districts provided comment responses, implemented changes to the notes and conceptual models, reviewed and incorporated additional references for this synthesis.

[1] American Rivers, American Whitewater, California Sportfishing Protection Alliance, California Trout, Inc., Central Sierra Environmental Resource Center, Environmental Defense Fund, Friends of the River, Golden West Women Flyfishers, Northern California Council Federation of Fly Fishers, Merced Fly Fishing Club, Pacific Coast Federation of Fishermen's Associations, Trout Unlimited, Tuolumne River Trust, and Water 4 Fish.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study was to summarize available information regarding in-river and out-of-basin factors affecting native lower Tuolumne River salmonids - namely Chinook salmon and *O. mykiss*[2]. The results of information reviews were used to develop and refine conceptual models of Chinook salmon and *O. mykiss* life history, reflecting the results of monitoring conducted by the Districts since 1971, under the 1995 Settlement Agreement (1995 SA) for the New Don Pedro Proceeding[3], other studies on habitat changes within the lower Tuolumne River corridor (e.g., from the 1997 flood), as well as recent advances in the understanding of Central Valley salmonid populations (e.g., genetic structure, hatchery influences, water exports from the Delta, and ocean conditions). Objectives in meeting this goal include:

- collect and summarize available existing data on Chinook salmon and *O. mykiss,* to characterize factors affecting their populations, and;
- develop hypotheses to understand potential impacts of contributing factors affecting Chinook salmon and *O. mykiss* populations.

Available data were used to characterize the watershed, Project operations, and issues affecting salmonid populations, and develop hypotheses for understanding the potential impacts of factors affecting them. As proposed in the Study Plan and recommended in the June 2011 *Integrated Life Cycle Models Workshop Report* (Rose et al. 2011), this synthesis was conducted in conjunction with the development of quantitative population models for Chinook salmon (Study W&AR-6) and *O. mykiss* (Study W&AR-10), which will be used to evaluate the relative influence of identified issues on juvenile Chinook salmon and potential steelhead production from the Tuolumne River.

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[2] The term '*O. mykiss'* is used to represent both resident and anadromous life history forms of *Oncorhynchus mykiss*. In circumstances when the discussion is specifically limited to one or the other life history form, the terms 'rainbow trout' will be used to identify resident *O. mykiss*, whereas 'steelhead' will be used to denote the anadromous form.

[3] Filed with FERC in February 1996 under Docket P-2299-024, signatories to the 1995 Settlement Agreement included TID, MID, CCSF, CDFG (now CDFW), USFWS, CSPA, Friends of the Tuolumne (now the Tuolumne River Conservancy), Tuolumne River Expeditions (TRE), Tuolumne River Trust (TRT), FERC staff, and the San Francisco Bay Area Water Users Association (now the Bay Area Water Supply and Conservation Agency).

3.0 STUDY AREA

The study area includes the lower 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), Delta[4], San Francisco Bay Estuary[5], and the Pacific Ocean are also addressed in terms of their use by outmigrant, adult, and upmigrant life stages of Chinook salmon, steelhead, and resident rainbow trout.

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[4] The Delta received its first official boundary in 1959 with the passage of the Delta Protection Act (Section 12220 of the California Water Code), with the southern boundary in the San Joaquin River located at Vernalis (RM 69.3) and a western boundary at the confluence of the Sacramento and San Joaquin Rivers (RM 0) near Chipps Island.

[5] The greater San Francisco Bay estuary extends from the Golden Gate Bridge in San Francisco Bay eastwards across salt and brackish water habitats included in San Leandro, Richardson, San Rafael, and San Pablo bays, as well as the Carquinez Strait, Honker, and Suisun bays further to the east near the western edge of the Delta.

4.0 METHODOLOGY

A large body of information on Chinook salmon biology and the ecology of the Tuolumne River has been collected to date, with less information on use of Tuolumne River habitats by resident and anadromous forms of *O. mykiss* (summarized in Sections 5.3.1 through 5.3.3 of the PAD). This synthesis focused on literature and data identifying factors affecting habitat availability and life history trajectories. This approach was first used to examine physical habitat needs for coho salmon by Reeves et al. (1989); the approach assumes that when habitat or other issues limit the progression of an individual life stage cohort (e.g., growth, survival), subsequent life stages and long-term populations may also be affected. As detailed further below, the synthesis was separated into three steps: (1) data compilation, (2) data analysis, and (3) identification of key issues affecting Tuolumne River salmonids.

4.1 Data Compilation

The first step of this synthesis was to assemble and review available information to characterize the physical and ecological attributes of habitats for individual salmonid life stages. Results of previous monitoring of Chinook salmon and *O. mykiss* populations in the lower Tuolumne River were supplemented with information on physical, biological, hydrological, and water quality relevant to the subject. An initial list of existing information sources was provided to relicensing participants on January 17, 2012 for review, and was subsequently updated and redistributed prior to Workshop No. 1, held on April 2, 2012. The list was further expanded as a result of comments and references received following Workshop No. 1 as well as following Workshop No. 2, which was held on June 18, 2012. Attachment A provides a list of references provided by relicensing participants that were reviewed as part of this synthesis.

Information in addition to that identified during PAD development and preliminary data compilation for the scheduled workshops was identified during focused literature reviews conducted for the purposes of this synthesis. The natural history and ecology of Central Valley salmonids has been described in detail in several reports (e.g., Moyle 2002, McEwan 2001, McEwan and Jackson 1996, Williams 2006, Yoshiyama et al. 2001). Literature and data sources providing quantitative information on linkages between habitat conditions and biological responses of Tuolumne River salmonids were identified. Sources were prioritized using a process included as Attachment 5 to the Workshop No. 1 notes. In general, the highest priority was given to data and reports specific to the lower Tuolumne River. Salmonid life-history information from other river systems in the San Joaquin River basin, California's Central Valley, and the Pacific Northwest was used to address specific data or information gaps identified as part of the data compilation process.

4.2 Data Analysis

Relevant information collected during data compilation was used to develop life-history-based conceptual models of linkages between land and water uses, physical and ecological watershed processes, habitat conditions in the Tuolumne River and Delta, hatchery operations, ocean conditions, and the effects of these factors on salmonid populations. As detailed in Attachments B and C, biological responses of Chinook salmon and *O. mykiss*, respectively, were separated into factors potentially affecting reproduction, growth, direct mortality (e.g., temperature, predation, and entrainment) and indirect mortality (e.g., disease and parasites).

4.3 Identification of Key Issues Affecting Tuolumne River Salmonids

Using a life-history framework, hypotheses about key in-river and out-of-basin factors thought to be of greatest importance to salmonid populations in the basin and survival from one-life stage to the next were identified and discussed with relicensing participants at a workshop held on June 26, 2012. Physical and biological mechanisms affecting Chinook salmon and *O. mykiss* populations were selected based on whether the mechanisms addressed were likely to be relevant and whether basin-specific data provided a demonstrable linkage to the identified mechanisms. In the event that no basin-specific information existed for a particular linkage/mechanism in the Tuolumne River, professional judgment and consultation with relicensing participants, prior population assessments of Tuolumne River salmonids, and study findings from other locations in the region were used to construct mechanistic linkages between habitat conditions and salmonid population levels. High priority issues were organized by seasonality and life-history stage, uncertainty regarding population-scale effects, and geographic source. Those factors affecting biological responses of in-river life stages were selected as the foundation for developing quantitative population models as part of interrelated salmon population modeling studies (Studies W&AR-6 and W&AR-10).

5.0 RESULTS

Based upon the information reviewed for this synthesis, available information was summarized to characterize issues and to develop hypotheses regarding key issues affecting Chinook salmon and *O. mykiss* from the Tuolumne River throughout their range. It was recognized during Study Plan development that the geographic scale of salmonid habitat extends from in-river to out-of-basin areas in the lower San Joaquin River, Delta, San Francisco Bay estuary, and to the Pacific Ocean. Because of these large spatial scales, a number of potential factors may affect Tuolumne River salmonids throughout their life cycle that cannot be readily discriminated from factors affecting salmonids originating in other river systems in California. In addition, salmonid populations may be affected by changes in habitat conditions across large temporal scales, such as changes in land uses and water developments in California, inter-annual and decadal changes in ocean productivity and harvest, changes in hatchery practices, and longer-term ecosystem changes due to factors such as global climate change.

At the broadest scales, limiting threats and stressors affecting Evolutionarily Significant Unit (ESU) viability and population genetics are more suitably described in resources such as the NMFS Draft Recovery Plan (NMFS 2009b) with information supplemented by various historical reviews of Central Valley salmonid populations (e.g., Hatton and Clark 1942, Fry 1961, Fry and Petrovich 1970, Yoshiyama et al. 2001, McEwan and Jackson 1996, USFWS 2001, McEwan 2001, Moyle 2002, Williams 2006). Local to the Tuolumne River, the Districts have conducted long-term monitoring and targeted research on Chinook salmon and *O. mykiss* since 1971. The results of the original 20-year program were reported in TID/MID (1992) and updated in TID/MID (1997). Monitoring required under this initial program and the 1996 FERC Order (FERC 1996) is further summarized in TID/MID (2005a). Information in these reports, as well as annual Article 39 and Article 58 FERC reports filed since 1991, are organized by topic in TID/MID (2012). These and other relevant reports were provided to relicensing participants for independent review on January 17, 2012 and April 2, 2012. Using information from these studies, information identified from past as well as ongoing salmonid studies on the Tuolumne River, and broader source including recommendations by relicensing participants (Attachment A), conceptual models for Chinook salmon (Attachment B) and *O. mykiss* (Attachment C) were developed in consultation with relicensing participants to evaluate factors that may affect salmonids at different life stages throughout the range of the two species in the Tuolumne River, lower San Joaquin River, Delta, and Pacific Ocean. Below, we present a summary of historical and present day influences on Tuolumne River salmonid ecology, an assessment of key issues affecting individual life stages, and an assessment of uncertainty of these preliminary conclusions.

5.1 Primary Ecosystem Inputs and Other Issues Affecting Tuolumne River Salmonids

Because the geographic scale of salmonid habitat extends across local (in-river) and regional (Delta and Pacific Ocean) scales, a number of potential factors may affect Tuolumne River salmonids throughout their life cycle. To provide context for the discussion of issues affecting individual Chinook salmon and *O. mykiss* life stages shown in the accompanying conceptual model summaries (Attachments B and C), an initial discussion of ecosystem inputs as well as historical habitat modifications and other factors affecting salmonids in the Tuolumne River and out-of-basin habitats is provided below.

5.1.1 Water Supply and Instream Flows

Historically speaking, perhaps the most defining features of California's Central Valley are those related to flow regulation by dams, tributary diversions, and the large volumes of water exported from the State Water Project (SWP) and Central Valley Project (CVP) pumping facilities in the Delta. As discussed in later sections of this synthesis, instream flows have both immediate impacts on habitat conditions for salmonids and predator species (e.g., depth, velocity, water temperature) as well as longer-term impacts upon aquatic habitat characteristics due to changes in flow magnitude and timing, flood frequency, sediment supply, transport, and channel morphology.

Water supply and flow in the Tuolumne River is regulated by several dams owned and operated by the Districts and the CCSF. The first dam on the Tuolumne, Wheaton Dam, was constructed ca. 1871 near La Grange for the purpose of diverting flow from the river to support local farming and domestic needs. The earlier Wheaton Dam and the present day La Grange Dam (completed in 1893) blocked upstream passage of anadromous salmonids (Yoshiyama et al. 2001) and reduced summer base flows. These earliest dams lacked storage capacity to affect high flow conveyance to the lower Tuolumne River during winter and spring (McBain and Trush 2000). Later dam construction, including CCSF's Hetch Hetchy Project (completed in 1923 and expanded in 1938), the Districts' Don Pedro dam (completed in 1923 and expanded with cooperative funding in 1971), and CCSF's Cherry Lake (completed in 1955) combined to reduce the magnitude and frequency of flood flows and snowmelt runoff to the lower Tuolumne River downstream of La Grange Dam (RM 52.2).

As summarized in the PAD and detailed further in the *Operations Model Study Report* (W&AR-2), present-day out-of-basin water diversions from the Tuolumne River upstream of the Project by CCSF may exceed 250 TAF in some years depending on water year[6] type. Downstream of the Project, the Districts divert an average of approximately 900 TAF per year from the river at La Grange Dam for irrigation and M&I water uses in the basin. On average, McBain and Trush (2000) estimated that annual water yield to the lower Tuolumne River averages 772 TAF, approximately 60% lower than the average annual unimpaired basin yield.

Completion of the New Don Pedro Dam in 1971 complied with ACOE flood control and other flow requirements as part of the Project license. Under the ACOE (1972), flood control manual, the Districts are required to maintain flood storage space in the Don Pedro Reservoir and limit instream flows in the Tuolumne River at Modesto (RM 16.2) to 9,000 cfs or less. McBain and Trush (2000) estimated that the mean annual flood (based on annual maximum series) has been reduced from 18,400 cfs to 6,400 cfs; the 1.5-year recurrence event (approximately bankfull discharge) has been reduced from 8,400 cfs to 2,600 cfs. The resulting effects upon flow

[6] CDWR Bulletin 120 estimates unimpaired runoff as TAF for the San Joaquin River and tributaries. The San Joaquin Basin 60-20-20 Index classifies water years (October 1 through September 30) into five basic types (C=Critical, D=Dry, BN=Below Normal, AN=Above Normal, W=Wet) which are further refined under Article 37 of the FERC (1996) license. For the purposes of this report, the broader CDWR Water Year types are used as a basis of discussion.

magnitude and timing have largely altered geomorphic processes, riparian vegetation structure and recruitment, and have modified aquatic habitats used by Tuolumne River salmonids and other aquatic and riparian species (McBain and Trush 2000).

As agreed by parties to the 1995 SA, the current project license (FERC 1996) includes a number of flow requirements for the benefit of salmonids and other aquatic resources (TID/MID 2011a)a). Depending on water year type, the current license prescribes annual release and pulse-flow volumes, limitations on the rate of flow changes (or "ramping rates"), and minimum-flow requirements measured at La Grange, for spawning, rearing, and over-summering of Tuolumne River salmonids. As part of the 1995 SA, carryover storage of up to 5 TAF from Wet water years may be used in Dry water year types for attraction flows, outmigration pulse flows, or other purposes. To date this provision has not been used.

Downstream of La Grange Dam (RM 52.2), instream flows are affected by local rainfall runoff, tributary inflow (primarily from Dry Creek at RM 16.4 near Modesto), operational outflows from the Districts' canal systems, agricultural drainage return flows, urban runoff, and groundwater accretion (McBain and Trush 2000). An inventory of major inflows and riparian diversions from the lower Tuolumne River was used in developing the Districts' current *Operations Model Study* (W&AR-2). Downstream of the Tuolumne River there are numerous unscreened diversions as well as four larger diversions between the Merced River confluence and the Delta. Screen and bypass facilities were recently installed by the West Stanislaus Irrigation District and Banta Carbona Irrigation District.

Correlations between San Joaquin River basin outflows and ocean recruitment of Chinook salmon were used as the basis of prior life cycle population models on the Tuolumne (Speed 1993; TID/MID 1997, Report 96-5) and more recent flow correlations using records from La Grange (USGS 11289650) and Vernalis (CDEC Station VNS) with juvenile production and escapement have been reported in Mesick et al. (2008). In the south Delta, the federal CVP C.W. "Bill" Jones Pumping Plant (completed in 1951) and the California SWP Harvey O. Banks Pumping Plant (completed in 1968) withdraw large volumes of water from the "Old River" channel of the San Joaquin River. Lund et al. (2007) report that combined SWP and CVP exports from the San Joaquin and Sacramento rivers and their tributaries have increased dramatically, from 0.7 MAF in WY 1956 to a record high of 6.5 MAF in WY 2006. Based on output from the CDWR DAYFLOW model, water exports have doubled from 1971 to the present and have remained high, even following the 2007 court-ordered flow reductions[7] put in place for the protection of delta smelt (*Hypomesus transpacificus*) entrained by these facilities. Outside of flood periods, Delta exports currently exceed San Joaquin River flows at Vernalis year-round except during the April 15 to May 15 period when pumping restrictions are imposed under D-1641[8]. Effects of Delta water exports on Tuolumne River salmonids are discussed in later sections of this synthesis.

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[7] Judge Oliver Wanger, U.S. District Court for the Eastern District of California, in Natural Resources Defense Council, et al. v. Kempthorne, 1:05-cv-1207 OWW GSA: Dec. 14, 2007.

[8] In addition to the maximum allowable export- to- inflow ratio, from April 15 to May 15 flow, exports by the CVP and SWP are limited to a combined, maximum 3-day running average, maximum of combined export of either 1,500 cfs or 100% of the flow, as measured at Vernalis, whichever is greater. This time period may be adjusted to coincide with fish migration timing and the maximum export rate may be varied by the CALFED Operations Group.

5.1.2 Sediment Supply and Transport

Alterations in water supply and instream flows discussed above have immediate impacts on habitat conditions for salmonids (e.g., depth, velocity, water temperature) but also on other habitat characteristics due to changes in sediment supply, transport, and channel morphology. La Grange and Don Pedro dams intercept all coarse sediment that would normally be supplied to the lower Tuolumne River (TID/MID 2011a) and the majority of sediment supply from the upper watershed has been completely lost (McBain and Trush 2000).

The Tuolumne River channel downstream of La Grange Dam shows evidence of channel down-cutting, widening, armoring, and reduction of sediment storage features (e.g., lateral bars, riffles) due to sediment capture in the upstream reservoirs, instream and floodplain gravel mining, and other land-use changes (McBain and Trush 2000, 2004). A historical timeline of channel and floodplain modifications throughout the San Joaquin River tributaries provided in McBain and Trush (2000) includes placer mining (1848–1880), dredge mining (1880–1960s), flow regulation (1890s to the present), sand and gravel mining (1940s to present), urbanization (1850s to the present) and grazing and farming (1850s to the present). On the Tuolumne River, dredge mining during the early 1900s excavated channel and floodplain sediments and left a legacy of dredger tailing deposits between RM 38.0 and 50.5. Sand and gravel aggregate mining extracted materials directly from the active river channel, leaving large in-channel pits (“special run-pools” [SRPs]) up to 400 feet (120 m) wide and 35 feet (11 m) deep and occupying approximately 32% of the length of the channel in the gravel-bedded reach (RM 24–52).

Much of the dredger tailings upstream of RM 45 were removed from the floodplain downstream of La Grange Dam as part of New Don Pedro Dam construction in the 1960s and broader historical deposits of dredger tailings (RM 38.0–50.5) confined the active river channel, resulting in channel down-cutting and preventing sediment recruitment that would otherwise result from the normal process of channel migration (McBain and Trush 2000). Channel migration has been nearly eliminated due to historical and present-day mining. In reaches with functionally connected floodplains, flow regulation by upstream dams limits the frequency, duration, and magnitude of high-flow events affecting channel migration and floodplain processes. Contemporary sediment transport rates were estimated by McBain and Trush (2000, 2004) to average 1,900 tons/year based on surveys near riffles R4A (RM 49) through R5A (RM 48), lower than under historical conditions. The legacy in-channel gravel mining pits intercept coarse sediment during bed mobilizing flows, which require flows in excess of 5,000 to 7,000 cfs depending on channel location (McBain and Trush 2004). In addition, more recent aggregate mining operations have excavated sand and gravel from floodplains and terraces immediately adjacent to the river channel at several locations downstream of Roberts Ferry Bridge (RM 39.5). These floodplain and terrace mining pits are typically separated from the river by narrow un-engineered berms (i.e., native soils at high bank slopes) that are susceptible to failure during high flows such as occurred during 1997. The current *Spawning Gravel Study* (W&AR-4) will provide more up-to-date information on spawning habitat area availability in the lower Tuolumne River.

During the 1997 flood, flows in excess of 60,000 cfs flowed over the Don Pedro emergency spillway, resulting in the loss of riffle habitats through substrate mobilization in the lower Tuolumne River as well as the erosion of approximately 200,000 yd^3 (150,000 m^3) of sediment below the spillway and above La Grange Dam (McBain and Trush 2004). Much of this material was deposited behind La Grange Dam. The remainder was transported downstream and deposited in the river and floodplain or was transported downstream to the San Joaquin River and the Delta. Fine sediment surveys completed in 2001 identified a large volume of sand stored within riffle substrates, but only limited amounts of sand were observed in pools upstream of Basso Bridge (RM 47.5) (McBain and Trush 2004). Lower Dominici Creek (RM 47.8) was assessed as having "moderate" fine sediment input potential, while the two other tributaries, Gasburg Creek (RM 50.3) and Peaslee Creek (RM 45.2) were assessed as having "large" input potential. A sediment basin was installed on Gasburg Creek in 2007 but fine sediments continue to enter the river from Peaslee and Dominici creeks during runoff events. For example, failure of sediment controls following grading operations along Lake Road resulted in extended periods of high turbidity during May 2009 (TID/MID 2010). Follow-up surveys of in-channel deposits of fine sediment were conducted as part of the current *Spawning Gravel Study* (Study W&AR-4).

In order to improve salmonid spawning and rearing conditions in the lower Tuolumne River, several coarse sediment augmentation projects, as well as habitat restoration projects have been completed (TID/MID 2005a). CDFG placed approximately 27,000 $yd^3$of gravel into the river near Old La Grange Bridge (RM 50.5) from 1999 to 2003 (TID/MID 2007, Report 2006-10). Riffle and floodplain reconstruction projects have also been completed at Bobcat Flat (RM 43.5), near the site of 7/11 Materials (RM 40.3–37.7), and at SRP 9 and 10 (~RM 25.7), with designs and preliminary permitting completed for additional gravel augmentation projects at upstream locations (TID/MID 2007, Report 2006-8). Changes in sediment storage and estimates of fine sediment within the dominant spawning reach of the lower Tuolumne River are assessed as part of the current *Spawning Gravel Study* (Study W&AR-4).

5.1.3 Anthropogenic Effects

A range of anthropogenic influences may affect habitat, as well as cause mortality of Tuolumne River salmonids, directly or indirectly. Beginning with the Gold Rush, the channel and floodplain of the Tuolumne River have been extensively modified due to resource extraction discussed above (e.g., water diversion, gold mining, aggregate mining), but also by changes in land-use practices (e.g., agriculture, ranching, and urbanization). As summarized in McBain and Trush (2000), between 1937 and 1993 nearly all of the areas in the gravel-bedded zone that historically supported riparian forests along the Tuolumne River have been altered through mining, livestock grazing, or agricultural activities. Vegetation along the lower Tuolumne River historically varied from grassland and open woodland/oak savannah in the gravel-bedded reach to a multi-layered riparian "gallery forest" extending from bluff to bluff in the downstream sand-bedded reach. Recent vegetation mapping by McBain and Trush (2000), updated as part of the *Riparian Study* (W&AR-19) shows that the riparian forest in many areas is now non-existent or confined to a narrow band along the active channel. Many miles of river bank have been leveed and stabilized with riprap by agencies or landowners, further reducing favorable salmon habitat during high flows. After the 1997 flood, new subdivisions that had been inundated in the Modesto area were found to have been constructed within the FEMA floodplain area designated prior to 1997. Levees and bank revetment extend along portions of the river bank from near Modesto (RM 16) downstream through the lower San Joaquin River and Delta, limiting rearing habitat for juvenile salmonids.

The San Francisco Bay estuary and Sacramento/San Joaquin River delta comprise the largest estuary on the west coast of North America, stretching from the San Francisco Bay to the west slope of the Sierra Nevada Range. Under historical conditions, the south Delta and lower San Joaquin River were composed of tidal wetlands merging southward into a floodplain wetlands interspersed with complex side channel habitats, lakes and ponds, with seasonal wetlands bordering upland habitats (Whipple et al. 2012). As summarized by Lund et al. (2007), the present day Delta encompasses about 60,000 acres (25,900 ha) of water surface exclusive of Suisun Bay, 520,000 acres (210,400 ha) of agricultural lands, 64,000 acres (26,000 ha) of towns and cities, and 75,000 acres (30,300 ha) of undeveloped areas. Much of the rich Delta farmland has lost soil from oxidation, compaction, and wind erosion, resulting in lowered elevations of some islands up to 25 feet below sea level (CDWR 2009). The Delta is interlaced with hundreds of miles of waterways, and relies on more than 1,000 miles (1,600 km) of levees for protection against flooding (Moore and Shlemon 2008). These levees have eliminated the majority of tidally exchanged marsh habitats in the Delta (Whipple et al. 2012), areas historically used as nursery areas for Delta fishes (Kimmerer et al. 2008). Completion of large dams on the major rivers of the Central Valley as well as the SWP and CVP facilities have led to other broad ecological changes (Whipple et al. 2012, Lund et al. 2007, Durand 2008), with effects on hydrology and aquatic habitat conditions for rearing and emigrating Tuolumne River salmonids discussed in later sections.

In addition to land use changes, discharge of nutrients such as nitrogen and phosphorus from non-point runoff of agricultural fertilizer as well as from publicly owned water treatment works (POTW) stimulates algae growth, with attendant increases in the magnitude of daily dissolved oxygen swings, as well as changes in the food web of the San Joaquin River and Delta (Durand 2008). In addition to discharges of nutrients, the California Department of Pesticide Regulation (CDPR) has documented over 300 herbicides and pesticides that are discharged throughout agricultural regions of California's Central Valley and Delta, with effects on plankton as well as juvenile salmonids (Werner et al. 2008).

Introduction of non-native species has resulted in large changes in the fish community structure of the Central Valley (Moyle 2002). 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. Ford and Brown (2001) identified a total of 33 taxa of fish (12 native and 21 introduced), including Chinook salmon and *O. mykiss*, that have been captured during various sampling programs on the Tuolumne River between the 1980's and 1997. Brown (2000) sampled twenty sites in the lower San Joaquin River drainage from 1993 to 1995 and concluded that the proportion of native and non-native species were related to modifications due to agriculture and water development. Over 200 non-native species have been introduced in the Delta and become naturalized (Cohen and Carlton 1995), including many fish which prey upon juvenile salmonids (e.g. smallmouth bass, largemouth bass, striped bass). Further, the introductions of several zooplankton species and the overbite clam (*Corbula amurensis*) have been attributed to dramatic changes in the lower trophic levels of the Delta food web (Feyrer et al. 2003) and have been identified in the lower San Joaquin and Tuolumne rivers (Brown et al. 1997), potentially affecting food availability for rearing salmonids.

Recent studies have increasingly demonstrated potentially adverse effects of hatchery-reared fish on co-occurring wild stocks with which they may interact via interbreeding, competition or predation (e.g., summaries in JHRC 2001, ISAB 2003, and Williams 2006). An issue of concern is the pervasive genetic introgression of hatchery stocks with “natural” stocks, resulting in a decrease of biological fitness in the natural stocks (e.g., ISAB 2003, Berejikian and Ford 2004, Kostow 2004, Araki et al. 2007, Lindley et al. 2007, CDFG and NMFS 2001). Although the proportions of adipose-fin-clipped salmon identified as originating from hatcheries has been historically low in Tuolumne River spawning surveys, this proportion increased dramatically in the 1990s to the present (TID/MID 2005a, Mesick 2009, TID/MID 2012, Report 2011-8). In the Central Valley as a whole, it is estimated that hatchery production provided over half of the Central Valley harvest and escapement of salmon in some years (CDFG and NMFS 2001). Barnett-Johnson et al. (2007) recently estimated that only 10% of Central Valley Chinook salmon captured in the ocean troll fishery were not raised in a hatchery setting. Assuming roughly equivalent survival of hatchery- and natural-origin fish from the fishery to the spawning grounds, these results imply that as much as 90% of annual escapement could consist of hatchery reared fish.

To provide more precise estimates of the proportions of hatchery-reared and naturally produced Chinook salmon in Central Valley rivers, a Constant Fractional Marking Program (CFM) was initiated by the Pacific States Marine Fisheries Council (PSFMC) in the spring of 2007, with an adipose fin clip and coded-wire tagging of at least 25% of the releases occurring from 2007–2012 (Buttars 2011). Although the nearby Merced River Fish Facility (MRFF) does not participate in the CFM Program, observations of adipose-fin-clipped salmon have steadily risen in all three of the San Joaquin River basin tributaries since 2007, reflecting a higher proportion of adipose-fin-clipping at the participating hatcheries[9] Natural and hatchery contributions to historical escapements are not available prior to the recent CFM years (Newman and Hankin, 2004). There is some evidence from genetic sampling and analyses that the majority of Central Valley steelhead stocks have been genetically introgressed by hatchery-produced ancestors, particularly from shared out-of-basin broodstocks (Eel River) used at the Nimbus (American River) and other hatcheries (Garza and Pearse, 2008). Lindley et al. (2007) suggest that hatchery introductions have altered the genetic structure of salmonid populations in the Central Valley.

5.1.4 Climate and Meteorology

Seasonal and longer-term variations in climate and local meteorology affects a number of ecosystem-scale processes for salmonids, primarily through changes in rainfall and runoff, but also changes in air and water temperatures at the watershed scale, as well as in the Pacific Ocean. The Mediterranean climate of the Sierra Nevada range and its foothills are characterized by hot, dry summers, with precipitation primarily falling from October to April, and peaking from November to March. Water temperatures downstream of Don Pedro Dam are moderated by the cold-water pool of the reservoir, with water temperatures in the lower Tuolumne River varying

[9] Hatcheries participating in the PFMC CFM Program include the Coleman National Fish Hatchery, Feather River Hatchery, Feather River Hatchery Annex, Nimbus Hatchery, and Mokelumne River Hatchery.

from approximately 10–13ºC (50–55ºF) near La Grange Dam and summer maximums reaching near 30ºC (86ºF) near the confluence with the San Joaquin River (TID/MID 2011a).

Lund et al. (2003) summarized the main factors expected to affect California climate and hydrology due to climate change, including 1) sea level rise, 2) increased runoff proportions from rainfall vs. snowmelt, 3) increased air temperatures, 4) potential increases/decreases in precipitation, and 5) potential changes in the duration and severity of droughts and/or floods. Water temperatures in the lower San Joaquin River and Delta generally range between 8–27°C (46–82ºF) on an annual basis. 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 expected increases in water temperatures (Wagner et al. 2011). Vanrheenan et al. (2004) and others discuss other potential ecosystem-scale changes in the Delta that might result due to earlier snowmelt, more precipitation falling as rain (vs. snow) in some locations, as well as changes in Delta exports and water deliveries. For the Tuolumne River and other San Joaquin River basin tributaries, reduced reservoir storage levels as well as an increased frequency of critically dry water year types are predicted.

In the open ocean, seasonal and longer term changes in air temperatures affect water temperature and ocean circulation patterns, with effects on nutrient upwelling and primary and secondary productivity of the marine food web that supports ocean feeding and growth of Tuolumne River and other Pacific salmonids. Considered separately from issues of climate change discussed above, both the Pacific Decadal Oscillation (PDO) and shorter-term El Niño/Southern Oscillation (ENSO), appear to change ocean productivity supporting California salmonid populations through a series of complex processes. The PDO is a pattern of ocean current circulation due to climate variability that varies on an inter-decadal time scale, usually at a period of 20 to 30 years (Mantua et al. 1997). In contrast, the ENSO occurs approximately every five years (Zhang et al. 2007). The ENSO is generally associated with patterns of rainfall in California (Schonher and Nicholson 1989) and has been attributed with changes in ocean currents and productivity off of the California coast (MacFarlane et al. 2005).

5.2 Key Issues Affecting Tuolumne River Fall-run Chinook Salmon

Using the conceptual model diagrams for Chinook salmon shown in Attachment B and building upon the preceding discussion of primary ecosystem inputs and other factors affecting Tuolumne River salmonids, the following sections discuss key issues affecting individual life stages (e.g., spawning gravel availability, water temperature, predation, food availability, etc.), separated into mechanisms affecting reproduction, growth, as well as sources of direct and indirect mortality. Many of the stressors identified in this report have been discussed in assessments of conditions for Chinook salmon in the San Joaquin River (SJRRP 2011), in prior limiting factors assessments contained in the 1992 *Fisheries Studies Report* by the Districts (TID/MID 1992, Volume 2), in preliminary analyses contained in the 2008 *Draft Limiting Factor Analyses & Recommended Studies for Fall-run Chinook Salmon and Rainbow Trout in the Tuolumne River* (Mesick et al. 2008), as well as other sources.

Chinook salmon exhibit variable life-history patterns dependent upon habitat conditions across the species' range (Healey 1991, Quinn 2005). Spawning populations of Chinook salmon and other anadromous salmonids are distributed across the northern temperate latitudes of the Pacific Ocean from Asia, Alaska, Washington, Oregon, and as far south as the San Joaquin River in California's Central Valley (Healey 1991). Table 5.2-1 and Figure 5.2-1 provide an overview of life history timing and residency of various fall-run Chinook salmon life stages occurring in the Tuolumne River, Delta, and ocean.

Table 5.2-1. 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	grey	dark grey	dark grey	grey								grey
Adult Spawning	grey	grey	dark grey	grey								
Egg Incubation and Fry Emergence		grey	dark grey	dark grey	dark grey							
In-river Rearing (Age 0+)					grey	dark grey	dark grey	grey	grey	grey		
Delta Rearing (Age 0+)						grey	dark grey	dark grey	dark grey	grey		
Smolt Outmigration (Riverine/Delta)						grey	grey	dark grey	dark grey	grey		
Ocean Rearing and Adult Residency	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey

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.

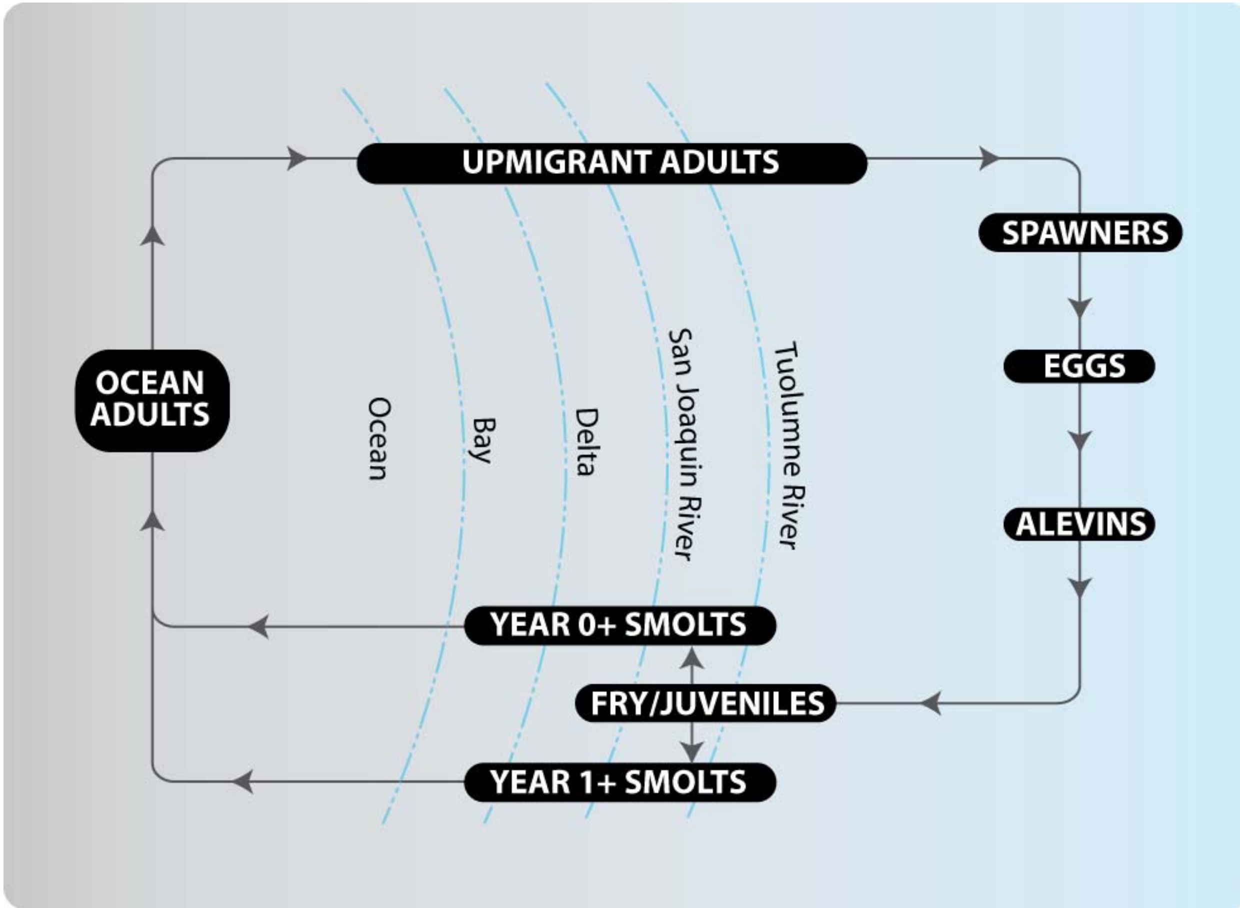

Figure 5.2-1. Fall-run Chinook salmon life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

Table 5.2-2 provides a summary of issues and associated mechanisms known to affect Chinook salmon life-history progression. The summary includes an assessment of whether the identified mechanism has the potential to affect individual Chinook salmon life stages and population levels, along with a preliminary assessment of the certainty of this determination. These assessments were based upon whether the mechanisms addressed are likely to be relevant and whether basin-specific data provided a demonstrable linkage to the identified mechanisms. If no Tuolumne River-specific information was found for a particular mechanism, the Districts relied upon sources from nearby San Joaquin River basin and Central Valley tributaries as well as regional information sources, using professional judgment and consultation with relicensing participants. Table 5.2-2 and the following discussion provides a summary, by life-stage, of key issues regarding population-scale effects, including seasonality, certainty, and the geographic source of information used for this synthesis. More detailed information regarding these issues is provided in Attachment B.

Table 5.2-2. Summary Issues affecting Tuolumne River Chinook salmon populations.

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
Upmigration	***Factors Contributing to Chinook salmon Homing, Straying and Timing of Arrival at Spawning Grounds***					
	Flow effects	Inconclusive	X	X	X	No relationship between flow and arrival timing on the Tuolumne, but Del Real and Saldate (2011) show a partial relationship on the Mokelumne River. Only broad relationship of San Joaquin vs. Sacramento straying with flow (Mesick 2001).
	Water quality	Unlikely		X	X	No relationship in San Joaquin basin timing other than Hallock et al. (1970) tracking study before DO improvements at Stockton (Newcomb and Pierce 2010). Although early life history contaminant exposure may impair olfactory sensitivity (Hansen et al. 1999, Scholz et al. 2000), no Central Valley studies have shown impairment of olfactory mediated homing.
	Water temperature	Unlikely	X	X		No relationship for the Tuolumne. Water temperature blockage suggested by Hallock et al. (1970) largely unaffected by pulse flows from tributaries.
	Straying of hatchery origin salmon	Unknown/ likely		X	X	Increased proportions of hatchery origin fish found in the Tuolumne (e.g., TID/MID 2012, Report 2011-8) and in the Central Valley as a whole (Barnett-Johnson et al. 2007).Although no information is available to assess effects of hatchery-origin fish on run-timing in the Tuolumne River, hatcheries broodstock selection practices can alter run timing (Flagg et al 2000) and affect spawning success.
	Factors Contributing to Direct Mortality of Upmigrant Adults					
	Ocean harvest	Likely		X		No San Joaquin basin-specific information available, but variations in ocean harvest indices (PFMC 2012) show broad effects on Central Valley population levels.
	Water quality	No			X	No water quality related reports of mortality in the Tuolumne River or other San Joaquin River tributaries.
	Water temperature	No		X	X	No Tuolumne-specific information on pre-spawn mortality exists. Guignard (2006) showed low levels of pre-spawn mortality on the Stanislaus River (2005–2006).
	In-river harvest and poaching	Unknown		X		San Joaquin river harvest banned during 2000s. No estimate of salmon lost to illegal poaching is available.
	Factors Contributing to Indirect Mortality of Upmigrant Adults					
	Disease and parasites	Unlikely			X	Although high water temperatures and poor water quality may increase stress and disease (Wedemeyer 1974), exposure time to these conditions is short and no reports of disease incidence have been identified.

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
Spawning	***Factors Contributing to Chinook Salmon Spawning Success***					
	Habitat availability	Importance increases with escapement	X			Evidence of competition for suitable spawning areas and exclusion of spawners at high escapement levels (TID/MID 1992, Appendix 6; TID/MID 2000, Report 1999-1; TID/MID 2001, Report 2000-1) as well as gravel losses at upstream spawning riffles (McBain and Trush 2004).
	Gravel quality	Unlikely	X			Previous gravel ripping experiments to improve gravel quality did not result in increased spawning activity (TID/MID 1992, Appendix 11). Chinook salmon are able to spawn in a wide range of gravel sizes (Kondolf and Wolman 1993).
	Hydraulic conditions	Unlikely	X			Chinook salmon are capable of spawning within a wide range of water depths and velocities (Healey 1991).
	Water temperature	Unknown	X			The current water temperature criteria assessment (W&AR-14) and ongoing IFIM study (Stillwater Sciences 2009a) will assess water temperature effects upon the river-wide distribution of suitable spawning habitat.
	Straying of hatchery origin salmon	Unlikely	X		X	Hatchery-origin fish generally return smaller than their wild counterparts (Flagg et al 2000), resulting in reduced fecundity. Increased proportions of hatchery origin fish found in the Tuolumne (e.g., TID/MID 2012, Report 2011-8) have not been accompanied by reduced fish size at return (e.g., TID/MID 2011b, Report 2010-2), suggesting hatchery influences on Tuolumne River spawner fecundity may be minor.
	Factors Contributing to Direct Mortality of Pre-Spawning Chinook Salmon Adults					
	Water temperature	No		X	X	Low pre-spawn mortality levels in the neighboring Stanislaus River have been documented (Guignard 2006).
	In-river harvest and poaching	Unknown				San Joaquin river harvest banned during 2000s. No estimate of salmon lost to illegal poaching is available.
	Factors Contributing to Indirect Mortality of Pre-Spawning Chinook Salmon Adults					
	Disease and parasites	Unknown/ unlikely			X	Although high water temperatures and poor water quality may increase stress and disease (Wedemeyer 1974), exposure time to these conditions is short and no reports of disease incidence have been identified.

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
Egg Incubation though Fry Emergence	***Factors Contributing to Egg/Alevin Growth and Fry Emergence of Chinook Salmon***					
	Water temperature	Yes	X	X	X	Water temperature conditions are generally suitable in the lower Tuolumne River and temperature exposure history is routinely used to predict emergence timing of Chinook salmon fry (TID/MID 2007, Report 2006-7, Jager and Rose 2003).
	Water quality	Unlikely	X			Survival-to-emergence studies found suitable intragravel DO on the Tuolumne (TID/MID 2007, Report 2006-7) and Stanislaus Rivers (Mesick 2002).
	Factors Contributing to Direct Mortality of Chinook Salmon Eggs/Alevins					
	Antecedent water temperature	Inconclusive			X	No studies were identified in the Tuolumne or San Joaquin River tributaries, but antecedent exposure of upmigrant adults has been attributed to reduced egg viability in broader studies (e.g., Mann and Peery 2005, Jensen et al. 2006).
	Intragravel water temperature	Unlikely	X	X		Intragravel water temperatures recorded in the 2001 survival-to-emergence study (TID/MID 2007, Rpt. 2006-7) within the suitable range for salmonid egg incubation and alevin development provided by Myrick and Cech (2001).
	Intragravel water quality	Unlikely	X	X	X	Although fine sediment was attributed to low survival-to-emergence in prior studies (TID/MID 1992, Appendix 7), suitable intragravel DO was found on the Tuolumne (TID/MID 2007, Report 2006-7) and Stanislaus Rivers (Mesick 2002).
	Redd superimposition	At high escapement	X			Previous studies (TID/MID 1997, Reports 96-5 and 96-6, TID/MID 1992, Appendix 7) suggest that redd superimposition has the potential to increase density dependent egg mortality and delayed fry emergence at moderately high escapement.
	Straying of hatchery origin salmon	Unknown/ unlikely	X		X	Increases in hatchery origin fish (e.g., TID/MID 2012, Report 2011-8) have not been accompanied by reduced fish size (e.g., TID/MID 2011b, Report 2010-2),
	Redd scour	No	X		X	Typical egg pocket depths (LaPointe et al. 2000) as well as high rearing density following the 1997 flood suggest low potential for redd scour mortality.
	Redd dewatering	No	X	X		Because of FERC (1996) requirements for steady spawning flows, redd dewatering is not considered to contribute to high rates of direct mortality.
	Entombment	No	X	X		A sedimentation basin was installed on Gasburg Creek in 2007 and entombment has not been reported on the Tuolumne River (e.g., TID/MID 2007, Report 2006-7).
	Factors Contributing to Indirect Mortality of Chinook Salmon Eggs/Alevins					
	Bacterial and fungal infections	Unknown/ unlikely			X	No reports of disease incidence on incubating eggs in the Tuolumne River or other Central Valley rivers.
Rearing/Outmi	***Factors Contributing to Juvenile Growth and Smoltification of Chinook Salmon***					

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
	Habitat availability	Unlikely	X		X	Fry rearing densities appear to be related to antecedent escapement (Figure 5.2-4), with variations in downstream dispersal timing related to flood control releases.
	Water temperature	Unlikely	X	X		Growth rate estimates from multiple seine surveys (TID/MID 2012, Report 2011-4) are within the range reported by Williams (2006) for Central Valley Chinook.
	Food availability	No	X	X		BMI monitoring (e.g., TID/MID 1997, Report 96-4; TID/MID 2003, Report 2002-8) and smolt evaluations (Nichols and Foott 2002) suggest adequate food supply.
	Factors Contributing to Direct Mortality of Juvenile Chinook Salmon					
	Water temperature	Inconclusive	X	X		Temperatures below thresholds in Myrick and Cech (2001) during spring and no mortality events observed. Temperature or predation mortality suggested by reduced juveniles in summer and fall surveys (TID/MID 2011b, Report 2010-5).
	Predation	Yes	X		X	Documented in direct surveys by Districts (TID/MID 1992, Appendix 22), in multi-year smolt survival tests (TID/MID 2003, Report 2002-4) and by comparisons of upstream and downstream smolt passage (TID/MID 2012, Report 2011-4).
	Habitat availability for predators	Yes	X			In-channel mining, non-native fish introductions, and reduced flood frequency have created suitable habitat for non-native predators (McBain and Trush 2000, Ford and Brown 2001, McBain and Trush and Stillwater Sciences 2006).
	Flow and water temperature effects on predation	Yes	X			Predator distribution (Brown and Ford 2002), year class success (McBain and Trush and Stillwater Sciences 2006), smolt survival (TID/MID 2003, Report 2002-4), and habitat suitability of salmon and predators (McBain and Trush and Stillwater Sciences 2006, Stillwater Sciences 2012b) vary with flow and water temperature.
	Water quality effects on predation	Unknown	X		X	The lower Tuolumne River is currently listed for pesticides shown to impair olfactory sensitivity in laboratory studies (Scholz et al. 2000).
	Stranding and entrapment	No	X			Project operations do not include daily hydropower peaking and ramping rates following flood control releases are limited under the current FERC (1996) license.
	Entrainment	Unknown/ unlikely		X		No studies examining fish losses as a result of in-river diversions are available for the Tuolumne River, and few available for the Central Valley.
	Factors Contributing to Indirect Mortality of Juvenile Chinook Salmon					
	Disease and parasites	Unlikely	X	X		Low disease incidence in Tuolumne River smolts (Nichols and Foott 2002) suggests a low risk of indirect mortality due to disease.
Delta Rearing/ Outmigration	***Factors Contributing to Juvenile Growth and Smoltification***					
	Habitat availability	Yes		X		Reductions in marsh and floodplain habitats due to levees as well as changes in flow magnitudes and timing have affected growth opportunities and survival of

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
						Chinook salmon in the Delta (Kimmerer et al. 2008, Lund et al. 2007).
	Water temperature	Yes		X		Growth rates in the Delta are generally higher than in upstream tributary habitats due to increased water temperature (Kjelson et al. 1982), with higher growth rates under warm water conditions on inundated floodplains (Sommer et al. 2001).
	Food availability	Yes		X		Food web changes (Durand 2008) and low growth rates (MacFarlane and Norton 2002, Kjelson et al. 1982) suggest limited food supplies in the Delta.
	Factors Contributing to Direct Mortality of Juvenile Chinook Salmon					
	Water temperature	Yes		X		Temperatures of 25°C (77°F) associated with increased mortality (Myrick and Cech 2001) are routinely found in the South Delta by late-May. Baker et al. (1995) show water temperature explains much of the variation in Delta smolt survival studies.
	Predation	Yes		X		Predation has been documented in the lower San Joaquin River (e.g., SJRGA 2011), in the Clifton Court Forebay (Gingras 1997), as well as nearshore and open water habitats (Lindley and Mohr 2003) of the Delta.
	Habitat availability for predators	Yes		X		Non-native fish introductions, levees, and changes in flow magnitudes and timing have increased predator distribution (Kimmerer et al. 2008, Lund et al. 2007).
	Flow effects on predation	Yes		X		Newman (2008) shows a significant Vernalis-flow-survival relationship to Jersey Pt. Although HORB improves survival through the Delta by 16–61%, a significant flow-survival relationship does not exist without HORB (Newman 2008).
	Water temperature effects on predation	Yes		X		Baker et al. (1995) show water temperature explains much of the variation in Delta smolt survival studies.
	Entrainment	Yes		X		Kimmerer (2008) shows salvage losses of Chinook salmon at the SWP and CVP increases with increasing export flows. Pre-screen losses of 63–99% for all fish entrained into the Clifton Court forebay (Gingras 1997).
	Water quality	Unknown			X	Pesticides shown to impair olfactory sensitivity in laboratory studies (Scholz et al. 2000). No Central Valley information identified to assess olfactory impairment effects on predation.
	Factors Contributing to Indirect Mortality of Juvenile Chinook Salmon					
	Disease and parasites	No	X	X		No clinical signs of disease in juvenile fall-run Chinook salmon collected from the Tuolumne River in 2002, with low rates of infections of fish collected in the Delta in 2001 and 2002 (Nichols et al. 2001, Nichols and Foott 2002).

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
Ocean Rearing	***Factors Contributing to Adult Chinook Salmon Growth in the Ocean***					
	Food availability	Yes		X	X	PDO and ENSO influence coastal productivity and salmon abundance (MacFarlane et al. 2005, Mantua and Hare 2002). Central Valley as well as Southern Oregon/ Northern California Coastal Chinook Salmon growth are dependent on prevailing coastal conditions for their growth (MacFarlane and Norton 2002, Lindley et al. 2009, Wells et al. 2007). Hatchery releases may result in density-dependent competition for food resources during early ocean rearing (Ruggerone et al. 2010).
	Factors Contributing to Direct Mortality of Adult Chinook Salmon					
	Harvest	Yes		X	X	Central Valley stocks have been exploited at average rates of more than 60 percent and selecting for larger fish for many years, a pattern that may reduce fish size and fecundity (Lindley et al. 2009, NMFS 2006).
	Predation	Inconclusive		X	X	Avian predation in San Francisco Bay (Evans et al. 2011) as well as pinniped predation along the California coast (Scordino 2010) has been documented but population-level impacts have not been assessed.
	Water quality	Inconclusive			X	Early life history exposure to pesticides may also affect predator avoidance (Scholz et al. 2000, NMFS 2006), but no reports have assessed predation effects due to contaminant exposure in the Central Valley or along the California Coast.
	Factors Contributing to Indirect Mortality of Adult Chinook Salmon					
	Disease and parasites	Unlikely			X	Based upon available monitoring data (Nichols et al. 2001, Nichols and Foott 2002), potential impacts of disease on juvenile Chinook salmon upon early ocean entry are considered unlikely.

5.2.1 Upstream Migration

As discussed in Attachment B (Section 2), a number of factors may potentially affect the numbers of Chinook salmon arriving in the Tuolumne River. Most Chinook salmon return from the ocean to spawn in freshwater streams when they are between two and five years old. For the Tuolumne River, the average age at return is 2.7 years, with two-, three-, and four-year-old salmon making up the largest proportions of the annual salmon run in the Tuolumne River since the 1980s (TID/MID 2012, Report 2011-2). Fall-run Chinook salmon enter the San Francisco Bay and Delta in late summer (Williams 2006). Based upon daily observations by Districts' operating staff on the timing of adult salmon arrival near the La Grange Powerhouse (RM 51.5) from 1981–2006 (TID/MID 2007, Report 2006-2), October 6th is the median date of first arrival in most years (Figure 5.2-2). Due to differences in the distance travelled, recent estimates of arrival timing at the RM 24.5 counting weir are earlier than the historical observations, with dates of weir passage of September 22nd, September 9th, and September 16th in each of the three years since operations began in 2009 (TID/MID 2012, Report 2011-8).

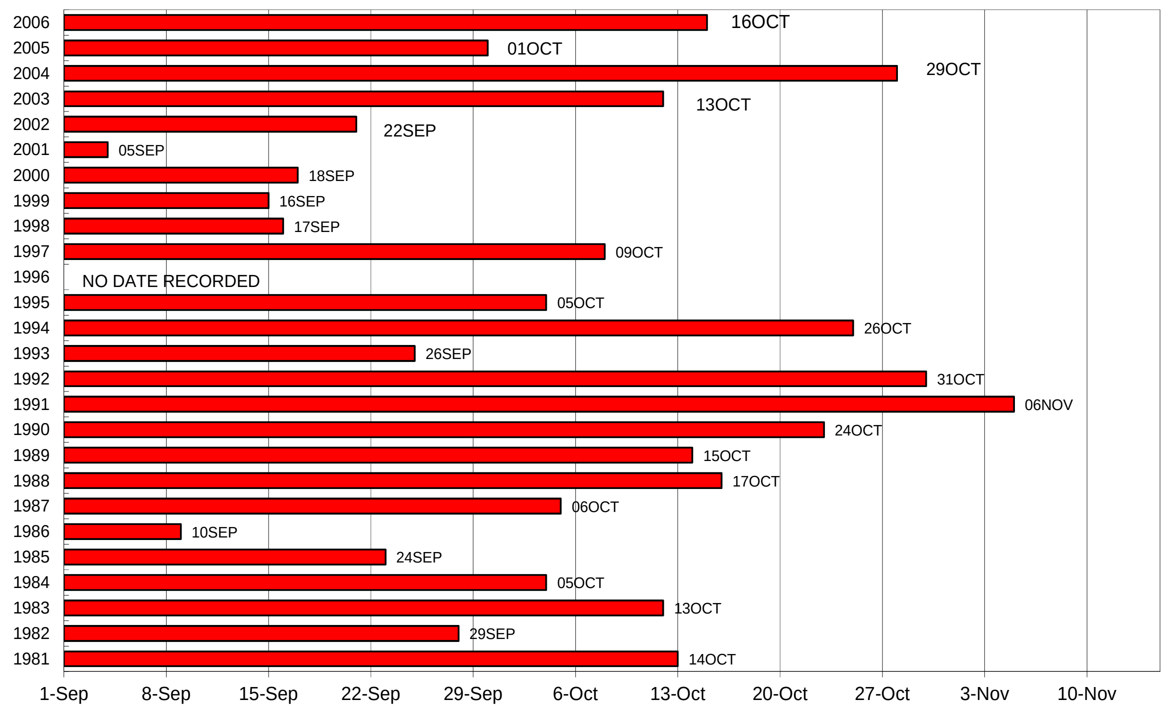

Figure 5.2-2. Dates of first observation of adult salmon near La Grange (1981–2006).

5.2.1.1 Factors Affecting Arrival at Spawning Grounds

Based upon review of available information, potential variations in arrival timing due to flow, water quality, or water temperature conditions, are unlikely to affect Chinook salmon population levels (Table 5.2-2). Although upmigration timing has been shown to be partially affected by variations in instream flows in the Mokelumne River (Del Real and Saldate 2011), based upon the review of available information, the observed arrival timing at the La Grange powerhouse has no relationships with antecedent flows, suggesting that these factors have had little influence on Chinook salmon arrival timing in the Tuolumne River.

Homing fidelity of Chinook salmon to their natal stream is related to the sequence of olfactory cues imprinted during juvenile rearing and outmigration, and so attraction flows as well as the entrainment of flows into the SWP and CVP may potentially affect the numbers of Chinook salmon returning to the Tuolumne River. However, other than broad relationships between Vernalis flows, water exports at the SWP and CVP facilities, and subsequent recoveries of hatchery-reared CWT fish recovered in Sacramento and San Joaquin River basin hatcheries showed by Mesick (2001), the relationship between San Joaquin River tributary homing and attraction flows remains poorly understood. Although early life history exposure to some heavy metals and pesticides has been shown to impair olfactory functions in salmonids (Hansen et al. 1999, Scholz et al. 2000), no Central Valley studies have shown impairment of olfactory mediated homing.

The high rates of straying of hatchery fish into the Tuolumne River have the potential to reduce the juvenile production and Chinook salmon population levels (Table 5.2-2). As discussed in Attachment B, hatchery origin fish contribute disproportionately to the salmon runs of the Central Valley (Barnett-Johnson et al. 2007, Johnson et al. 2011) and have been increasingly identified in Tuolumne River salmon runs (TID/MID 2005a; Mesick 2009; TID/MID 2012, Report 2011-8). 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 may potentially select for early run timing by spawning a disproportionately higher percentage of earlier returning fish (Flagg et al. 2000), resulting in reduced spawning success.

5.2.1.2 Factors Contributing to Direct and Indirect Mortality

Ocean harvest has the potential to reduce the numbers of upmigrant adults to the Tuolumne River. However, water quality, and water temperature conditions in the Delta, San Joaquin River, and lower Tuolumne River are unlikely to result in direct mortality of upmigrant adults or mortality due to diseases. No information was available to address potential disease incidence in spawning Chinook salmon adults in the lower Tuolumne River or other San Joaquin River tributaries. Lastly, no information was identified to assess the magnitude of poaching effects on the number of upmigrating Chinook salmon.

5.2.2 Spawning

As discussed in Attachment B (Section 3), many factors may potentially affect the numbers of successfully spawning Chinook salmon in the Tuolumne River. Chinook salmon spawner abundance, as estimated by historical and recent spawning surveys, has been highly variable. The results of spawning surveys since 1971 are shown in Figure 5.2-3 based upon data compiled by CDFG (2012) with modifications described in individual monitoring reports submitted by the Districts (e.g., TID/MID 2012, Report 2011-2). As reported in TID/MID (2005), some spawning surveys were conducted by CDFG and USFWS in the 1940s, with more routine surveys by CDFG beginning in 1951 (Fry 1961, Fry and Petrovich 1970). Since 1971, these estimates range from a high of 40,322 in 1985 to a low of 77 in 1991, with a secondary peak of 17,873 spawners estimated in 2000. Most recently, escapement estimates since 2009 shown in Figure 5.2-3 have been based upon weir counts at RM 24.5 (TID/MID 2012, Report 2011-2). Periods of high and low escapement are generally associated with climate driven changes in ocean conditions (MacFarlane et al 2005; Lindley et al 2009) and have been correlated with runoff patterns resulting in flood control releases and extended San Joaquin River basin outflows during spring (Speed 1993; TID/MID 1997, Report 96-5).

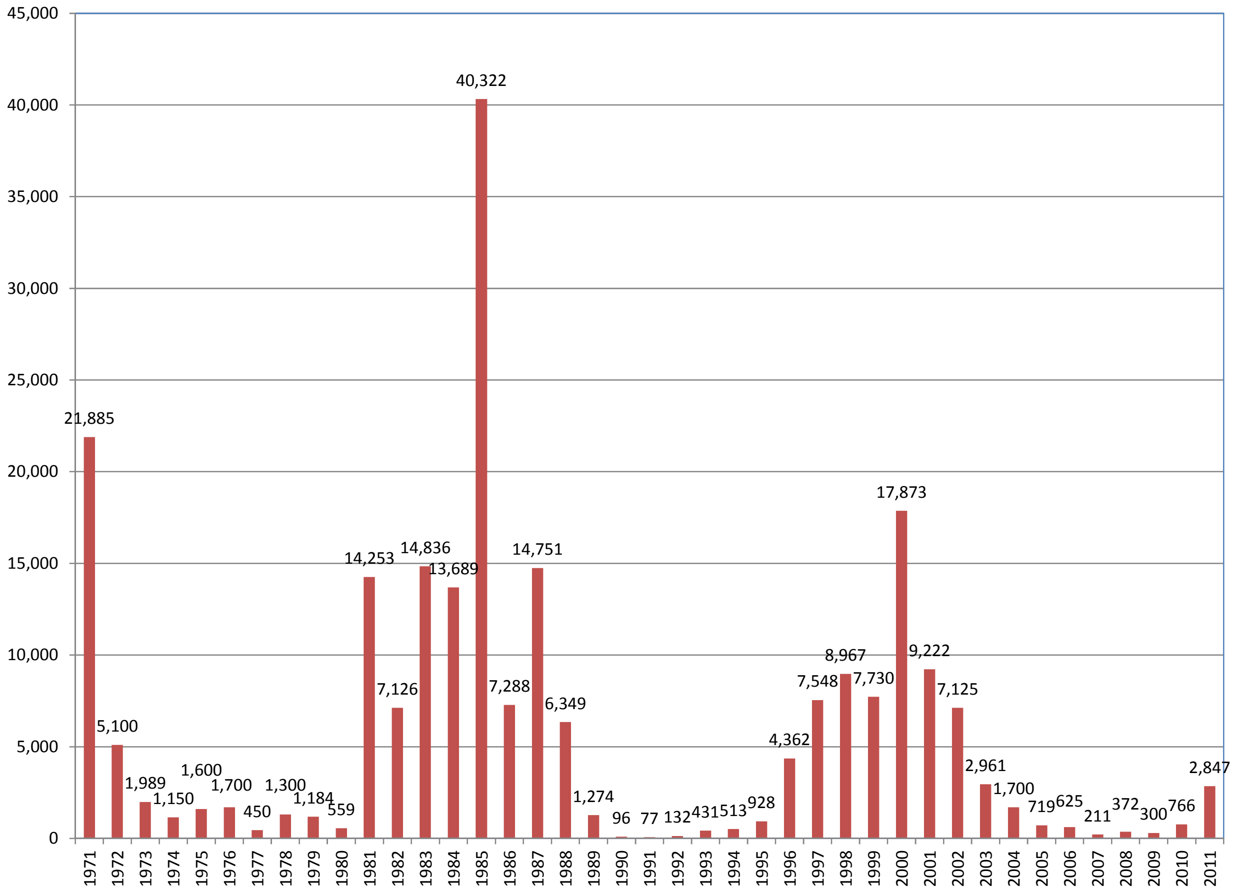

Figure 5.2-3. Tuolumne River Chinook salmon run estimates, 1971-2011 (Years 2009-2011 based on weir counts).

5.2.2.1 Factors Contributing to Chinook salmon Spawning Success

Upon arrival at the spawning grounds, adult female Chinook salmon dig shallow depressions or pits in suitably sized gravels, depositing eggs in the bottom during the act of spawning, and then covering them with additional gravel. Over a period of one to several days, the female gradually enlarges the salmon "redd" by digging additional pits in an upstream direction. Redds are typically 2.4–6.5 m^2 (25–75 ft^2) in size (Burner 1951, Chapman 1943), with a typical size of 5.1 m^2 (55 ft^2) reported for the Tuolumne River based upon detailed measurements (n=354) recorded in 1988–1989 (TID/MID 1992, Appendix 6). Previously conducted studies on the Tuolumne River indicate that spawning gravel availability may result in density-dependent competition and exclusion from suitable spawning sites and may limit the numbers of female Chinook salmon that successfully spawn in the lower Tuolumne River (TID/MID 1992, Appendix 6; TID/MID 2000, Report 1999-1; TID/MID 2001, Report 2000-1). Recent gravel losses documented at upstream spawning riffles (McBain and Trush 2004) following the 1997 flood may increase competition for suitable spawning sites at downstream locations. Redds are typically located in low-gradient riffles near pool tailouts (i.e., heads of riffles) where high concentrations of intragravel dissolved oxygen are available, but spawning activity is generally concentrated upstream, in spawning gravels nearest to La Grange Dam (RM 52.2), as found in historical spawning surveys (e.g., TID/MID 1992, Appendix 6, TID/MID 2005a). Since the installation of a counting weir at RM 24.5, spawning activity downstream of the weir has increased relative to the years prior to 2009 (TID/MID 2011b, Report 2010-1) indicating that spawning activity and distribution can be affected by even partial spawning barriers.

Before, during, and after spawning, both male and female Chinook salmon defend the redd from superimposition by other potential spawners. Redd superimposition by later-arriving spawners has been associated with subsequent egg mortality in studies conducted in 1988 and 1989 (TID/MID 1992, Appendix 7, TID/MID 1997, Report 96-6). Although it is likely that Chinook salmon are limited by spawning habitat availability only at high spawning densities, reductions in the numbers of successfully spawning adults has the potential to reduce subsequent juvenile production.

Based upon the review of available information, Chinook salmon are capable of spawning within a wide range of water depths and velocities (Healey 1991) as well as gravel sizes (Kondolf and Wollman 1993). Gravel composition at spawning redds was directly sampled in the Tuolumne River in 1987–1988 (TID/MID 1992, Appendix 8) but 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, gravel quality is unlikely to affect spawning success under current conditions.

Previous studies did not attribute mapped locations of spawning redds to variations in water temperature (TID/MID 1992, Appendices 6 and 11). The potential effects of current water temperature conditions on spawning Chinook salmon are assessed as part of the *Temperature Criteria Assessment (Chinook salmon and O. mykiss) Study* (W&AR-14). The ongoing IFIM study (Stillwater Sciences 2009) will assess river-wide spawning habitat area suitability, including any potential water temperature limitations on weighted usable area (WUA).

Although the proportion of hatchery origin fish in Tuolumne River spawning runs has increased in recent years, 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. Hatchery salmon studied in the Pacific Northwest have been shown to return smaller 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 2011b, Report 2010-2) suggesting any hatchery influences on Tuolumne River spawner fecundity may be minor.

5.2.2.2 Factors Contributing to Direct and Indirect Mortality

Although direct mortality of Chinook salmon due to elevated water temperatures has the potential to reduce the numbers of successfully spawning females in the Tuolumne River, no evidence of pre-spawning mortality due to temperature has been identified in the lower Tuolumne River and only low rates of pre-spawn mortality have been identified on the Stanislaus

River (Guignard 2006). No information was available to address potential disease incidence in spawning Chinook salmon adults in the lower Tuolumne River or other San Joaquin River tributaries. Lastly, no information was identified to assess the magnitude of poaching effects on the number of spawning Chinook salmon.

5.2.3 Egg Incubation, Alevin Development, and Fry Emergence

As discussed in Attachment B (Section 4), a number of factors may potentially affect Chinook salmon egg incubation, alevin development, and fry emergence in the Tuolumne River. Eggs hatch in 60–90 days, depending on water temperature (Alderdice and Velson 1978, as cited in Healey 1991). After hatching, Chinook salmon alevins remain in the gravel for two to three weeks and absorb their yolk sac before emerging from the gravels into the water column. The Districts have conducted redd trapping experiments (TID/MID 1992, Appendices 6 and 7; TID/MID 2007, Report 2006-7) as well as annual seining surveys (e.g., TID/MID 2012, Report 2011-3) to provide information on Chinook salmon emergence timing.

5.2.3.1 Factors Contributing to Egg Incubation, and Fry Emergence

Suitable water temperatures, intragravel dissolved oxygen concentrations, and substrate composition are required for proper Chinook salmon embryo and alevin development and emergence. Previous measurements of water column dissolved oxygen (TID/MID 2005b, Report 2004-10) and intragravel dissolved oxygen in artificial redds (TID/MID 2007, Report 2006-7; Mesick 2002) indicate that water quality conditions provide for successful egg incubation during the egg incubation period in the lower Tuolumne River (Table 5.2-1). Suitable water temperature conditions are also present during the egg incubation period (TID/MID 2007, Report 2006-7, Jager and Rose 2003). Fine sediments are discussed as a potential mortality source below.

5.2.3.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality to eggs and alevins include water temperature, water quality, gravel quality (particularly related to fine sediments), redd superimposition, redd scour and redd dewatering. Of these factors, redd superimposition and gravel quality may potentially affect Chinook salmon populations in the lower Tuolumne River. Previous studies (TID/MID 1997, Reports 96-5 and 96-6, TID/MID 1992, Appendix 2) suggest that redd superimposition has the potential to increase density dependent egg mortality as well as effectively delaying the fry emergence period due to higher mortality of the earliest deposited eggs. Although the magnitude of hatchery-reared fish in the population and Tuolumne River is only partly understood, Flagg et al. (2000) suggested that since nest depth was strongly correlated with female size, eggs from smaller females from hatchery returns may be at increased risk from redd superimposition by later arriving spawners. However, fish size at return does not appear to have decreased for the period 1981–2010 (e.g., TID/MID 2011b, Report 2010-2) suggesting any hatchery influences on redd superimposition may be minor.

Fine sediment intrusion was suggested to explain low survival-to-emergence in prior redd trapping studies (TID/MID 1992, Appendix 7). Intra-gravel DO measurements (TID/MID 2007, Report 2006-7; TID/MID 2005b, Report 2004-10) suggest hyporheic water quality conditions that are suitable for incubating Chinook salmon eggs occur in the lower Tuolumne River. Excavations documenting very low rates of entombment (TID/MID 1992, Appendix 7; TID/MID 2007, Report 2005-7) suggest that gravel quality conditions exist on the lower Tuolumne River that can support reasonable rates of Chinook salmon egg survival. High intragravel water temperatures were suggested as a potential mortality factor in a 1988 survival-to-emergence study (TID/MID 1992, Appendix 8). Although no studies were identified in the Tuolumne or San Joaquin River tributaries, antecedent exposure of upmigrant adults has been attributed to reduced egg viability in broader studies (e.g., Mann and Peery 2005, Jensen et al. 2006). Based on assessments of seasonal water temperatures as well as typical spawning periods (Table 5.2-2), fall-run Chinook salmon in the San Joaquin River basin are unlikely to encounter unsuitable water temperatures leading to reduced egg viability, and Myrick and Cech 2001 suggested that only the earliest spawners arriving in the San Joaquin River basin tributaries during September might encounter unsuitable temperatures.

Based upon review of available information, redd scour, redd dewatering, and disease are not expected to contribute to high rates of mortality. Because the normal egg pocket depth of Chinook salmon is generally deeper than typical scour depths in most rivers (LaPointe et al. 2000) scour related mortality is not expected to affect overall population levels. Scour-related mortality may have occurred during the extreme flood event of 1997 which peaked at 60,000 cfs, resulting in channel down cutting and the elimination of entire spawning riffles near La Grange Dam (RM 52) (McBain & Trush 2000, 2004). Figure 5.2-4 shows juvenile rearing density was relatively low in comparison to the antecedent run size, suggesting that scour-related mortality or early dispersal of fry may have occurred. Separate from the potential occurrence of redd scour during flood events, FERC (1996) spawning flow requirements have served to reduce the risk of redd dewatering. Lastly, because no reports of disease incidence on incubating eggs has been reported in the Tuolumne River or other Central Valley rivers, disease is not expected to contribute to high rates of indirect mortality.

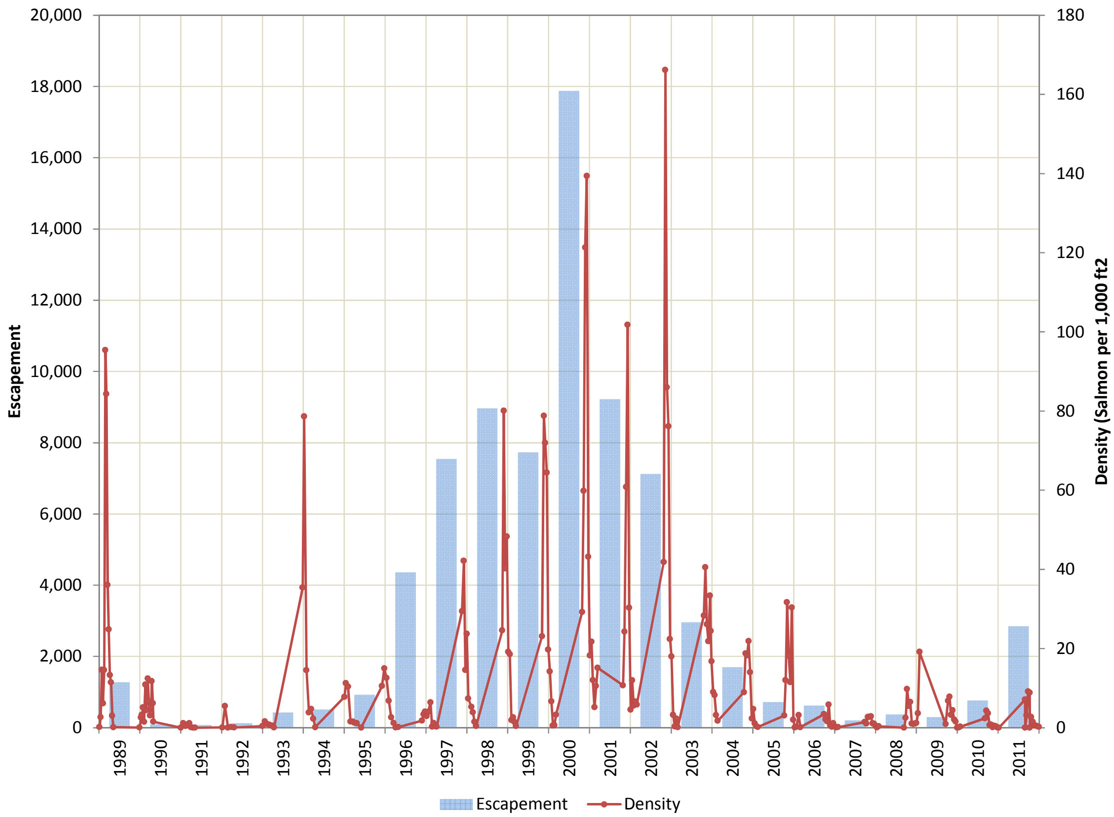

Figure 5.2-4. Average juvenile salmon density in all seine hauls by survey with estimated escapement (1989–2011).

5.2.4 In-river Rearing/Outmigration

As discussed in Attachment B (Section 5), a number of factors may potentially affect in-river rearing of Chinook salmon juveniles and subsequent smolt emigration from the Tuolumne River. Juvenile Chinook rearing densities vary widely according to habitat conditions, presence of competitors and predators, as well as variations in life history strategies with changing environmental conditions (Bjornn and Reiser 1991). The length of time spent rearing in freshwater also varies greatly (Healey 1991). Following emergence from the spawning gravels, Tuolumne River Chinook salmon disperse downstream as fry, and typically emigrate as smolts later in the spring. Chinook salmon fry generally occupy low-velocity areas near stream margins as well as in the presence of cover provided by woody debris, bankside vegetation, substrate, or other materials (Everest and Chapman 1972). As shown in Figure 5.2-1, after over-summering as juveniles and over-wintering in the following year, low numbers of Chinook salmon may emigrate as yearlings in some years (TID/MID 2005a).

Chinook salmon juvenile distribution and rearing densities have been sampled using seining surveys conducted at 5–11 sites in the Tuolumne River and 2–6 sites in the San Joaquin River since 1986 (TID/MID 2005a) with standardized sampling sites used since 1999 (e.g., TID/MID 2012, Report 2011-7). Figure 5.2-4 shows average juvenile salmon densities by survey in recent years, with peak density generally occurring in mid-February. Juvenile fish size typically increases through May in most years, with interannual variations in size attributed to timing of fry emergence, the presence of yearlings, and competing species (TID/MID 2005a).

In addition to seining, rotary screw trap (RST) monitoring of juvenile salmon has been conducted over portions of the January through June rearing period since 1995 at Shiloh Rd. (RM 3.5) and Grayson (RM 5.2), with upstream monitoring at Waterford (RM 29.8) added in 2006 (TID/MID 2012, Report 2011-4). RSTs were also operated at several upstream sites from 1998 to 2000 as part of mark-recapture studies employed as an alternative to paired-release coded-wire-tag (CWT) studies of smolt survival (TID/MID 2001, Report 2000-4). Table 5.2-3 shows RST passage estimates for fry (<50 mm), parr (51–69 mm), and smolt-sized (≥ 70 mm) fish in all years with RST sampling, with data from spring-only sampling shown with shading. Only partial season monitoring was conducted in several years due to funding as well as logistical constraints such as high flow conditions. Since various size-classes of Chinook salmon juveniles are present in greater numbers in different months during spring, partial season sampling may result in over- or under-estimation of juvenile production. The RST data provides an indication of outmigration timing as well as juvenile production estimates. Capture efficiency tests have been conducted but not for all fish sizes at each location or in all years.

Table 5.2-3. 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

Water Year and (Type)[1]	Sampling Period	Fry (<50 mm)		Parr (50–69 mm)		Smolt (≥ 70 mm)		Total
		Est. Passage	%	Est. Passage	%	Est. Passage	%	
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.

For the upstream RST at Waterford, the majority of juveniles passing the trap prior to mid-March are generally fry-sized fish, with subsequent passage dominated by smolt sized fish for the remainder of the season (TID/MID 2012, Report 2011-4). Although passage estimates were reported to be biased low in 2006 due to flow-related issues at the traps, generally high river flows during Above Normal and Wet water year types results in greater RST captures and the highest passage estimates. At the downstream RST, winter-spring sampling (i.e., Jan–Jun in 1999-2002, 2006, and 2008–2011), total estimated passage ranged from a high of 869,636 juveniles in 1999 to a low of 3,287 in 2008.

5.2.4.1 Factors Contributing to Juvenile Growth and Smoltification

Suitable habitat conditions, including spatial variations in hydraulic conditions, cover, water temperature, as well as adequate food supplies are required for juvenile Chinook salmon growth and smoltification. No studies have directly mapped the amounts of suitable juvenile rearing habitat for juvenile Chinook salmon in the Tuolumne River. 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 on the relationship between in-channel rearing habitat and flow, as well as water temperature. As river flows increase above bankfull discharge and overbank habitats become accessible, the amount of available salmonid rearing habitat in the lower Tuolumne River has been shown to increase with increasing flows (Stillwater Sciences 2012b; TID/MID 2007, Report 2006-7).

Mesick and Marston (2007) showed 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, which show that long term variations in peak fry density vary with antecedent escapement. Although a number of factors affect egg survival-to-emergence and early in-river rearing of fry, simple regression of these data suggest that approximately 60% of the variation in peak fry density is explained by antecedent escapement (Attachment B, Section 5.1.1). For moderately high escapements in recent years that might be expected to result in rearing habitat limitation (1997–2003), downstream fry dispersal generally occurred sooner in years with early 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). Presuming that a habitat limitation would likely lead to either reduced upstream densities or early fry dispersal in non-flood years, this does not appear to have occurred in the years examined. For this reason, rearing habitat is not likely the key issue limiting juvenile Chinook salmon production in the lower Tuolumne River.

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). 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 (Myrick and Cech 2001). As discussed in Attachment B (Section 5.1.2), growth rate estimates from multiple seine surveys (TID/MID 2012, Report 2011-4) are within the range reported by Williams (2006) for Central Valley Chinook salmon, with smolt-sized fish captured at the lower RST at Grayson River Ranch (RM 5.2) from April to mid-June in most years (TID/MID 2012, Report 2011-4). This is consistent with prior studies that have found smoltification generally occurs during April and May for the Tuolumne River as well as other San Joaquin River tributaries (Rich and Loudermilk 1991).

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. High river flows during Above Normal and Wet water year types generally result in both cooler temperatures and higher smolt passage estimates than in other years (Table 5.2-3). Routine RST monitoring indicates passage of smolt-sized Chinook salmon extends 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). Because the proportion of fry- and smolt-sized fish in seasonal RST sampling may be related to both flow conditions as well as antecedent escapement, the ongoing *Chinook Salmon Otolith Study* (W&AR-11) is expected to provide information on the relative contributions of fry and smolt production in Above- and Below-Normal water year types.

Mesick (2009) suggested that in-river food availability was insufficient to support high levels of fry and juvenile production, citing benefits of increased food resources found in floodplain rearing studies on the Yolo bypass (Sommer et al 2001). However, previous assessments of benthic macro-invertebrates as well as insect drifty on the Tuolumne River concluded that food supplies for juvenile salmon were more than adequate to support the population (TID/MID 1992, Appendix 16; TID/MID 1997, Report 1996-4; TID/MID 2003, Report 2002-8; TID/MID 2005, Report 2004-9; TID/MID 2009, Report 2008-7). Further details are provided in Attachment B (Section 5.1.3). Evidence of high lipid content found in Tuolumne River Chinook salmon smolts sampled in 2001 by Nichols and Foott (2002) also suggests that food resources are adequate for rearing and smoltification of Chinook salmon in that year.

5.2.4.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality include predation effects due to the relative habitat availability for predators and juvenile salmon, water temperature, water quality, juvenile stranding, and entrainment within unscreened riparian diversions. Of these factors, the apparent variations in the relationship between springtime flows and subsequent adult escapement noted in multiple assessments (TID/MID 1992, Volume 2; Speed 1993; TID/MID 1997, Report 96-5; Mesick and Marston 2007; Mesick et al. 2008) as well as juvenile smolt passage (Mesick et al. 2008) are consistent with predation as a primary mortality source, with effects upon long-term population levels. Table 5.2–3 suggests substantially reduced juvenile production between the upstream and downstream RSTs. Using the ratio of these passage estimates as approximate survival indices, survival from the upstream to downstream RST locations has averaged 10–20 percent since 2006 (TID/MID 2012, 2011-4). Although avian predation has not been assessed, Attachment B (Section 5.2) discusses results documenting predation by non-native fish species in direct surveys (TID/MID 1992, Appendix 22), in numerous smolt survival studies from 1987–2004 (TID/MID 2002, Report 2001-5; TID/MID 2003, Report 2002-4; TID/MID 2005, Report 2004-7) as well as the current *Predation Study* (W&AR-7).

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. As discussed in Section 5.1, the legacy of numerous in-channel mining pits has created large amounts of suitable habitat for non-native predator species (McBain and Trush 2000). Reductions in flood frequency since the construction of large dams on the Tuolumne River have resulted in increased predator habitat suitability in the mining pits (McBain and Trush 2000, Ford and Brown 2001). Predator habitat suitability is also affected by flow, with effective spatial separation of juvenile salmonids and predator species at higher flows suggested by 2D modeling at in-channel sites (McBain and Trush and Stillwater Sciences 2006) as well as in overbank habitats (Stillwater Sciences 2012). Interannual variations in flows and water temperatures have been associated with variations in river-wide predator distribution (Ford and Brown 2001) and year-class strength in multi-year surveys for the SRP 9 predator isolation project at RM 25.7 (McBain and Trush and Stillwater Sciences 2006).

Of the remaining potential sources of direct and indirect mortality, few are expected to affect juvenile production or longer term population levels. Although water temperature effects on predation have been well documented in the Central Valley (Marine 1997, Marine and Cech 2004), instances of water temperature mortality such as fish kills have not been observed on the lower Tuolumne River. Water temperatures during spring rearing and outmigration are generally below critical thresholds of 25°C (77°F) identified by Myrick and Cech (2001) as resulting in chronic mortality. Although it is unknown whether pesticide levels in the downstream reaches of the lower Tuolumne River affect rearing or outmigrating Chinook salmon juveniles, the river is currently included in California 2010 Section 303(d) List of Water Quality Limited Segments for pesticides that have been shown to inhibit olfactory-mediated alarm responses (Scholz et al. 2000). Because current Project operations do not include power peaking, potential risk of stranding and entrapment evaluated by the Districts (TID/MID 2001, Report 2000-6) are limited to flow reductions following flood control releases. The low frequency of these events as well as ramping rate restrictions included in the current FERC (1996) license suggests a low risk of mortality due to stranding and entrapment. Similarly, low disease incidence in Tuolumne River smolts (Nichols and Foott 2002) suggests a low risk of indirect mortality due to disease. Lastly, the lower Tuolumne River corridor has numerous unscreened riparian diversions (Moyle and White 2002), but the magnitude of entrainment mortality of juvenile Chinook salmon is largely unknown. Only a small number of riparian diversions exist along the lower reaches of the Tuolumne River and instances of irrigation withdrawal for frost protection during in-river rearing (April-May) are relatively infrequent, therefore, significant mortality due to entrainment is considered unlikely.

5.2.5 Delta Rearing/Outmigration

As discussed in Attachment B (Section 6), a number of factors may potentially affect rearing conditions for Chinook salmon juveniles and subsequent smolt emigration from the Delta. Based on past seine and RST monitoring, juvenile Chinook salmon outmigrate from the lower Tuolumne River into the San Joaquin River and Delta as fry (<50 mm) as early as February in years with high flows, with smolts (>70mm) emigrating in April and May in most years (TID/MID 2005a). In addition to smolt survival and acoustic tracking experiments conducted under the Vernalis Adaptive Management Program (VAMP), CDFG has monitored Chinook salmon outmigration at Mossdale[10] in the San Joaquin River (RM 56) since 1988 to document smolt production and outmigration timing from the San Joaquin River basin. Indices of San Joaquin River basin smolt production from 1989 to 2010 are provided in SJRGA (2011), with the basin production and timing of the outmigration corresponding to the numbers of fish entrained at the Delta water export facilities, as documented by salvage records (e.g., <ftp://ftp.delta.dfg.ca.gov/salvage\>; TID/MID 2005a).

Specific information on Delta rearing of Tuolumne River salmonids is unavailable, with most of this information based on trawl and seine monitoring conducted by USFWS on behalf of the Interagency Ecological Program (IEP[11]) beginning in the 1970s. Substantial numbers of fry were found in the Delta from January through March, but relatively few were found in the rest of the year during 20 years of sampling from 1977 to 1997 (Brandes and McLain 2001). The annual abundance of juvenile Chinook (< 70 mm) in the Delta during this period appears related to Sacramento River and San Joaquin River basin outflows, with the highest numbers observed in wet years (Brandes and McLain 2001).

5.2.5.1 Factors Contributing to Juvenile Growth and Smoltification

Juvenile growth, survival and smoltification of Tuolumne River Chinook salmon rearing in the Delta are affected by in-channel and floodplain habitat availability, water temperature and food availability. As discussed in Section 5.1.3, historical habitat conditions in the Delta included

[10] The Mossdale Trawl is currently operated by CDFG from early April to mid-June and by USFWS for the remaining months of the year. Sampling effort typically consists of ten trawls per day for 20-minute intervals between 10AM and 2PM, three to seven days per week. Depending on fish abundance and other considerations, effort has been expanded to twenty trawls per day between 8AM and 4PM in some weeks.

[11] Agencies in the IEP, in addition to the USFWS, include the USBR, USGS, NMFS, ACOE, USEPA, CDWR, CDFG, and the SWRCB.

access to extensive marsh and floodplain habitats (Atwater et al. 1979). Levee construction and land use conversions have largely eliminated access to tidal exchanges with marsh habitats used as nursery areas for Delta fishes (Kimmerer et al. 2008) and few locations in the eastern and central Delta provide suitable habitat for rearing Chinook salmon. In flood bypasses and floodplains along the lower portions of some tributaries to the Sacramento and San Joaquin Rivers, some juvenile Chinook salmon rear on seasonally inundated floodplains in the winter. Chinook salmon have been documented to utilize the floodplain habitat in the Sutter Bypass, Yolo Bypass, and in the Cosumnes River (Feyrer et al. 2006, Sommer et al. 2001, Sommer et al. 2005, Moyle et al 2007). The extent of historical flooding in the Sacramento River valley was vast (Kelley 1989), and the timing of juvenile salmon outmigration would have allowed them to take advantage of these prolonged periods of floodplain inundation. However, based upon a Draft evaluation of Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) evaluations of BDCP Conservation Measures (Essex Partnership 2009), access to historically inundated floodplain habitat for juvenile rearing in the south Delta is limited under present day conditions due to extensive habitat alterations such as levee construction and land use conversions for agriculture and urban uses. 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. Therefore, it is likely that historical changes in Delta habitats have affected the opportunity for growth of rearing Chinook salmon with subsequent effects upon the numbers of smolts entering the ocean.

As discussed for in-river rearing (Section 5.1), suitable water temperatures are required for growth and subsequent smoltification of juvenile Chinook salmon rearing in the Delta. Because juvenile growth rates increase with water temperature (Myrick and Cech 2001), 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 cooler upstream tributaries (e.g., Healey 1991, Kjelson et al. 1982). Although water temperature has a strong influence upon Chinook salmon life history timing, separate from direct and indirect mortality effects discussed below, both the degree to which water temperature affects smoltification in the Delta as well as long term population levels is unknown. For juveniles undergoing smoltification in the Delta or emigrating from cooler upstream habitats, Myrick and Cech (2001) report that 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 emigration of smolts from upstream tributaries may occur as late as June, it is unlikely that successful smoltification occurs in the Delta beyond late-May in most years.

A number of factors affect food supplies for rearing juvenile Chinook salmon in the Delta, principally related to water exports at the SWP and CVP facilities (Section 5.1.1), but also affected by levee conversions of marsh habitats to other agricultural and urban land uses, as well as anthropogenic introductions of nutrients, contaminants and non-native species (Section 5.1.3) affecting Delta food supplies. Durand et al. (2008) provides a recent conceptual model of the Delta food web and based upon his summary of habitat and food web changes in the Delta, food resources may limit juvenile salmonids under some conditions. For fish not entrained in the Delta water export facilities, MacFarlane and Norton (2002) found that as compared to upstream rearing locations, juvenile Chinook grew more slowly in the Delta and San Francisco Bay estuary (0.18 mm d^{-1} on average) during their 40-day migration to 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. Based upon review of available information, 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 effects upon early ocean survival and long-term population levels.

5.2.5.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality include predation effects due to the relative habitat availability for predators and juvenile salmon, water temperature, water quality, as well as entrainment within the Delta export facilities and numerous unscreened riparian diversions. Of these factors, predation in the lower San Joaquin River, Delta, as well as predation due to entrainment in the SWP and CVP export facilities is considered a primary mortality source, with effects upon long term population levels. Delta water exports discussed in Section 5.1.1 as well as non-native species introductions (Section 5.1.3) have resulted in dramatic changes in the Delta fish species assemblage, with numerous predatory fish species benefitting from current Delta hydrology (Lund et al. 2007). As discussed in Attachment B (Section 6.2.2), predation may have the greatest impact on salmon populations when juveniles and smolts outmigrate in large concentrations during the spring through the lower reaches 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). Based upon review of available information, predation in the Delta has strong effects upon the numbers of adult recruits to the ocean fishery.

As discussed in Attachment B, large numbers of juvenile salmon are lost to predation due to variations in river flows (Section 6.2.4) and water exports at the SWP and CVP facilities (6.2.5). A number of physical and mechanical barriers are operated within the Delta to control the path of flow toward the SWP and CVP export pumping facilities, including the installation of a temporary barrier at the head of Old River (HORB) since 1992, as well as more recent efforts documented in various VAMP Study Reports (e.g., SJRGA 2011). In a statistical re-analysis of VAMP survival study results, 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. The results of south Delta survival 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). For salmon entrained into the Clifton Court forebay of the SWP, paired releases of CWT fish at the entry to the 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. Lastly, 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.

Because water temperatures in the south Delta rise above 21°C (70°F) by mid-May in some years, and because higher temperatures (25°C [77°F]) are associated with increased mortality incidence (Myrick and Cech 2001), water temperature related mortality may occur during warmer meteorological conditions. 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 in the Delta has a strong influence upon juvenile Chinook salmon survival as well as juvenile life history timing.

Of the remaining potential sources of direct and indirect mortality of juvenile Chinook salmon in the Delta, few are expected to affect juvenile production or longer term population levels. Large numbers of pesticides are used upstream and within the Delta (Brown 1996, Kuivala and Foe 1995) that have been shown to inhibit olfactory-mediated alarm responses (Scholz et al. 2000). However, it is unknown whether pesticide levels in Delta waters affect rearing or outmigrating Chinook salmon juveniles and no studies of predation related mortality due to chemical contaminants were identified in the Central Valley. Based upon review of available information, water quality effects upon predation of juvenile Chinook salmon is considered unknown but unlikely due to the episodic nature of potential contaminant releases. Lastly, despite some evidence of impaired water quality and temperature conditions in the Delta that may potentially contribute to disease incidence, Nichols et al. (2001) identified no clinical signs of disease, virus, or obligate bacterial pathogens in juvenile fall-run Chinook salmon collected from the Delta in 2000, with low numbers of fish showing clinical levels in the lower San Joaquin River in 2001 (Nichols and Foott 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.

5.2.6 Ocean Rearing

As discussed in Attachment B (Section 7), several factors may potentially affect rearing conditions for adult Chinook upon entry of the Pacific Ocean and during their adult residency prior to returning as upmigrants. Chinook salmon generally spend 2–4 years in the ocean and exhibit variable ocean entry patterns, with juveniles generally moving along the coastal shelf north of the Gulf of the Farallones during the first year of their life (Pearcy 1992). Because specific information regarding Tuolumne River Chinook salmon is limited to low numbers of CWT fish recovered from past Tuolumne River smolt survival studies in the Regional Mark

Information System (RMIS) database, inferences regarding conditions for Tuolumne River Chinook salmon discussed below are based upon Central Valley Chinook salmon assessments as well as broader assessments of conditions off of California and the Pacific Northwest.

Williams (2006) notes that Chinook salmon juveniles are found in slow eddies at either side of the Golden Gate Bridge during summer, but that their distribution shifts north beyond Point Reyes later in the fall. Central Valley Chinook salmon are primarily distributed between British Columbia and Monterey, California, with the highest percentages found off the coasts near the cities of San Francisco and Monterey. The Pacific Fishery Management Council (PFMC) routinely reports harvest data, with Sacramento River fish contributing over 90% of the California harvest (PFMC 2012). Combined harvest and escapement data from 1984 to 2011 (Figure 5.2-5) provides an index of ocean abundance except in years with partial commercial troll fishery closures (2002–2004) and full season closure (2008–2009; along with the majority of 2010) (PFMC 2012).

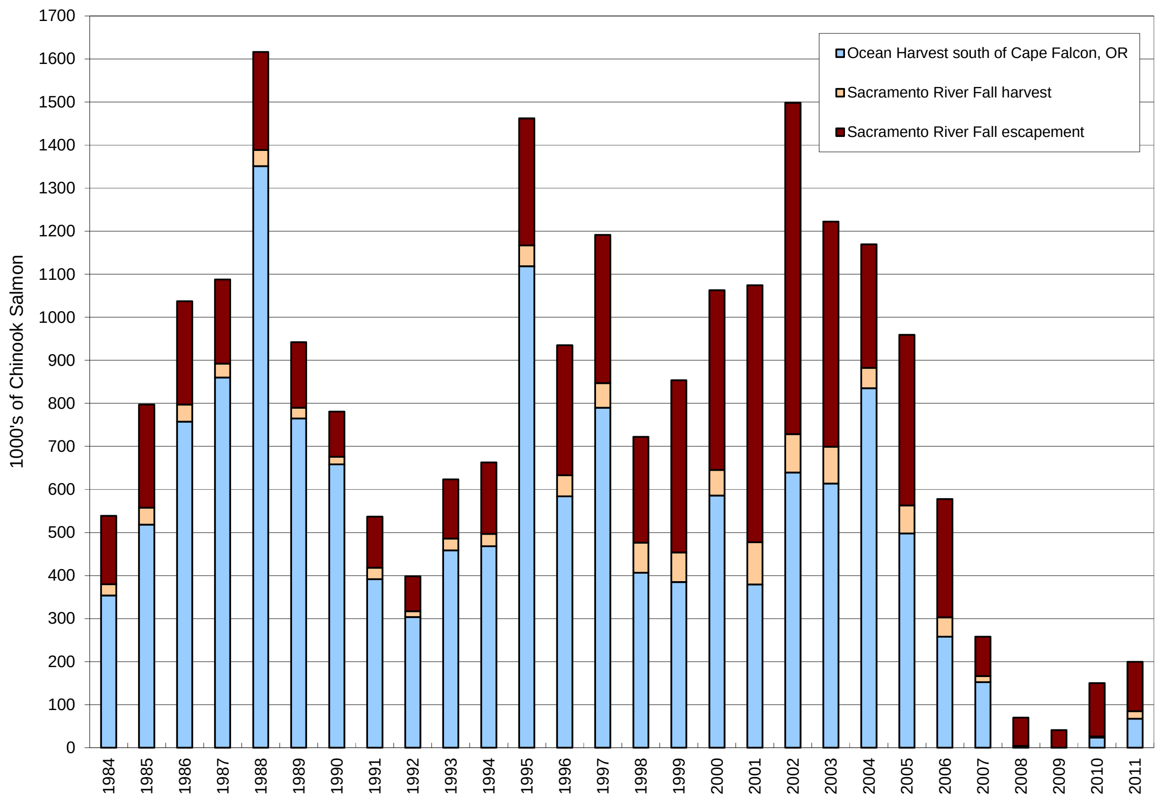

Figure 5.2-5. Sacramento River Chinook salmon abundance from ocean and Sacramento River harvest plus escapement (1984–2011).

5.2.6.1 Factors Contributing to Adult Growth in the Pacific Ocean

As discussed in Section 5.1.4, both the PDO and shorter-term ENSO influence water temperature and ocean circulation patterns that, in turn, influence coastal productivity through a series of complex interactions. Historical reviews of the PDO (Mantua and Hare 2007, Mantua et al. 1997) as well as ENSO (MacFarlane et al. 2005) suggests large changes in ocean productivity and salmon harvest over extended periods are due to variations in climate conditions. 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 to the Smith River, California. 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. Further, large hatchery releases may potentially result in density-dependent competition for food resources during early ocean rearing (Ruggerone et al. 2010), further compounding any potential food limitations along the California coast.

5.2.6.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality during ocean residency are primarily related to ocean harvest and predation, with limited evidence that early life history exposure to contaminants or disease may potentially affect adult Chinook salmon from the Tuolumne River. The Central Valley Harvest Index shows that Central Valley stocks have been exploited at average rates of more than 60 percent, and select for older fish for many years, a pattern that may reduce fish size and fecundity (Lindley et al. 2009, NMFS 2006). Because overall variations in Sacramento River Chinook salmon harvest (Figure 5.2-5) are similar to long term variations in Tuolumne River escapements (Figure 5.2-3), ocean harvest assessments for Central Valley stocks are likely representative of Tuolumne River salmon.

Avian predation of Chinook salmon smolts in San Francisco Bay (Evans et al. 2011) as well as pinniped predation along the west coast (Scordino 2010) may potentially reduce subsequent escapement, however, population-level impacts have not been sufficiently quantified to assess population level effects. Although early life history exposure to some pesticides may also affect predator avoidance (Scholz et al. 2000, NMFS 2006), no reports have identified these effects in Central Valley salmonids or have assessed predation effects due to contaminant exposure along the California Coast. Exposure of juveniles to contaminants may also affect disease incidence that extends into ocean rearing (Arkoosh et al. 2001; NMFS 2006). However, Nichols et al. (2001) identified no clinical signs of disease, virus, or obligate bacterial pathogens in juvenile fall-run Chinook salmon collected from the Delta in 2000, with low numbers of fish showing clinical levels in the lower San Joaquin River in 2002.

5.3 Key Issues Affecting *O. mykiss*

Using the same assessment framework as for Chinook salmon in Section 5.2 above, and building upon the preceding discussion of primary ecosystem inputs and other factors affecting Tuolumne River salmonids, the following sections discuss key issues (e.g., spawning gravel availability, water temperature, predation, food availability, etc.) affecting individual life stages, separated into mechanisms affecting reproduction, growth, as well as sources of direct and indirect mortality. Like Chinook salmon, *O. mykiss* exhibit a variety of life history patterns (Shapovalov and Taft 1954, Quinn and Myers 2005). Anadromous steelhead populations are distributed across the northern Pacific Ocean (Barnhart 1991) and as far south as Malibu, San Juan, San Luis Rey and San Mateo creeks in southern California (Moyle 2002, Moyle et al. 2008). Steelhead differ from other Pacific salmon in that juveniles have a longer freshwater rearing duration, lasting from one to three years, and that both adults and juveniles show greater variability in the amount of time they spend in fresh and salt water (McEwan 2001, Quinn 2005). Table 5.3-1 and Figure 5.3-1 provide an overview of life history timing and residency of various *O. mykiss* life stages occurring in the Tuolumne River, Delta, and ocean.

Table 5.3-1. 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.

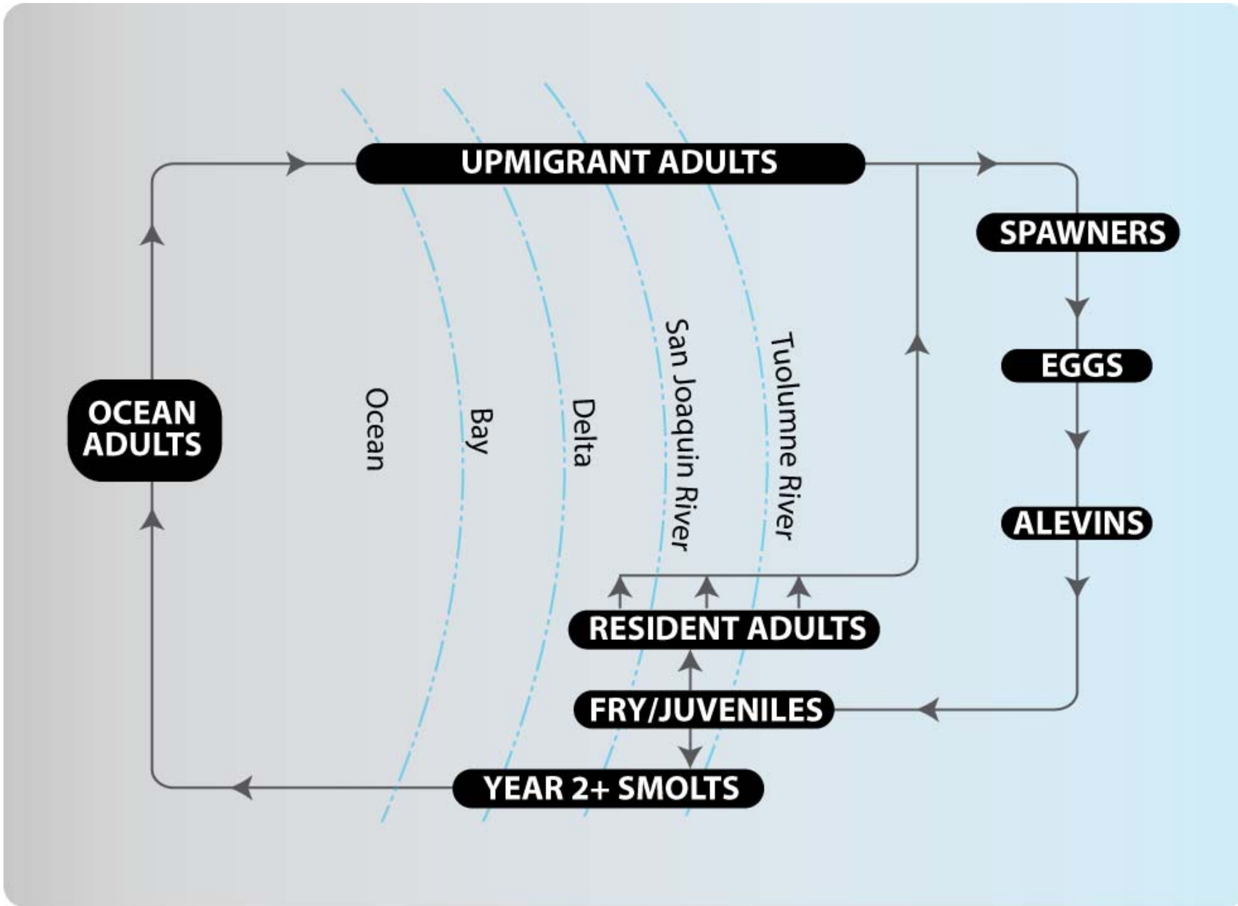

Figure 5.3-1. Central Valley steelhead and rainbow trout life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne rivers.

The relationship between anadromous and resident life history forms of *O. mykiss* is poorly understood, but available evidence suggests that genetics (Nichols et al. 2008) as well as growth and environmental conditions (Beakes et al. 2010) play a role in the development of one or the other life-history trajectory. Both life-history forms can produce offspring that exhibit the alternate form (i.e., resident rainbow trout can produce anadromous progeny and vice versa) under some conditions (Hallock 1989, Zimmerman et al. 2009). Nielsen et al. (2005, 2007) found genetic differences between *O. mykiss* collected upstream and downstream of Don Pedro Dam, suggesting reproductive isolation of these populations may show either or both of the possibilities that a pre-dam population exists above Don Pedro Dam, or historical planting and genetic drift has resulted in genetic separation in the two populations.

Due to historical planting operations and straying of steelhead, most steelhead as well as resident rainbow trout in the Central Valley are genetically similar (Pearse et al. 2009) and of common hatchery origin (Garza and Pearse 2008). For these reasons, discriminating between anadromous and resident forms is limited to inferences from upstream migration timing and appearance as well as the results of sacrificial sampling and otolith analysis of Strontium to Calcium (Sr:Ca) ratios (Zimmerman et al. 2009). For example, in historical accounts of steelhead upmigration in the Tuolumne River by CDFG from the 1940s, 66 steelhead were reported to have passed upstream of the former Dennett Dam (RM 16.2) between October 1 and November 30, 1940 near

Modesto, with five counted in late October 1942 (CDFG 1993). Recognizing the very low occurrence of steelhead in Tuolumne River samples analyzed by Zimmerman et al. (2009), the majority of *O. mykiss* found in more recent monitoring surveys are likely resident rainbow trout. Because of the rarity of anadromous steelhead in the Tuolumne River, and general limitations for monitoring methods other than direct observation (e.g., snorkel, videography at the RM 24.5 weir) under the Endangered Species Act (ESA), the timing (Table 5.3-1) and life history information for *O. mykiss* presented below is based on general Central Valley steelhead assessments (e.g., McEwan and Jackson 1996, McEwan 2001, NMFS 2009b), with much of the Tuolumne-specific data representing resident rainbow trout abundance, timing, and distribution.

Table 5.3-2 provides a summary of issues affecting life-history progression, whether the identified issue or mechanism has the potential to affect *O. mykiss* production or population levels, along with a preliminary assessment of uncertainty of this conclusion. Below, a summary of key issues is provided by life-stage, seasonality and uncertainty regarding population-scale effects, along with the geographic source of information used for this synthesis.

Table 5.3-2. Summary issues affecting Tuolumne River *O. mykiss* populations.

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
Upmigration	**Factors Contributing to Central Valley Steelhead Homing. Straying and timing of Arrival at Spawning Grounds**					
	Flow effects	Inconclusive	X	X	X	Because homing is related to olfaction (Dittman and Quinn 1996), CVP/SWP flows, tributary attraction and flood flows all potentially affect the numbers of Tuolumne River upmigrants. Low occurrences and flow limits on RM 24.5 counting weir operation preclude assessment of this issue under flood conditions.
	Water temperature and water quality	Unknown/ unlikely	X	X	X	Since 2009, few upmigrant *O. mykiss* arrived earlier than October (TID/MID 2012, Report 2011-4) when water temperatures could be high. DO conditions in the lower San Joaquin River are suitable (Newcomb and Pierce 2010). Potential olfactory impairment due to contaminants (Hansen et al. 1999; Scholz et al. 2000; Tierney et al. 2010) has not been shown in Central Valley.
	Hatchery straying	Unknown/ unlikely		X	X	Although hatchery fish generally stray at higher rates than wild fish (Björnsson et al. 2011), the effects of hatchery influences on the upmigration timing of any Central Valley Steelhead arriving in the Tuolumne River are unknown,
	Factors Contributing to Direct Mortality of Upmigrant Central Valley Steelhead					
	Water quality	Unknown/ unlikely	X	X	X	Upmigration timing and ability to avoid unsuitable conditions suggests steelhead mortality is unlikely to result from DO depletion or episodic toxicity events.
	Water temperature	Unknown/ unlikely	X	X	X	Upmigration timing, high temperature tolerance, and ability to avoid unsuitable water temperatures are unlikely to result in high rates of pre-spawn mortality.
	Sportfishing and poaching	Unknown/ unlikely		X		Annual fishing report cards (Jackson 2007) do not provide data to quantitatively assess hooking mortality or other sportfishing impacts, and no data are available to evaluate potential impacts of poaching.
	Factors Contributing to Indirect Mortality of Upmigrant Central Valley Steelhead					
	Disease and parasites	Unlikely		X	X	Although many populations throughout California's coast and Central Valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), no information was available to address potential disease incidence in spawning *O. mykiss* adults in the lower Tuolumne River or other San Joaquin River tributaries.
Spawning	**Factors contributing to Spawning Success of O. mykiss**					
	Habitat availability	Inconclusive	X			*O. mykiss* spawning has not been well documented (TID/MID 2012, Report 2011-

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
						2). Current *Spawning Gravel Study* (W&AR-4) provides spawning habitat area estimates. *Redd Mapping Study* (W&AR-8) may document spawning use. Ongoing IFIM study (Stillwater Sciences 2009b) will estimate habitat maximizing flows.
	Gravel quality	Inconclusive	X			Spawning gravels are larger on Tuolumne River than typical steelhead or rainbow trout (McBain and Trush 2004, Kondolf and Wolman 1993). Current *Redd Mapping Study* (W&AR-8) will examine gravel sizes at any spawning sites.
	Water temperature	Unlikely	X			Steelhead spawning generally occurs December through April (Table 5.3-1), so water temperature is unlikely to affect spawning success.
	Hatchery straying	Unknown/ likely		X	X	Hatchery fish generally stray at higher rates than wild fish (Björnsson et al. 2011) and are typically smaller at return (Flagg et al. 2000), potentially resulting in reduced fecundity. However, available data are insufficient to determine the proportion of hatchery-origin Central Valley steelhead that spawn in the lower Tuolumne River.
	Factors Contributing to Direct Mortality of Spawning O. mykiss					
	Sportfishing and poaching	Unknown/ unlikely		X		Annual fishing report cards (Jackson 2007) do not provide data to quantitatively assess hooking mortality or other sportfishing impacts, and no data are available to evaluate potential impacts of poaching.
	Water temperature	No	X	X		Given the general upmigration timing of adult steelhead (Table 5.3-1), water temperature effects on pre-spawn mortality are unlikely.
	Factors Contributing to Indirect Mortality of Spawning O. mykiss					
	Disease and parasites	Unknown/ unlikely		X		Bacterial infections have been identified in coastal and Central Valley rivers (Foott 1992). No data for Tuolumne or other San Joaquin River tributaries.
Egg Incubation through Fry Emergence	**Factors Contributing to Successful O. mykiss Egg Growth and Fry Emergence**					
	Water temperature	Yes	X			Suitable intragravel water temperatures in 1991 ranged from 11–15°C (51–58°F) during February and March (TID/MID 1997, Report 96-11).
	Water quality	No		X	X	Intragravel dissolved oxygen conditions were in the range of 7–12 mg/L during winter (TID/MID 2007, Report 2006-7).
	Factors Contributing to Direct Mortality of O. mykiss Eggs and Alevins					
	Antecedent water temperature	Unknown				No studies identified examining reduced egg viability due to antecedent water temperature.

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
	Intragravel water temperature	Unlikely	X			Intragravel temperatures during in winter 1991 ranged between 11–15°C (51–58°F) (TID/MID 1997, Report 96-11). Low mortality potential earlier than April.
	Water quality	No	X			Intragravel dissolved oxygen conditions were in the range of 7–12 mg/L during winter (TID/MID 2007, Report 2006-7).
	Redd superimposition	Unknown/ unlikely	X	X		Low levels of superimposition (2%) documented in Stanislaus (Del Real and Rible 2009). *Redd Mapping Study* (W&AR-8) will provide information on *O. mykiss* spawning and observations of redd superimpositions.
	Redd scour	No	X		X	*O. mykiss* spawning has not been well documented (TID/MID 2012, Report 2011-2). Egg pockets typically below scour depths (Devries 1997, Lapointe et al. 2000). Low bed mobilization occurs under current conditions (McBain and Trush 2004).
	Redd dewatering	Unlikely	X			*O. mykiss* spawning has not been well documented (TID/MID 2012, Report 2011-2) and likelihood of spawning under flood flows subject to flow reductions is low.
	Entombment	Unlikely	X			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.
	Factors Contributing to Indirect Mortality of O. mykiss Eggs and Alevins					
	Bacterial and fungal infections	Unknown/ unlikely			X	Egg infection has generally only been raised as an issue of concern in intensive fish culture practices (e.g., Scholz 1999) and no observations have been made in the Tuolumne or other Central Valley Rivers.
In-River Rearing/Outmigration	**Factors Contributing to Growth and Smoltification of O. mykiss**					
	Habitat availability	Inconclusive	X		X	Density dependent exclusion of juveniles from riffle/pool transitions, as well as the absence of structural elements (e.g., Boulders, LWD) typical of high gradient habitats may limit adult density. Ongoing IFIM Study (Stillwater Sciences 2009a) will provide up-to-date results regarding habitat maximizing flows.
	Water temperature	Yes, in the summer	X	X	X	Density and distribution increased since implementation of FERC (1996) flows. PHABSIM and water temperature modeling (Stillwater Sciences 2003) suggests optimal flows for larger fish (300–350 cfs) may limit juvenile habitat (maximized at 150–200 cfs). Stable flows and temperatures in summer may select for a largely residential life history (T.R. Payne & Assoc. and S.P. Cramer & Assoc. 2005).
	Food availability	No	X	X		BMI monitoring (TID/MID 1997, Report 1996-4; TID/MID 2003, Report 2002-8; TID/MID 2005, Report 2004-9; TID/MID 2009, Report 2008-7) show consistent

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
						densities of salmonid prey organisms in comparison to other Central Valley rivers.
	Factors Contributing to Direct Mortality of O. mykiss					
	Water temperature	Likely in downstream habitats	X	X		Mortality due to water temperature or predation is suggested by reduced numbers of over-summering Age 0+ *O. mykiss* in years with multiple surveys. Temperatures generally below thresholds in Myrick and Cech (2001) in upstream habitats used by Age 1+ fish, but increased probability of mortality downstream of Roberts Ferry Bridge (RM 39.5) where Age 0+ fish have been observed.
	Predation	Inconclusive	X		X	Mortality due to water temperature or predation is suggested by reduced numbers of over-summering Age 0+ *O. mykiss* in years with multiple surveys, but predation not documented in direct surveys. Avian predation has not been assessed.
	Habitat availability for predators	Unlikely	X			Predation on Age 0+ *O. mykiss* is likely limited to the reach upstream of Roberts Ferry Bridge (RM 39.5), and would only occur in water years with low flows and warmer temperatures allow predator foraging farther upstream.
	Flow and water temperature effects on predation	Unlikely	X			Predator distribution (Brown and Ford 2002) and relative habitat suitability with Age 0+ *O. mykiss* (McBain and Trush and Stillwater Sciences 2006; Stillwater Sciences 2012b) suggest low risk of encounter in most conditions.
	Water quality effects on predation	Unknown	X		X	The lower Tuolumne River is currently listed for pesticides shown to impair olfactory sensitivity in laboratory studies (Scholz et al. 2000).
	Stranding and entrapment	No	X			Project operations do not include daily hydropower peaking and ramping rates following flood control releases are limited under the current FERC (1996) license.
	Entrainment	Unknown/ unlikely		X		No studies examining fish losses as a result of in-river diversions are available for the Tuolumne River, and few available for the Central Valley.
	Sportfishing and poaching	Unknown/ unlikely		X		Annual fishing report cards (Jackson 2007) do not provide data to assess hooking mortality. No data are available to evaluate potential impacts of poaching.
	Factors Contributing to Indirect Mortality of O. mykiss					
	Disease and parasites	Unknown/ unlikely	X	X		Bacterial infections have been identified in coastal and Central Valley rivers (Foott 1992). No data for Tuolumne or other San Joaquin River tributaries. Low rates of infection were found in Chinook salmon smolts (Nichols and Foott 2002).
Delta Outmigration	**Factors Contributing to Growth and Smoltification of any Central Valley Steelhead Emigrating from the Tuolumne River**					
	Habitat availability	Yes		X		Reductions in marsh and floodplain habitats as well as changes in flow magnitudes

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
						and timing have reduced Delta habitats (Whipple et al. 2012, Lund et al. 2007) potentially used by emigrating or actively feeding steelhead smolts.
	Water temperature	No		X	X	Temperatures at Vernalis 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.
	Food availability	Unknown/ likely		X		Little data on steelhead feeding in the Delta. Because of poor growth of Chinook salmon (MacFarlane and Norton 2002) and declines in pelagic prey species (Baxter et al. 2008), food resources may be limiting during non-flood conditions.
	Factors Contributing to Direct Mortality of any Central Valley Steelhead Emigrating from the Tuolumne River					
	Water temperature	Likely for later outmigrants		X		Temperature in excess 25°C (77°F) thermal maxima of steelhead identified by Myrick and Cech (2001) are likely exceeded at Vernalis by late June in most years.
	Predation	Inconclusive		X		Although no steelhead smolts were found in predator stomachs at the Chipps Island trawl (USBR 2008), predation has been documented in the Clifton Court forebay (Clark et al 2009).
	Entrainment	Likely		X		It is likely that much steelhead outmigration occurs outside of HORB window of April 15th to May 15th in most years. For entrained fish, high rates of pre-screening (78–82 %) estimated by Clark et al. (2009).
	Water quality	Unknown/ unlikely		X	X	Pesticides shown to impair olfactory sensitivity in laboratory studies (Scholz et al. 2000). No direct toxicity or predation identified.
	Factors Contributing to Indirect Mortality of Central Valley Steelhead Emigrating from the Tuolumne River					
	Disease and parasites	Unknown/ unlikely	X	X	X	Central Valley steelhead have been shown to have bacterial infections (Foott 1992). No data for San Joaquin tributaries. Assuming steelhead vulnerable to Chinook salmon pathogens, only low rates of infections of fish collected in the Delta were identified in 2001 and 2002 (Nichols et al. 2001; Nichols and Foott 2002).
Ocean Rearing	**Factors Contributing to Adult Growth of Central Valley Steelhead Originating in the Tuolumne River**					
	Food availability	Yes		X	X	PDO and ENSO influence coastal productivity, but less is known about how steelhead respond to changes in coastal productivity patterns. Atcheson (2010) found age-related influences in steelhead growth at sea with density-dependent factors prevailing after the first year.
	Factors Contributing to Direct Mortality of Central Valley Steelhead Originating in the Tuolumne River					

Life Stage	Process/Mechanism	Initial Assessment of Relative Importance	Tuolumne	San Joaquin or Central Valley	General	Notes/Primary Citations
	Harvest by-catch	Unknown/ unlikely		X	X	USBR (2008) suggest broad mortality estimates (5–30%) for steelhead which may be caught in either unauthorized drift net fisheries, or as bycatch in other authorized fisheries such as salmon troll fisheries.
	Predation	Unknown		X	X	Scordino (2010) review of monitoring results of pinniped predation on Pacific coast salmonids revealed instances of seal and sea lion predation on steelhead, but conceded that more research is needed to better estimate this impact.
	Factors Contributing to Indirect Mortality of Central Valley Steelhead Originating in the Tuolumne River					
	Disease and parasites	Unknown/ unlikely	X	X	X	Central Valley steelhead have been shown to have bacterial infections (Foott 1992). No data for San Joaquin tributaries. Assuming steelhead vulnerable to Chinook salmon pathogens, only low rates of infections of fish collected in the Delta were identified in 2001 and 2002 (Nichols et al. 2001; Nichols and Foott 2002).

5.3.1 Upmigration

Based on the low numbers of anadromous steelhead identified by Zimmerman et al. (2009), very little evidence is available to suggest that the Tuolumne River supports a self-sustaining population of Central Valley steelhead. Nevertheless, as discussed in Attachment C (Section 2), a number of factors may potentially affect the numbers of any Tuolumne River origin or stray steelhead arriving in the river. Steelhead typically return to spawn in their natal stream in their third or fourth year of life (Shapovalov and Taft 1954). Based on variability in life-history timing, steelhead are broadly categorized into winter and summer runs. As shown in Table 5.3-1, upstream migration of winter-run steelhead, the only ecotype remaining in the Central Valley of California, begins with estuarine entry from the ocean as early as July, and may continue through February or March in most years (McEwan and Jackson 1996, NMFS 2009). Historical information on the upstream migration timing of adult steelhead in the Tuolumne River is limited to historical accounts of passage at the former Dennett Dam (RM 16.2) during October and November in 1940 and 1942 (CDFG 1993). More recently, using the counting weir at RM 24.5, upstream passage of a single *O. mykiss* was documented on November 7, 2009 in the first year of operation, no observations in 2010, and four individuals in 2011 (two on September 20, one on September 23 and one on November 15) (TID/MID 2012, Report 2011-8).

5.3.1.1 Factors Affecting Arrival at Spawning Grounds

Based upon review of available information, potential variations in arrival timing as well as homing and straying of upmigrant adults in relation to flow, water quality, and water temperatures are unlikely to affect *O. mykiss* population levels (Table 5.3-2). Judging from the arrival timing in the nearby Stanislaus River (Table 5.3-1), Central Valley steelhead may potentially arrive in the lower Tuolumne at any time from July through March. The infrequent occurrences of steelhead upmigrating to the Tuolumne preclude direct assessment of the relationship between arrival timing and flow. Because homing fidelity of salmonids to their natal stream has been shown to be related to the sequence of olfactory cues imprinted during juvenile rearing and outmigration (Dittman and Quinn 1996), the entrainment of flows into the SWP and CVP export facilities and the managed (i.e., attraction flows as well as flood-control releases) flows from the Tuolumne and other San Joaquin River tributaries all may potentially affect the numbers of Central Valley steelhead returning to the Tuolumne River (Table 5.3-2). However, as discussed in Attachment C (Section 2.1.1), the relationship between tributary homing and attraction flows remains poorly understood because weir operations on the Tuolumne River are typically limited to flows below 1,300 cfs and no data are available on other Central Valley rivers describing the relationships between homing/straying of migrating adult steelhead and flows.

Because the majority of steelhead migration occurs from November through March, the effects of water temperature encountered during upmigration are unlikely to affect steelhead arrival timing or population levels. Broad literature sources suggest that early life history exposure to trace metals, herbicides and pesticides may impair olfactory sensitivity (Hansen et al. 1999, Scholz et al. 2000, Tierney et al. 2010) required for homing, which may affect arrival of adult steelhead. However, olfactory impairment of Central Valley steelhead has not been documented in the Tuolumne or other Central Valley rivers.

Although hatchery fish generally stray at higher rates than wild fish (Björnsson et al. 2011), the magnitude of hatchery-reared fish in the Tuolumne River *O. mykiss* population is unknown. 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.

5.3.1.2 Factors Contributing to Direct and Indirect Mortality

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 (Attachment C, Section 7.2.2). Water quality as well as water temperature conditions in the Delta, San Joaquin River, and lower Tuolumne River are unlikely to result in direct mortality of upmigrant adults or mortality due to diseases. Although many of the natural and hatchery steelhead populations throughout California's coast and Central Valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), no information was available to address potential disease incidence in spawning *O. mykiss* adults in the lower Tuolumne River or other San Joaquin River tributaries. No information was identified to assess the magnitude of poaching effects on the number of upmigrating adults. However, McEwan and Jackson (1996) believe that legal harvest in the years prior to listing Central Valley steelhead were not associated with recent population declines in Central Valley steelhead.

5.3.2 Spawning

As discussed in Attachment C (Section 3), there are several factors that may potentially affect the numbers of successfully spawning *O. mykiss* in the Tuolumne River. Other than isolated carcass observations (e.g., TID/MID 2001, Report 2000-1) along with more routine observations of young-of-the-year (Age 0+) *O. mykiss*, spawning activity has not been well documented in Chinook salmon spawning surveys extending from mid-October to mid-January in most years (TID/MID 2012, Report 2011-2). Because this survey timing is typically too early to observe steelhead spawning, the current *Redd Mapping Study* (Study W&AR-8) is evaluating habitat conditions for, and evidence of, steelhead or rainbow trout spawning in the Tuolumne River through April 2013. For the purposes of this synthesis, Table 5.3-1 shows that spawning timing in the Tuolumne River is assumed to extend from December through April based on run timing in the nearby Stanislaus River and other locations reviewed by NMFS (2009). However, because of the low occurrence of juvenile *O. mykiss* (<150 mm) in snorkel surveys conducted in March 2009 and 2010 relative to those found in July of those years (Stillwater Sciences 2010; TID/MID 2011b, Report 2010-6), the majority of *O. mykiss* likely spawn in the Tuolumne River from February through April.

Upon arrival at spawning riffles or suitable gravel patches, female *O. mykiss* create redds in a manner similar to Chinook salmon described above. Although no steelhead redd measurements are available for the Tuolumne River, typical redd sizes have been reported as large as 4.4–5.4 m^2 (47–58 ft^2) (Hunter 1973, Orcutt et al. 1968) with a median of 1.7 m^2 (18 ft^2) reported in redd surveys (n=399) occurring in the American River between 2002–2005 (Hannon and Deason 2005). Sizes of spawning gravels used by *O. mykiss* are also generally smaller than those used by Chinook salmon; McBain and Trush (2004) summarize information on suitable size ranges for gravel augmentation projects.

5.3.2.1 Factors Contributing to *O. mykiss* Spawning Success

O. mykiss spawning success in the lower Tuolumne River is potentially affected by spawning habitat availability, gravel quality, water temperatures, as well as the presence of stray hatchery origin steelhead. Lack of documentation of *O. mykiss* spawning locations precludes direct assessment of this issue. Because gravel sizes used by *O. mykiss* are generally smaller than for Chinook salmon (Kondolf and Wollman 1993), spawning may be limited to suitable gravel patches. 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. Because the steelhead spawning period extends from through April and peaks in February and March (Table 5.3-1), water temperature is unlikely to affect spawning success. The ongoing IFIM study (Stillwater Sciences 2009) will assess river-wide spawning habitat area suitability, including any potential water temperature limitations on WUA. Lastly, although hatchery reared fish are typically smaller at return than their wild counter parts (Flagg et al. 2000), resulting in reduced fecundity, available data are insufficient to determine the proportion of hatchery-origin Central Valley steelhead that may potentially spawn in the lower Tuolumne River. 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.

5.3.2.2 Factors Contributing to Direct and Indirect Mortality

Direct mortality of *O. mykiss* due to elevated water temperatures has the potential to reduce the numbers of successfully spawning females in the Tuolumne River. However, given the general wintertime up-migration timing of adult steelhead (Table 5.2-3), water temperature effects on pre-spawn mortality are unlikely. As discussed for upmigrant steelhead (Section 5.3.1.2), although bacterial infections have been identified in coastal and Central Valley rivers (Foott 1992), no information was available to address potential disease incidence in spawning *O. mykiss* in the lower Tuolumne River or other San Joaquin River tributaries. Further, no information was identified to assess the magnitude of poaching effects on the number of spawning *O. mykiss*.

5.3.3 Egg Incubation, Alevin Development, and Fry Emergence

As discussed in Attachment C (Section 4), a number of factors may potentially affect *O. mykiss* egg incubation, alevin development, and fry emergence in the Tuolumne River. Eggs hatch within 20–100 days, depending on water temperature (Shapovalov and Taft 1954, Beacham and

Murray 1990). Newly-hatched *O. mykiss* alevins remain in the gravel for an additional 14–35 days while being nourished by their yolk sac (Barnhart 1991). Fry emerge from the substrate just before total yolk absorption under optimal conditions and later-emerging fry that have already absorbed their yolk supply are likely to be weaker (Barnhart 1991).

5.3.3.1 Factors Contributing to Egg Incubation, and Fry Emergence

Suitable water temperatures, intragravel dissolved oxygen concentrations, as well as suitable substrates are required for proper *O. mykiss* embryo development and emergence. As discussed for Chinook salmon (Section 5.3.2.1), previous measurements of water column dissolved oxygen as well as intragravel dissolved oxygen in artificial Chinook salmon spawning redds (TID/MID 2007, Report 2006-7) indicate water quality conditions in the lower Tuolumne are generally suitable during the egg incubation period (Table 5.3-1). Intragravel water temperatures measured during February and March 1991 at several locations in the lower Tuolumne River ranged between 11–15°C (51–58°F) (TID/MID 1997, Report 96-11), indicating suitable water temperature conditions for egg incubation.

5.3.3.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality include water temperature, water quality, fine sediment effects upon gravel quality, redd superimposition, as well as redd scour and dewatering. Of these factors, only the potential for water temperature related mortality is considered to potentially affect eggs deposited at downstream locations during warmer conditions that may potentially occur later in the spring (e.g., late March or April). Egg displacement and mortality resulting from redd superimposition spawning steelhead has been observed at very low levels in the Mokelumne River (Del Real and Rible 2009) and is not expected to occur to any appreciable extent on the Tuolumne River at current spawning levels. The current *Redd Mapping Study* (Study W&AR-8) will document locations of any *O. mykiss* spawning occurring in 2013, including any evidence of redd superimposition. The risk of mortality due to redd scour, redd dewatering, and entombment is expected to be low Tuolumne River due to current dam operations and reduced fine sediment supply. Although bacterial infections have been identified in coastal and Central Valley rivers (Foott 1992), no information was available to address potential disease incidence for incubating *O. mykiss* eggs in the Central Valley. Since disease incidence is typically not been raised as a concern outside of fish hatchery practices (e.g., Scholz 1999), disease upon eggs is not expected to contribute to high rates of mortality on the Tuolumne River.

5.3.4 In-river Rearing/Outmigration

As discussed in Attachment C (Section 5), a number of factors may potentially affect in-river rearing of *O. mykiss* juveniles and subsequent smolt emigration from the Tuolumne River. 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 steelhead typically rear for 1–3 years in fresh water before outmigrating to the ocean as smolts (McEwan 2001). Distribution of *O. mykiss* in the Tuolumne River has been documented during winter and spring seine surveys, as well as during summer snorkel surveys first conducted in the early 1980s (Ford and Kirihara 2010, Stillwater Sciences 2012). Low numbers of *O. mykiss* fry are found from February through May in bi-weekly seining in the Tuolumne River (e.g., TID/MID 2012, Report 2011-3). Figure 5.3-2 shows the size-distributions of Age 0+ *O. mykiss* from bi-weekly seine surveys. Observations of 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) since 2001 (Table 5.3-3). Juvenile *O. mykiss* (<150-mm) as well as Age 1+ and older adult fish (>150 mm) have been routinely documented in summer snorkel surveys since the 1980s (Ford and Kirihara 2010) and during intensive surveys (Stillwater Sciences 2008, 2009; TID/MID 2011b, Report 2010-6; TID/MID 2012, Report 2011-6) from 2008–2011 (Attachment C Section 5.1.1). Almost no *O. mykiss* were observed in summer snorkel surveys from 1983–1996 but have been observed in greater numbers since increased summer flows were implemented under the FERC (1996) Order (TID/MID 2005a, Ford and Kirihara 2010). Figure 5.3-3 shows numbers of individuals observed and corresponding population size estimates of juvenile and adult *O. mykiss* during summer and winter between July 2008 and September 2011. The present-day age class structure of juvenile Tuolumne River *O. mykiss* is assessed as part of the *O. mykiss Scale Collection and Age Determination Study* (W&AR-20).

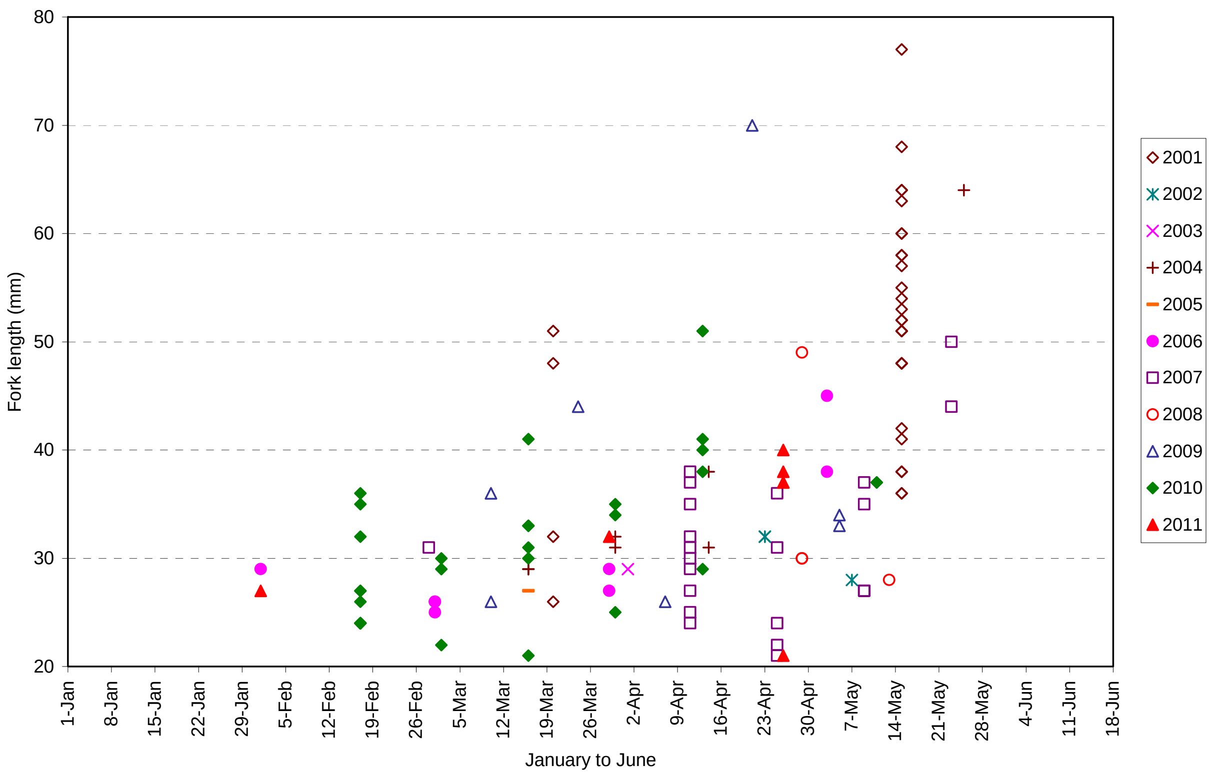

Figure 5.3-2. Seasonal sizes of juvenile *O. mykiss* captured during Tuolumne River seining surveys, 2001–2011.

Table 5.3-3. 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**	**1,179**	**148**

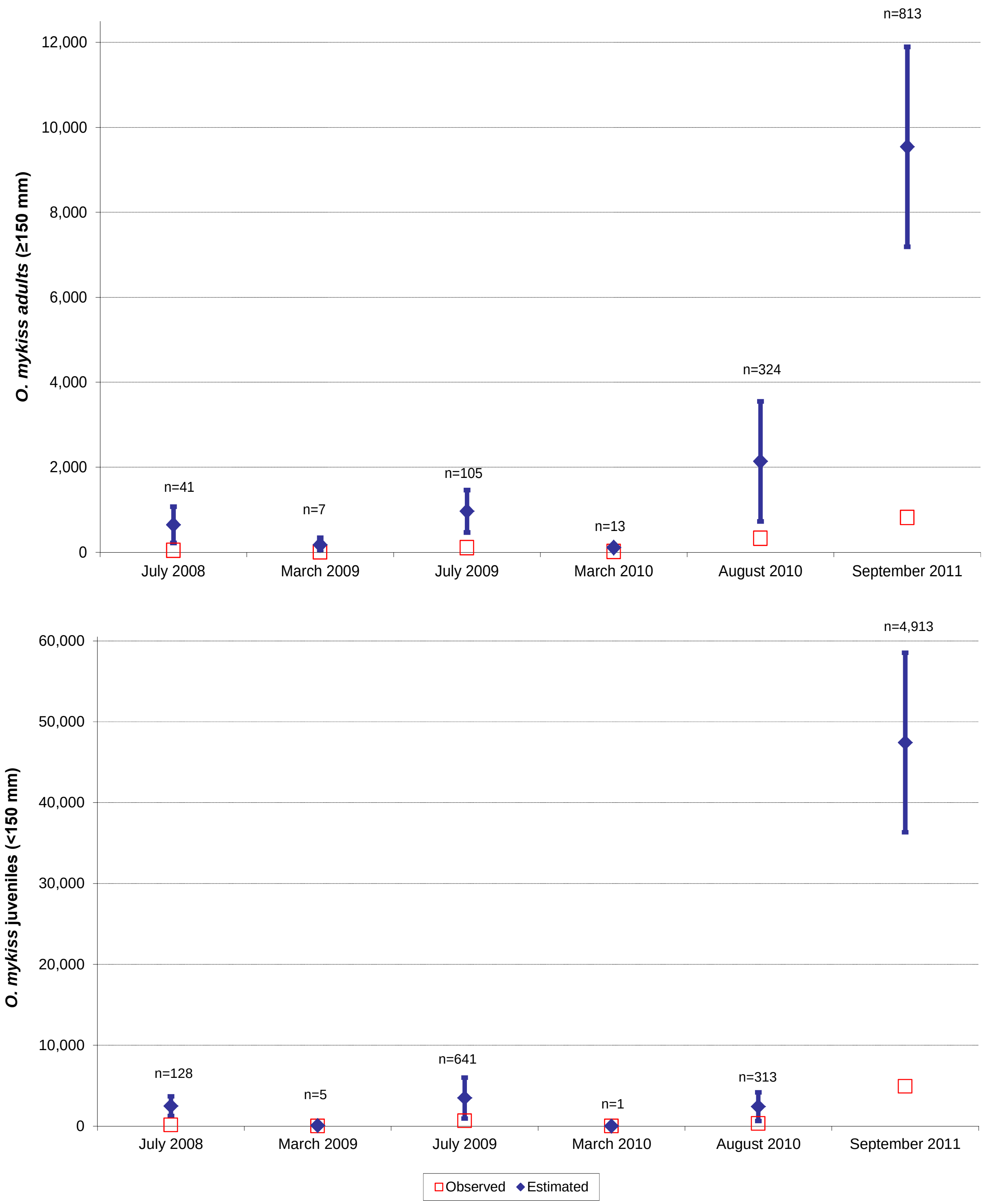

Figure 5.3-3. Population size estimates (95% CI) of juvenile (<150 mm) and adult (≥150 mm) *O. mykiss* in the Tuolumne River, July 2008 through September 2011.

5.3.4.1 Factors Contributing to Juvenile Growth and Smoltification

As discussed in Attachment C (Section 5), suitable habitat conditions including spatial variations in hydraulic conditions, structural cover, water temperature, as well as adequate food supplies are required for juvenile *O. mykiss* growth and any subsequent steelhead smoltification. The current *O. mykiss Habitat Survey Study* (W&AR-12) provides an overall assessment of juvenile and adult habitat. In earlier PHABSIM studies on the Tuolumne River (USFWS 1995), habitat maximizing flows for juvenile *O. mykiss* at modeled transects occurred in the range of 50–125 cfs in the absence of temperature limitations, whereas habitat maximizing flows for adults occurred in the range of 175–375 cfs. As river flow increases above bankfull discharge and overbank habitats become accessible, the amount of available juvenile *O. mykiss* rearing habitat in the lower Tuolumne River has been shown to increase with increasing flows (Stillwater Sciences 2012b). As noted for Chinook salmon juvenile rearing (Section 5.2.4.1), 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 tailings (Stillwater Sciences 2012).

Based upon review of available information to date, juvenile *O. mykiss* rearing habitat may potentially be limiting in the lower Tuolumne River during summer due to a combination of high water temperatures as well as potential territorial interactions with older age classes. In preliminary analyses exploring the potential for increased downstream extent of summertime cool water habitat, Stillwater Sciences (2003) re-analyzed the USFWS (1995) results discussed above by excluding areas of hydraulically suitable habitat that exceeded various temperature thresholds. For example, the results showed habitat maximizing flows for juveniles were on the order of 150–200 cfs, which 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. Table 5.3-1 shows increased numbers of *O. mykiss* were observed in snorkel surveys during recent years with higher summer flows (e.g., 2005, 2006, 2010, and 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.

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 2011b, Report 2010-6; TID/MID 2012, Report 2011-6). Where these age classes 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 5.3-4 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 no density dependence was observed in either run/pool bodies or riffle habitats. Age 0+ fish can generally use riffle habitats from which Age 1+ fish may be excluded (Attachment C, Section 5.1.2). 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 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.

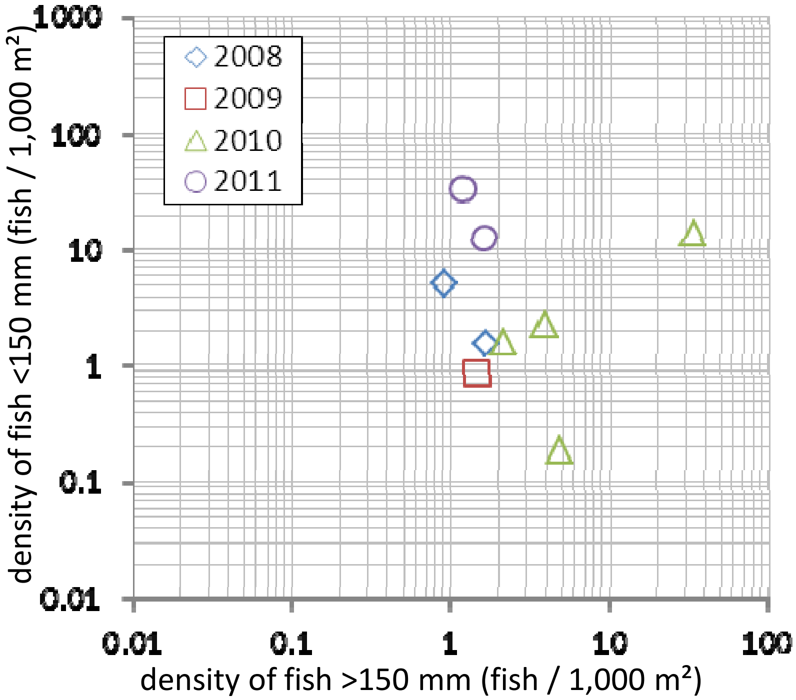

Figure 5.3-4. Comparison of Age 0+ vs. Age 1+ *O. mykiss* density in pool head habitats sampled in the Tuolumne River (2008-2011).

In addition to water temperature effects on *O. mykiss* growth rates (Myrick and Cech 2005), 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). Steelhead smoltification is affected by water temperatures (Myrick and Cech 2001), but also has been shown to have a complex relationship between water temperatures and food availability (Beakes et al. 2010). Summertime water temperatures are generally below 19°C (68°F) corresponding to optimal growth (Myrick and Cech 2001) for 7–10 miles downstream of La Grange Dam (RM 52) in most years, and food resources have not been shown to be limiting for juvenile Chinook salmon (Section 5.2.4.1). Annual growth rate estimates for Tuolumne River *O. mykiss* are provided in the current *O. Mykiss Scale Collection and Age Determination Study* (W&AR-20). It is unknown whether the relatively high food availability in the Tuolumne River may currently select for a greater proportion of resident *O. mykiss* rather than anadromous steelhead. For example, T.R. Payne & Assoc. and S.P. Cramer & Assoc. (2005) suggests large extremes in environmental conditions such as water temperature may potentially affect the degree of anadromy expressed in local *O. mykiss* populations.

5.3.4.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality include predation effects due to the relative habitat availability for predators and juvenile *O. mykiss*, water temperature, water quality, juvenile stranding and entrainment within unscreened riparian diversions. Of these factors, 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). 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). Because adult sized fish are generally found in upstream habitats year-round (Stillwater Sciences 2012a), temperature related mortality is unlikely to occur except as it would be related to potential smolt emigration occurring late in the spring in (late May or June). Although predation by piscivorous fish species has been identified as a factor potentially limiting the survival and production of juvenile Chinook salmon (Section 5.2.4.2), no data exist documenting avian or piscine predation of juvenile *O. mykiss*. However, predation risk is likely low since *O. mykiss* distribution is generally restricted to cool water locations upstream of Roberts Ferry Bridge (RM 39.5) in summer (Table 5.3-3) and predators are generally found downstream of this reach (Brown and Ford 2002). Because predation on larger fish is limited by both cold water habitat use and larger body size, predation related mortality is most likely generally limited to Age 0+ fish during water-year types with low flows and warmer temperatures that allow predators to move upstream. The *Predation Study* (W&AR-7) will provide additional information on predator distribution.

Of the remaining potential sources of direct and indirect mortality, few are expected to affect juvenile production or longer term population levels. 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 (Scholz et al. 2000). However, it is unknown whether levels of any pesticides in the water column affect rearing or outmigrating steelhead and no other studies of predation related mortality due to contaminants were identified in the Central Valley. Because current Project operations do not include power peaking, potential risk of stranding and entrapment are limited to flow reductions following flood control releases with only potential risks to the earliest emerging *O. mykiss* fry. The low frequency of these events as well as ramping rate restrictions included in the current FERC (1996) license suggests a low risk of mortality due to stranding and entrapment. Although many of the natural and hatchery steelhead populations throughout California's coast and Central Valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), no information regarding disease incidence was identified for steelhead in the Tuolumne River or other San Joaquin River tributaries. Because 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. Lastly, although the lower Tuolumne River corridor has numerous unscreened riparian diversions, based upon reviews of Central Valley assessments (Moyle and White 2002), the potential for entrainment mortality of Age 0+ *O. mykiss* is largely unknown. Because juvenile habitat is generally restricted to locations upstream of Roberts Ferry Bridge (39.5), the number of riparian diversions may be sufficiently small to consider mortality by entrainment unlikely.

5.3.5 Delta Outmigration

As discussed in Attachment C (Section 6), 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 (Ford and Kirihara 2010, TID/MID 2012, Report 2011-4), a number of factors may potentially affect the survival and growth of any outmigrating Central Valley steelhead smolts emigrating from the Tuolumne River as they pass through the Delta. Based on run timing of steelhead from the Stanislaus River, the closest tributary to the Tuolumne River with a steelhead run, smolt-sized steelhead may potentially outmigrate from the Tuolumne River at any time from January to June (Table 5.3–3). Less is known regarding the use of the Delta and San Francisco Bay estuary by steelhead than for other anadromous salmonid species (USBR 2008). Annual production of steelhead smolts from the San Joaquin River basin is estimated by CDFG at the Mossdale Trawl at RM 56 (SJRGA 2011). These surveys have been typically conducted between January and June with fish recovered in 230–280 mm (9.1–11.0 in). At the SWP Skinner Fish Protection Facility (SFPFP), steelhead are typically collected from January to June at broader sizes that range from 200–300 mm (7.9–11.8 in) with peak abundance observed during February (USBR 2008). Steelhead have been routinely observed between October and July by USFWS in the Chipps Island trawl[12] at the western edge of the Delta (USBR 2008).

5.3.5.1 Factors Contributing to Growth and Smoltification

Delta survival and growth of any Central Valley steelhead smolts originating in the lower Tuolumne is affected by in-channel and floodplain habitat availability, water temperature and food availability. Although the Delta has generally been considered to serve as primarily an outmigration corridor for steelhead, active feeding of juvenile steelhead have been documented in the Yolo bypass during flood conditions in some years (USBR 2008). Historical modifications in the Delta (Section 5.1.3) have limited potential access to floodplain and marsh habitats, with the majority of these lands now bordered by levees and riprap under current conditions (Whipple et al. 2012). 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. 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 (Attachment C, Section 6.1.2). Although little is known regarding prey items eaten by steelhead in the Delta, because of evidence of poor Chinook salmon growth conditions in the Delta (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

[12] The Chipps Island Trawl has been in operation since 1976 with a typical survey effort of ten 20-minute surface tows per day between 1 and 7 days per week and recently has been conducted in all months of the year.

conditions occurring in drier water year types, with affects early ocean survival and long-term population levels.

5.3.5.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality include predation effects due to the relative habitat availability for predators and juvenile salmon, water temperature, water quality, as well as entrainment within the Delta export facilities and numerous unscreened riparian diversions. Of these factors, entrainment in the SWP and CVP export facilities and subsequent predation is considered a primary mortality source, with effects upon long term population levels. Based upon routine recoveries of smolt sized steelhead at the CVP fish protection facilities (USBR 2008) as well as entrainment into the Clifton Court forebay is occurring and may result in increased rates of predation (Clark et al 2009), physical damage and stress during salvage operations. Although steelhead have been routinely documented by CDFG in trawls at Mossdale (RM 56) since 1988 (SJRGA 2011), it is unknown whether successful outmigrating occurs 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. For any steelhead smolts originating in the Tuolumne River entrained into the Clifton Court forebay of the SWP, Clark et al. (2009) estimated pre-screening mortality of steelhead on the order of 78–82%. Based upon review of available information, entrainment in smaller irrigation diversions have not been well quantified, but is not considered to contribute to high rates of mortality of steelhead smolts in the Delta.

Of the remaining potential sources of direct and indirect mortality of any steelhead smolts emigrating from the Tuolumne River, few are expected to affect steelhead production or longer term *O. mykiss* population levels. Large numbers of pesticides are used upstream and within the Delta (Brown 1996, Kuivala and Foe 1995) that have been shown to inhibit olfactory-mediated alarm responses (Scholz et al. 2000). However, it is unknown whether pesticide levels in Delta waters affect outmigrating steelhead smolts, despite some evidence of impaired water quality and temperature conditions in the Delta that may potentially contribute to disease incidence. Despite some indications that Central Valley steelhead may have bacterial infections (Foott 1992), no information on disease incidence in steelhead from the lower San Joaquin River or upstream tributaries has been identified. Because Nichols et al. (2001) identified no clinical signs of disease, virus, or obligate bacterial pathogens in juvenile fall-run Chinook salmon collected from the Delta in 2000, and only low numbers of fish showing clinical levels in the lower San Joaquin River in 2001 (Nichols and Foott 2002), potential effects of disease incidence on steelhead emigrating from the Tuolumne River through the Delta are considered unlikely.

5.3.6 Ocean Rearing

As discussed in Attachment C (Section 7), several factors may potentially affect rearing conditions for any adult Central Valley steelhead originating in the Tuolumne River upon entry of the Pacific Ocean and during their adult residency prior to returning as upmigrants. 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. Steelhead ocean residency may last from two to five years and Williams (2006) notes that Central Valley steelhead begin ocean rearing in the Gulf of the Farallones and may migrate long distances to the north and south. For example, Pearcy et al. (1990) identified one Central Valley steelhead in sampling off of Cape Blanco, Oregon. In a broader assessment, Burgner et al. (1992) interpreted data collected from 1955 to 1990 by research vessels of the United States, Canada, and Japan. Outmigrating smolts occurred in nearshore sampling in May, but by July they had generally moved offshore. The only nearshore area where first ocean year steelhead remained by July was off of northern California.

5.3.6.1 Factors Contributing to Adult Growth in the Pacific Ocean

As discussed in Section 5.1.4, both the PDO and shorter-term ENSO influence water temperature and ocean circulation patterns that, in turn, influence coastal productivity through a series of complex interactions. Other than individual accounts, there is little information on the ocean growth rate of Central Valley steelhead, except what can be inferred from their size and age at outmigration and upstream migration when collected in the Chipps Island trawl (Williams 2006). Steelhead are thought to migrate quickly to the open ocean upon smoltification (Burgner et al. 1992) where they feed primarily on fish and squid (Atcheson 2010). Historical reviews of the PDO (Mantua and Hare 2007, Mantua et al. 1997) as well as ENSO (MacFarlane et al. 2005) suggests climate induced changes in ocean productivity have affected troll fishery harvests, with potential effects upon year class strength long term population levels. For the North Pacific Ocean, 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.

5.3.6.2 Factors Contributing to Direct and Indirect Mortality

Potential sources of direct and indirect mortality during ocean residency are primarily related to harvest and predation, with limited evidence that early life history exposure to contaminants or disease may affect Central Valley steelhead originating in the Tuolumne River. USBR (2008) suggest broad mortality estimates (5–30%) for steelhead which may be caught in either unauthorized drift net fisheries, or as bycatch in other authorized fisheries such as salmon troll fisheries. Current harvest-related mortality is unknown, but could potentially affect year class strength and population levels. However, 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. Although Scordino (2010) reviewed monitoring results of pinniped predation on Pacific coast salmonids, predation of steelhead smolts following ocean entry has not been well documented. Despite some evidence of impaired water quality and temperature conditions in the Delta that may potentially contribute to disease incidence as well as some indications that Central Valley steelhead may have bacterial infections (Foott 1992) no information on disease incidence in steelhead from the lower San Joaquin River or upstream tributaries was identified. Because Nichols et al. (2001) identified no clinical signs of disease, virus, or obligate bacterial pathogens in juvenile fall-run Chinook salmon collected from the Delta in 2000, and only low numbers of fish showing clinical levels in the lower San Joaquin River in 2001 (Nichols and Foott 2002), potential effects of disease incidence upon any Central Valley steelhead originating in the Tuolumne River is unlikely.

6.0 DISCUSSION AND FINDINGS

All readily available and relevant information regarding in-river and out-of-basin factors affecting juvenile Chinook salmon and potential steelhead production from the Tuolumne River has been summarized for this synthesis. In updating prior ecosystem level conceptual models (e.g., McBain & Trush 2000, TID/MID 2002, Report 2001-7) as well as species-specific conceptual models of Tuolumne River salmonids (e.g., TID/MID 1992, Volume 2; TID/MID 2992, Report 2001-7; Mesick et al. 2008), this synthesis reflects the results of monitoring conducted since the 1995 SA and the FERC (1996) order, changes in Tuolumne River conditions since 1995 (e.g., from the 1997 flood), as well as recent advances in the understanding of Central Valley salmonid populations (e.g., genetic structure, hatchery influences, Delta and ocean conditions, etc.). A wide range of influences have affected conditions for Chinook salmon and *O. mykiss* in both in-river (Tuolumne River RM 52–0) as well as in out-of-basin habitats (lower San Joaquin River, Delta, San Francisco Bay and Pacific ocean) since the 1800s, including the construction of tributary dams and storage reservoirs in the Tuolumne River and throughout the Central Valley, modifications to instream flows, flood frequency and magnitude, interception of sediment supplies, in-channel and floodplain mining, riparian and Delta land use conversions, water exports from the Delta, as well as long-term variations in ocean productivity and harvest. It is recognized that all of these influences cumulatively affect individual life stages during inland portions of the life cycle of fall-run Chinook salmon and Central Valley steelhead as well as resident rainbow trout in the Tuolumne River. The following specific key findings of the synthesis are presented below by species and life stage for fall-run Chinook salmon and *O. mykiss* in the Tuolumne River (in-river) as well as in out-of-basin habitats in the lower San Joaquin River, Delta, San Francisco Bay estuary, and Pacific Ocean.

6.1 Tuolumne River Fall run Chinook salmon

Long-term variations in the number of fall run Chinook salmon arriving in the lower Tuolumne River are generally associated with climate driven changes in ocean conditions, antecedent precipitation and runoff patterns affecting conditions for rearing and smolt emigration in both in-river and out-of basin habitats. In addition to long-term changes in habitat conditions, production of juvenile Chinook salmon from the Tuolumne River is affected by the influence of hatchery straying into the Tuolumne River, spawning and rearing habitat availability as well as mortality influences due to a combination of predation and water temperature. Key findings by life stage are summarized presented below.

Key issues affecting Chinook salmon during upmigration include:

- Variations in ocean productivity as well as harvest directly affect the numbers of fall-run Chinook salmon escaping the ocean troll fishery to spawn in the lower Tuolumne River (Section 5.2.6).
- During upmigration, Tuolumne River flows; flows of other San Joaquin River tributaries, as well as flows entrained by the SWP and CVP water export facilities may potentially affect homing of Tuolumne River origin Chinook salmon, and may also affect straying of fish from other rivers into the Tuolumne River (Section 5.2.1.1).

- At the present time, hatchery origin fish represent a large proportion of Central Valley fall-run Chinook salmon harvest. Although precise estimates of the proportion of hatchery and naturally produced salmon cannot be readily be discriminated in the historical record, straying of hatchery origin fish has been documented in the Tuolumne River and has likely affected the numbers of salmon in annual spawning runs. Depending upon the broodstocks used and applicable hatchery management practices, progeny of stray hatchery origin fish spawned in the Tuolumne River may have potentially resulted in alterations of subsequent run-timing (Section 5.2.1.1).

For fall-run Chinook salmon spawning, egg-incubation and fry emergence:

- The potential for redd superimposition, documented in previous studies, is low under current conditions, but may result in increased density dependent mortality of deposited eggs as escapement levels increase (Section 5.2.2.1). The current *Redd Mapping Study* (W&AR-8) provides recent assessments of spawning use as well as documentation of any redd superimposition occurring at current escapement levels.
- Although not well quantified, straying of hatchery fish may potentially result in reduced size at return, reduced fecundity, as well as reductions in the typical egg pocket depths constructed by smaller fish. However, based upon recent spawning records for the Tuolumne, fish size at return does not appear to be declining in response to hatchery introgression or other factors (e.g., ocean harvest pressure) and it is unlikely that fish size effects of hatchery straying is adversely affecting spawning success of fall run Chinook salmon in the Tuolumne River (Section 5.2.2.1).

For in-river rearing and smolt outmigration of fall-run Chinook salmon:

- Apparent variations of juvenile production with flow are consistent with predation as a key factor affecting Chinook salmon in the Tuolumne River. High levels of predation related mortality have been documented in direct surveys by the Districts, in multi-year smolt survival tests, and by comparisons of upstream and downstream smolt passage at rotary screw traps (Section 5.2.4.2).
- Predator distribution, year class success, predator habitat suitability, and predator activity vary with inter-annual runoff and flows as well as seasonal variations in flow and water temperature at particular locations (Section 5.2.4.2).
- Historical habitat changes in the Tuolumne River, including the creation of in-channel mining pits, non-native fish introductions, and reduced flood frequency have created suitable habitat for non-native predators (Section 5.2.4.2).

For Delta rearing of and smolt emigration of fall-run Chinook salmon:

- Predation in the lower San Joaquin River, Delta, as well as predation related mortality within the Clifton Court forebay of the SWP and CVP water export facilities are key factors affecting the numbers of Chinook salmon recruited to the ocean fishery. For Chinook salmon outmigrants from the Tuolumne River, increased flows at Vernalis have been shown to reduce predation related mortality, but the relationship is highly dependent on the presence of the Head of Old River Barrier (Section 5.2.5.2).

- Salvage losses of Chinook salmon entrained into the SWP and CVP increases with increasing export flows and pre-screen losses of 63–99% have been estimated for fish entrained into the Clifton Court forebay (Section 5.2.5.2).
- For juvenile Chinook salmon not entrained by the SWP and CVP export facilities, non-native fish introductions, levee construction, and changes in flow magnitudes and timing have increased predator distribution. In addition, water temperature related mortality during late spring explains much of the variation in historical smolt survival studies in the Delta (Section 5.2.5.2).
- Reductions in marsh and floodplain habitats in the lower San Joaquin River and South Delta, and changes in tributary flow magnitudes and timing have all reduced access to Delta habitats used by rearing and emigrating Chinook salmon smolts from the Tuolumne River (Section 5.2.5.1).
- Although warmer waters in the Delta provide higher growth rate potential than in upstream tributary habitats, degradation of Delta habitat conditions has resulted in low primary and secondary productivity supporting the Delta food webs, with low growth rates of Chinook salmon juveniles (Section 5.2.5.1).

For ocean rearing of fall-run Chinook salmon:

- Ocean harvest of Central Valley Chinook salmon stocks have been exploited at average rates of more than 60 percent for many years, directly affecting the numbers of adults escaping the ocean fishery. Harvest mortality of larger fish has reduced the age- and size-at-return, with reduced fecundity of any upmigrating spawners (Section 5.2.6.2).
- Multi-year (ENSO) and decadal (PDO) variations in ocean circulation patterns affect food web productivity, growth and year class strength of Chinook salmon. Ocean growth conditions affect the numbers of salmon escaping the ocean fishery to spawn in the lower Tuolumne River (Section 5.2.6.1).
- The timing of large hatchery releases in the Central Valley may potentially result in density-dependent competition with wild fish during the first few months following ocean entry. Early growth conditions in the ocean affect year class strength and the numbers of salmon escaping the ocean fishery to spawn in the lower Tuolumne River (Section 5.2.6.1).

6.2 Anadromous and Resident *O. mykiss* originating in the Tuolumne River

Very little evidence of a self-reproducing anadromous run of Central Valley steelhead has been identified on the Tuolumne River. As discussed for Chinook salmon above, for any steelhead potentially originating in the Tuolumne River, variations in ocean conditions, rainfall, and runoff conditions are expected to affect the numbers of adults returning to spawn as well as to affect habitat conditions for in-river rearing and successful smolt emigration. As with Chinook salmon, production of juvenile steelhead from the Tuolumne River is affected by rearing habitat availability as well as mortality influences due to a combination of predation and water temperature. Key findings by life stage are presented below.

Central Valley steelhead upmigration:

- Although few upmigrant steelhead have been documented in either historical or present day monitoring, Tuolumne River flows, flows of other San Joaquin River tributaries, as well as flows entrained by the SWP and CVP water export facilities may potentially affect homing of any Central Valley steelhead originating in the Tuolumne River. Tributary flows and flow entrainment by the Delta water export facilities may also affect the number of hatchery-origin steelhead that may potentially stray into the Tuolumne River (Section 5.3.1.1).

For *O. mykiss* spawning, egg-incubation and fry emergence:

- It is unknown whether the Tuolumne River currently supports a self-sustaining spawning population of Central Valley steelhead, and only very low numbers of anadromous steelhead have been documented in recent otolith analyses. Indications of spawning activity of *O. mykiss* is limited to isolated carcass recoveries and by the presence of Age 0+ and Age 1+ fish in the Tuolumne River in seining, snorkeling, and RST monitoring (Section 5.3.2). The current *Redd Mapping Study* (W&AR-8) provides information on any spawning documented in 2012–2013.
- Although the current *Spawning Gravel Study* (W&AR-4) as well as the ongoing IFIM Study (Stillwater Sciences 2009a) provide spawning habitat area estimates, because *O. mykiss* have more often been found to spawn in tributary habitats and smaller habitat patches, it is unknown whether spawning is limited by habitat availability (Section 5.3.2.1).
- Although *O. mykiss* may potentially spawn within small patches of suitably sized gravels, because spawning gravels are generally larger on Tuolumne River than typically used by spawning *O. mykiss*, it is unknown whether spawning is limited by spawning gravel quality (Section 5.3.2.1). The current *Redd Mapping Study* (W&AR-8) examines gravel sizes at any identified spawning sites.

For in-river rearing of *O. mykiss* and potential smolt outmigration of any Central Valley steelhead:

- There is apparent density dependent exclusion of Age 0+ juveniles from riffle/pool transitions by Age 1+ and older fish. Other than riffle/pool transitions, the absence of structural elements (e.g., Boulders, LWD) within alluvial portions of the lower Tuolumne River limits habitat use of Age 0+ fish to riffle habitats and may result in reduced densities of adult-sized fish within available habitats (Section 5.3.4.1).
- In years with multiple snorkel surveys, habitat exclusion due to water temperature or mortality from predation is suggested by reduced numbers of over-summering Age 0+ *O. mykiss* in downstream areas. Increased densities and downstream distribution since implementation of increased flows under FERC (1996) order as well as during years with extended flood control releases indicate that the downstream extent of suitable water

temperatures may limit habitat conditions for Age 0+ fish excluded from preferred upstream habitats used by adult-sized fish (Section 5.3.4).

- Prior PHABSIM modeling combining water temperature suitability suggests habitat maximizing flows for larger fish (300–350 cfs) may limit juvenile habitat (maximized at 150–200 cfs). The ongoing IFIM Study (Stillwater Science 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 (Section 5.3.4.1).
- Although *O. mykiss* populations have increased in the years since implementation of increased summer flows under FERC (1996) order, stable flows and temperatures in summer may select for a largely resident life history (Section 5.3.4.1). It is unknown whether increased flows since implementation of the FERC (1996) order have resulted in larger numbers of Central Valley steelhead in the Tuolumne River.

For Delta rearing and smolt emigration of any Central Valley steelhead originating in the Tuolumne River:

- Although only limited reports have suggested Central Valley steelhead actively feed in the Delta, reductions in marsh and floodplain habitats in the lower San Joaquin River and South Delta, and changes in tributary flow magnitudes and timing have all reduced access to habitats potentially used by emigrating or actively feeding steelhead smolts originating in the Tuolumne River. Based upon documentation of reduced Chinook salmon growth rates in the Delta as well as declines in pelagic prey species, food resources may be limiting for any actively feeding steelhead smolts outside of flood conditions (Section 5.3.5.1).
- Because it is likely that much Central Valley steelhead outmigration from San Joaquin River tributaries occurs outside of typical April 15th to May 15th placement of the Head of Old River Barrier, entrainment and predation related mortality may potentially limit the number of any steelhead from the Tuolumne River that successfully emigrate to the Pacific Ocean. For steelhead entrained by the CVP and SWP water export facilities, high rates of pre-screening mortality (78–82 %) are likely to occur, substantially reducing the numbers of adult recruits in the ocean as well as long-term population levels (Section 5.3.5.2).
- Suitable water temperatures for smolt emigration in the range of 18–21°C (65–70°F) are available at Vernalis as late as mid-May in most years and it is likely that Delta conditions are suitable for smolt emigration as late as June in some years. Unsuitable temperature conditions in excess of 25°C (77°F) are likely exceeded at Vernalis by late June in most years, limiting successful emigration or any Delta rearing opportunities during summer (Section 5.3.5.1).

For ocean rearing of any Central Valley steelhead originating in the Tuolumne River:

- Although multi-year (ENSO) and decadal (PDO) variations in ocean circulation patterns affect food web productivity used by other Pacific salmonids along the California and the Pacific Northwest, less is known about how steelhead respond to changes in coastal productivity patterns. Studies of steelhead in the North Pacific concluded that food competition for food resources and inter-annual changes in sea surface temperatures are limiting factors on steelhead growth (Section 5.3.6.1).

As recommended in the June 2011 *Integrated Life Cycle Models Workshop Report* (Rose et al. 2011), this synthesis has been conducted in conjunction with the development of quantitative population models as part of interrelated relicensing studies, including the *Tuolumne River Chinook Salmon Population Model* (Study W&AR-6) and the *O. mykiss Population Study* (Study W&AR-10). Several of the findings in this report serve as preliminary hypotheses regarding the relative importance of identified in-river factors upon juvenile Chinook salmon and potential steelhead production from the Tuolumne River. Hypotheses regarding the importance of various in-river factors will be examined in developing potential management questions to be evaluated as part of these interrelated modeling studies. Along with information developed in this synthesis, the results of these studies are intended to provide the context for rejecting, accepting, or modifying preliminary hypotheses and also to inform conclusions regarding the effectiveness of any potential management measures.

7.0 STUDY VARIANCES AND MODIFICATIONS

The synthesis has been prepared to meet the goals and objectives outlined in the *Salmonid Populations Information Integration and Synthesis Study Plan* (W&AR-5) as modified and approved by FERC in its December 22, 2011 Study Plan Determination for the ongoing ILP Relicensing Studies for the Don Pedro Project (FERC Project No. 2299-075). No study variances or modifications were necessary to meet the goals and objectives of this synthesis.

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

ATTACHMENT A

INFORMATION SOURCES PROVIDED FOR REVIEW BY RELICENSING PARTICIPANTS AS PART OF CONSULTATION PROCESS FOR WORKSHOPS NO. 1 AND NO. 2

Citations and Information Sources submitted by Relicensing Participants following the April 10, 2012 and June 26, 2012 Salmonid Information Synthesis Workshops

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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.

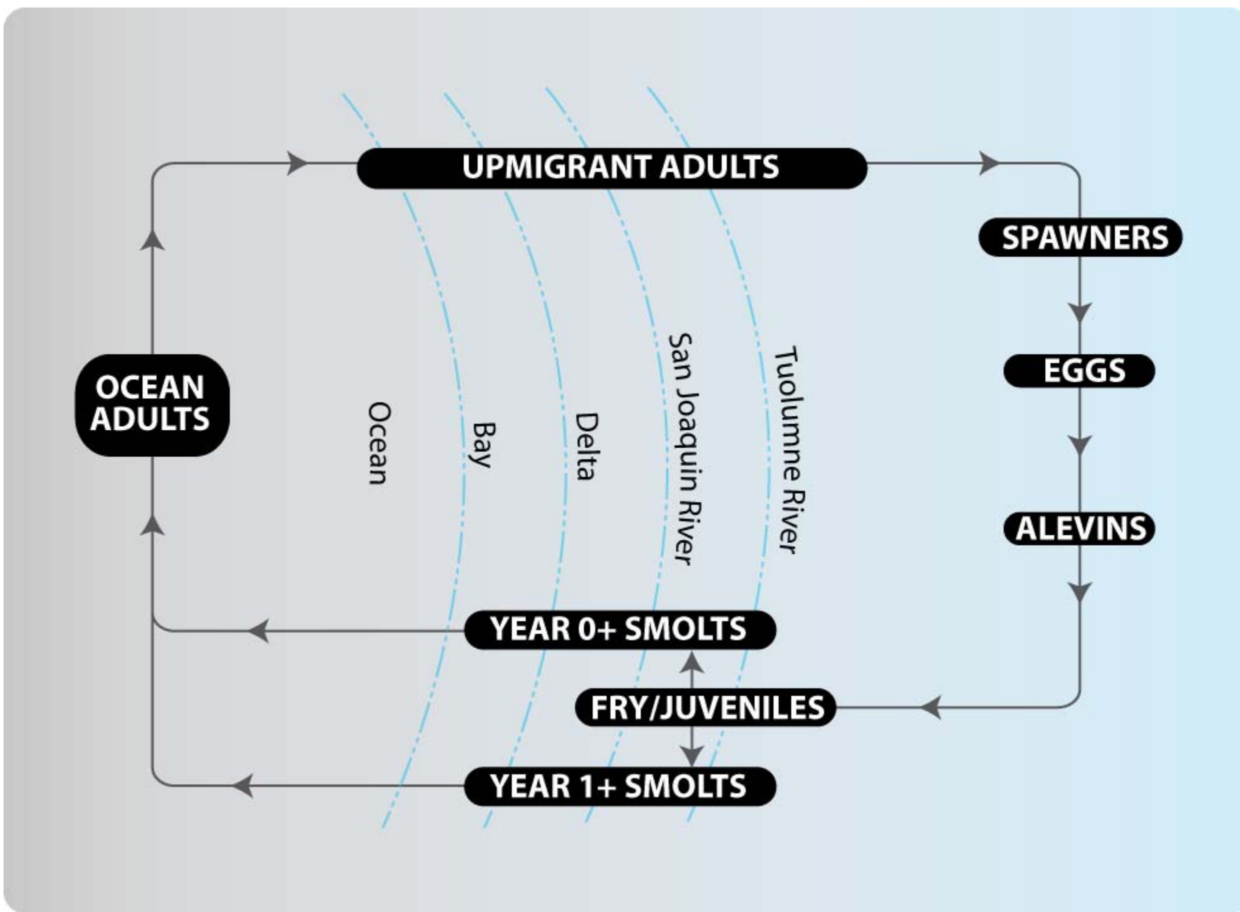

Figure B-1. Fall-run Chinook salmon life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

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.

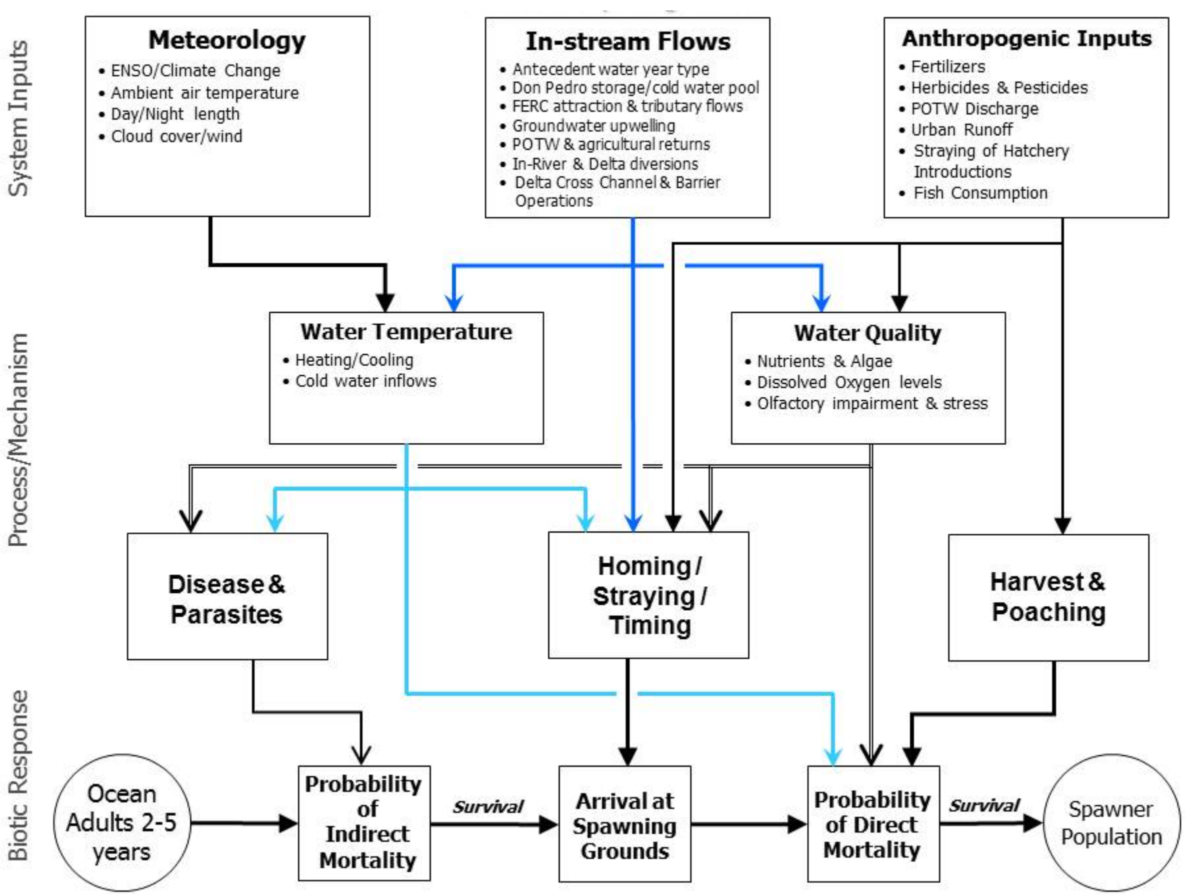

Figure B-2. Potential issues affecting fall-run Chinook salmon upmigration through the San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

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.

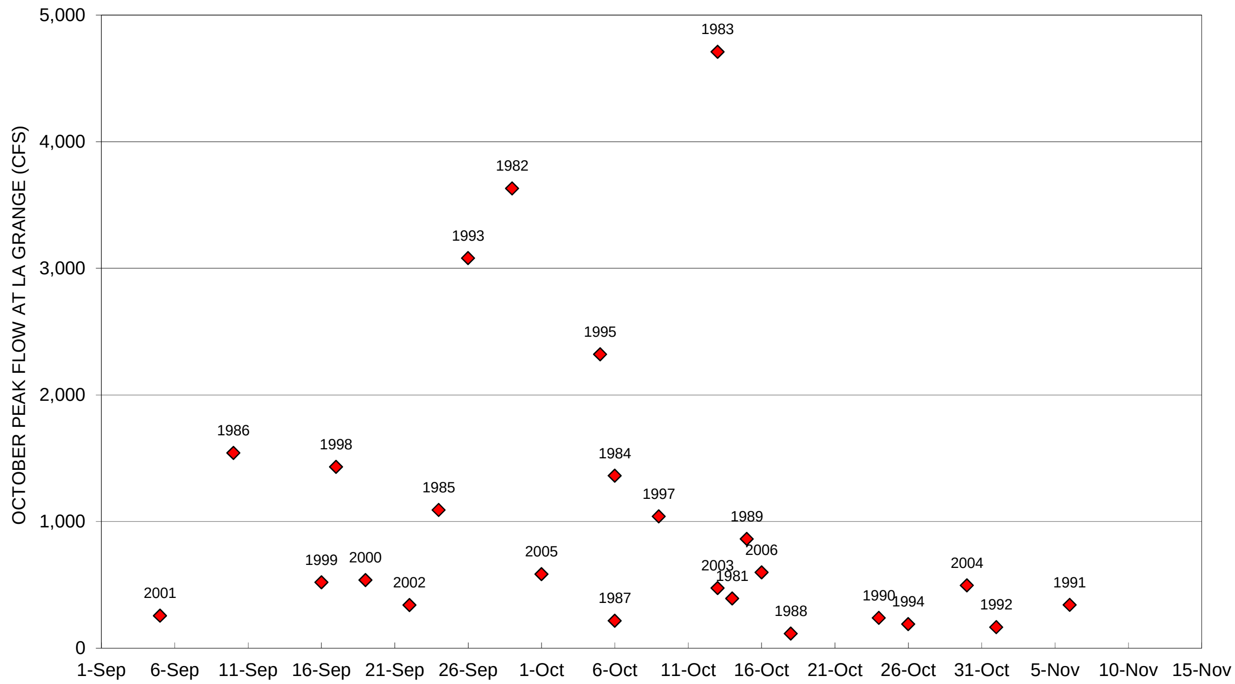

Figure B-3. Relationship between Chinook salmon arrival timing as observed near La Grange and peak flows at La Grange during October from 1981–2006.

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.

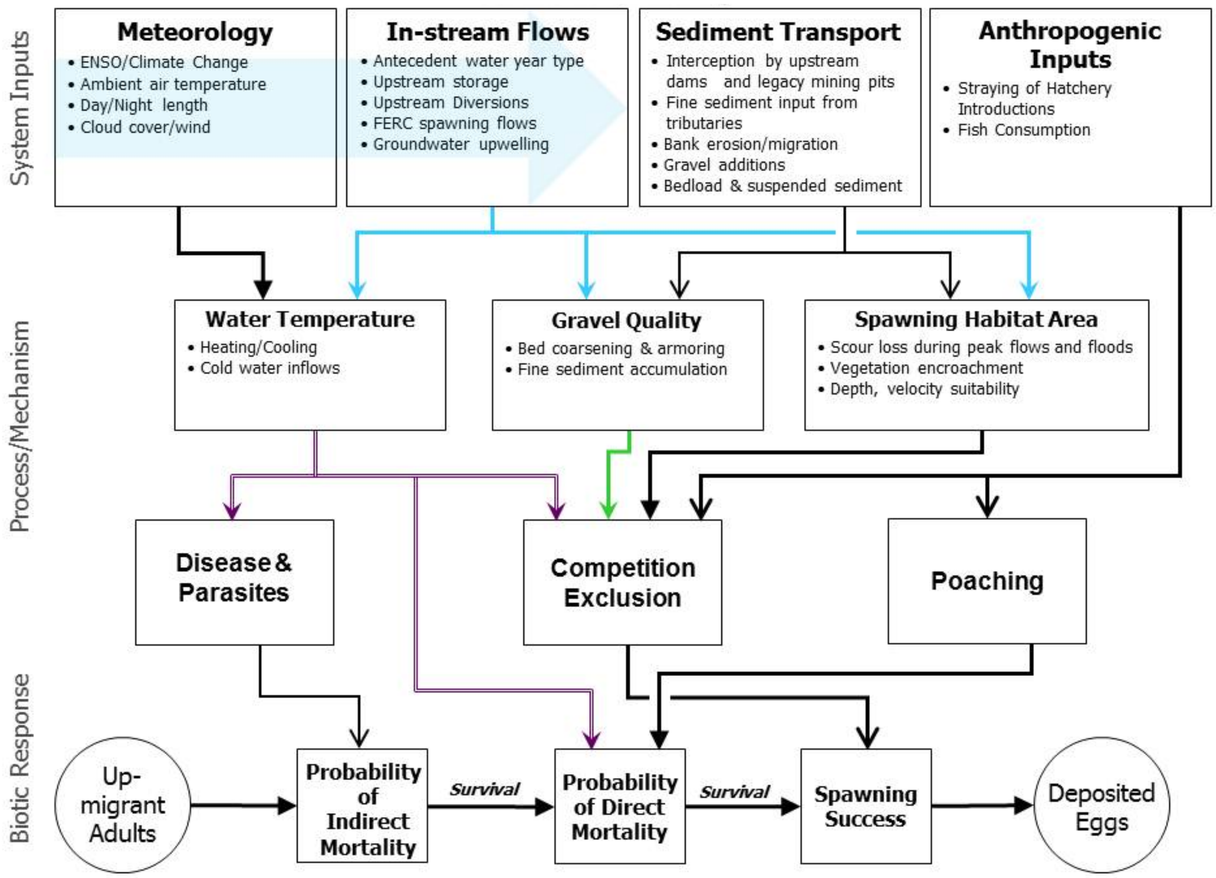

Figure B-4. Potential issues affecting fall-run Chinook salmon spawning in the lower Tuolumne River.

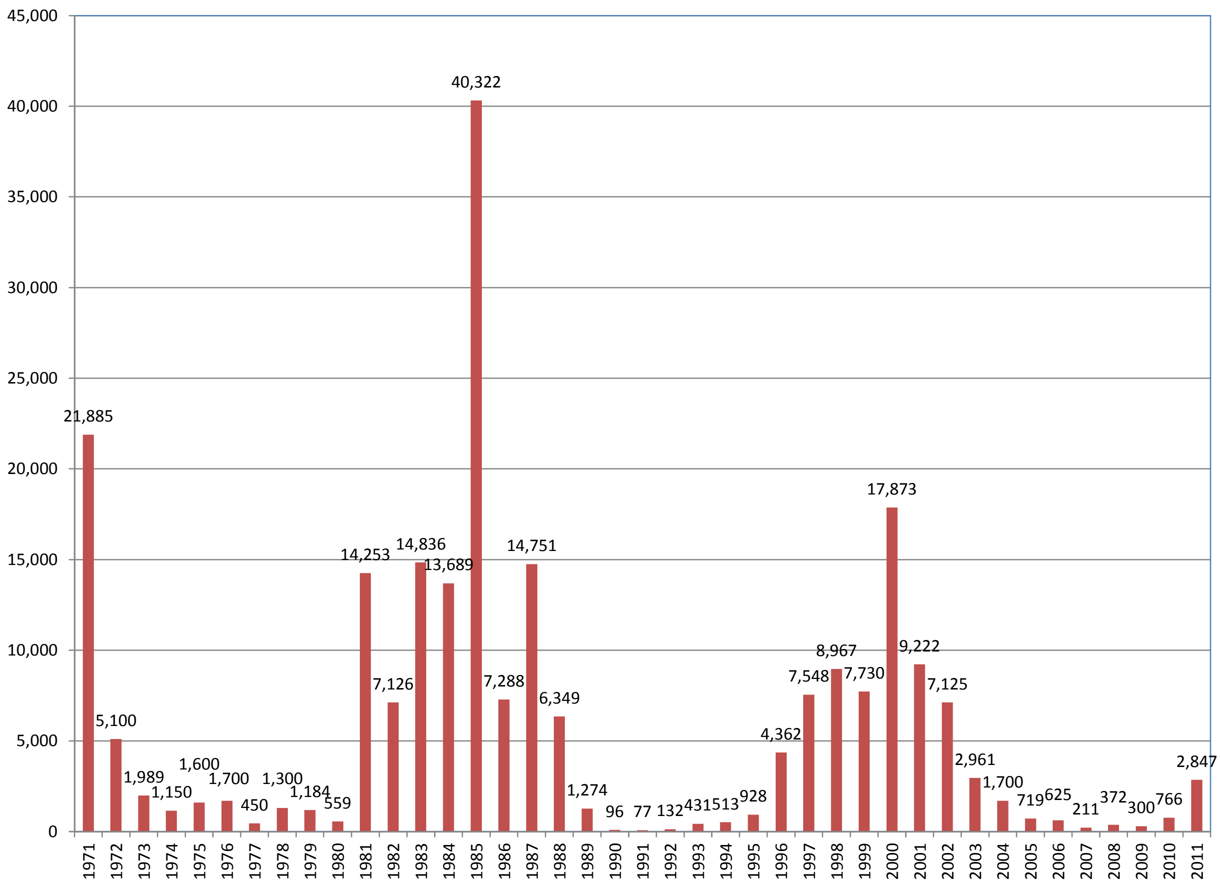

Figure B-5. Tuolumne River Chinook salmon run estimates, 1971-2011 (Years 2009-2011 based on weir counts).

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.

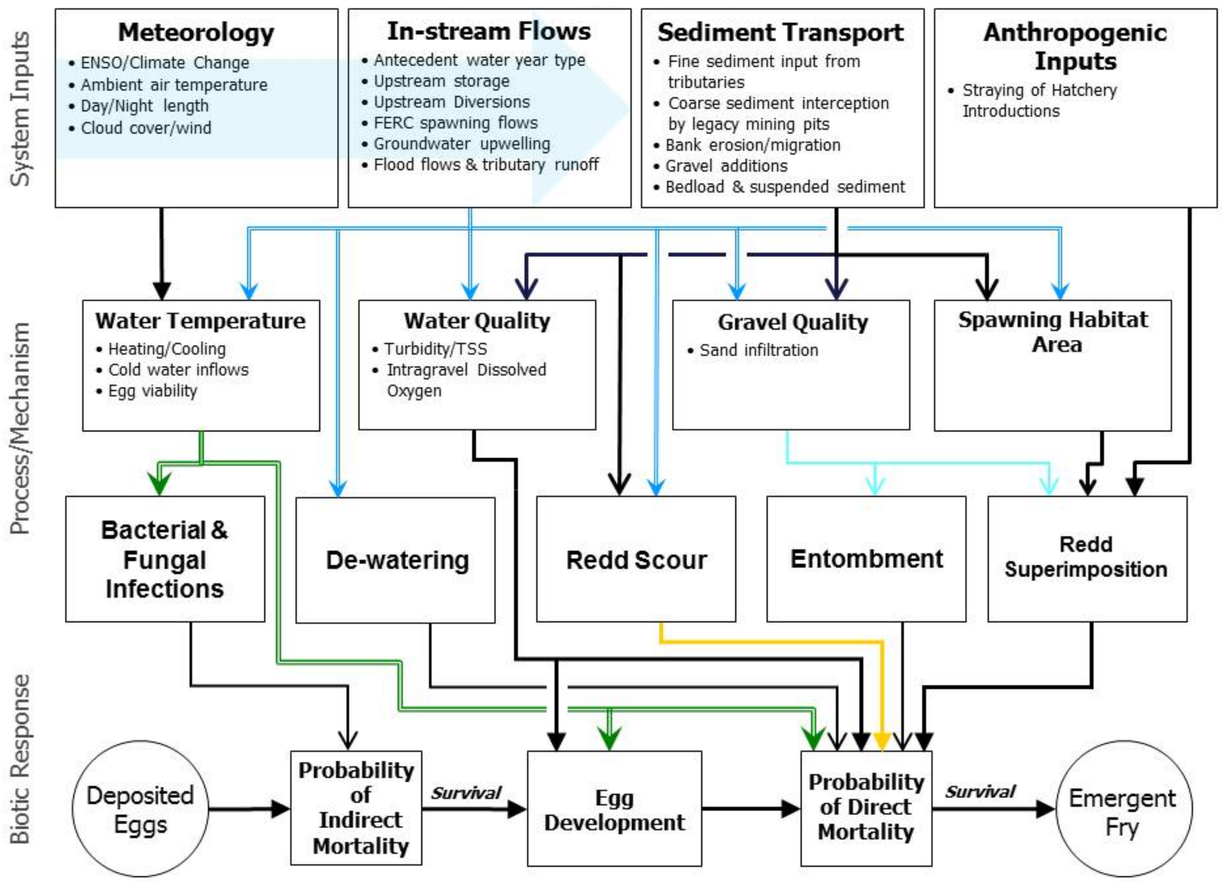

Figure B-6. Potential issues affecting fall-run Chinook salmon egg incubation, alevin development, and fry emergence in the lower Tuolumne River.

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.

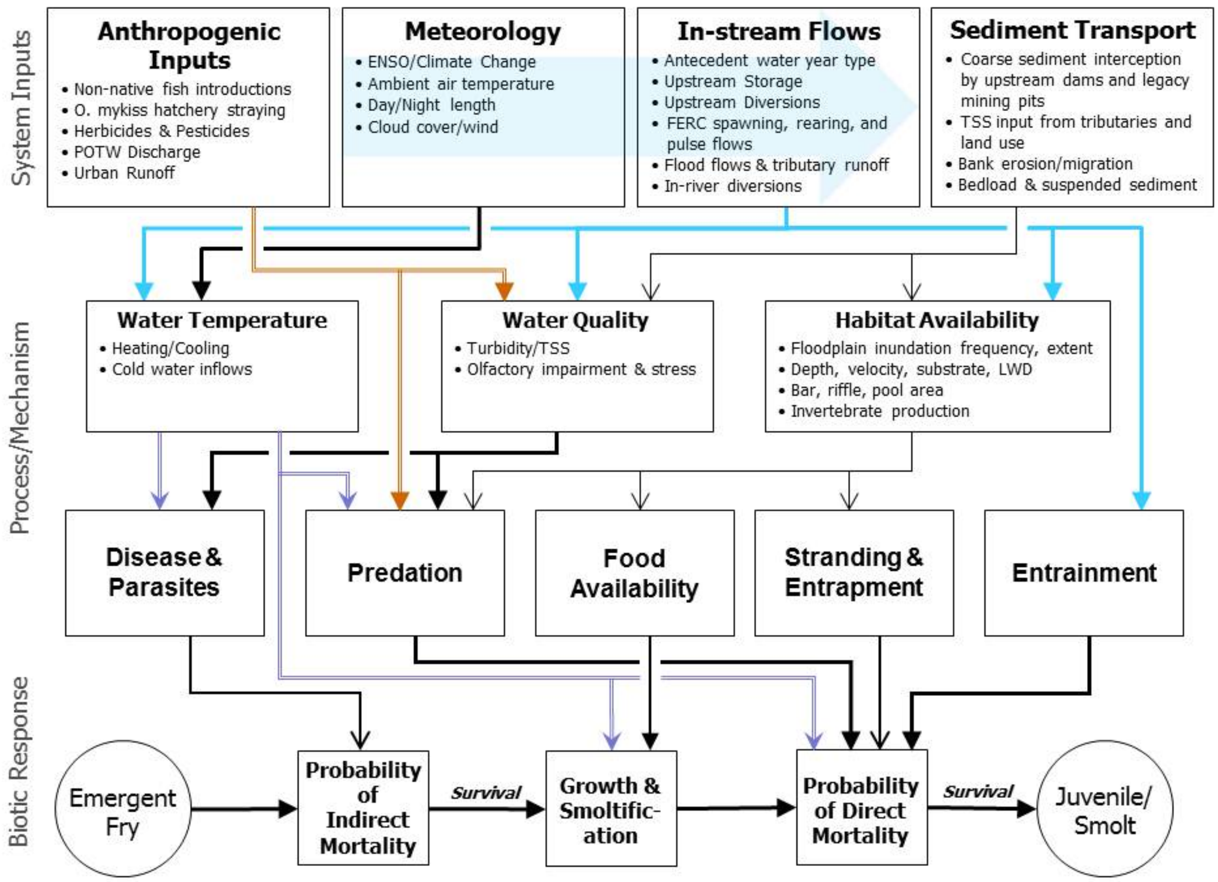

Figure B-7. **Potential issues affecting in-river rearing and smolt emigration of fall-run Chinook salmon from the lower Tuolumne River.**

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).

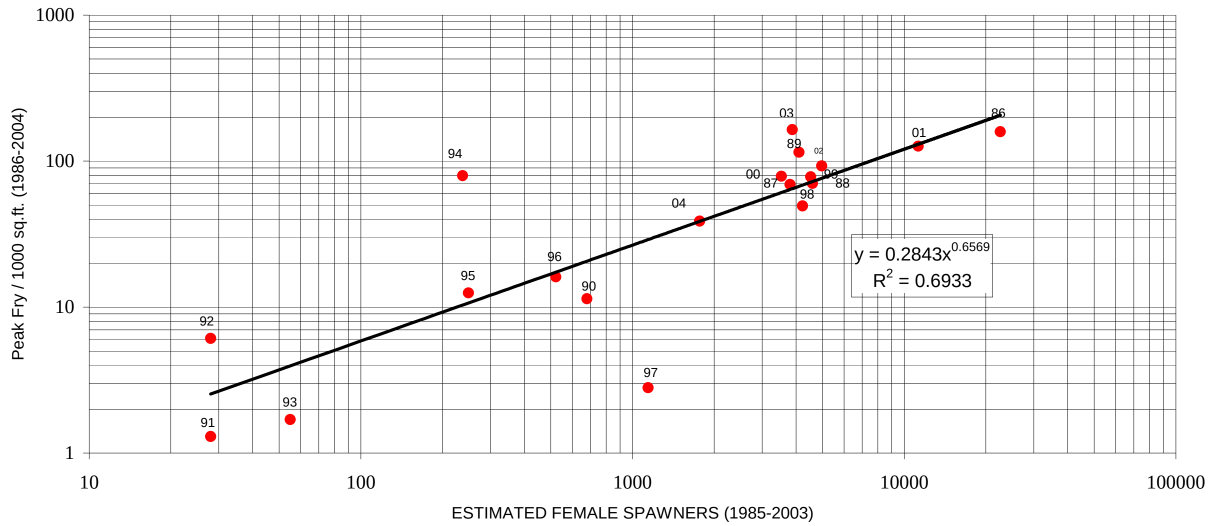

Figure B-8. Relationship between peak salmon fry density in annual biweekly seine surveys and estimates of female spawners (1985–2003).

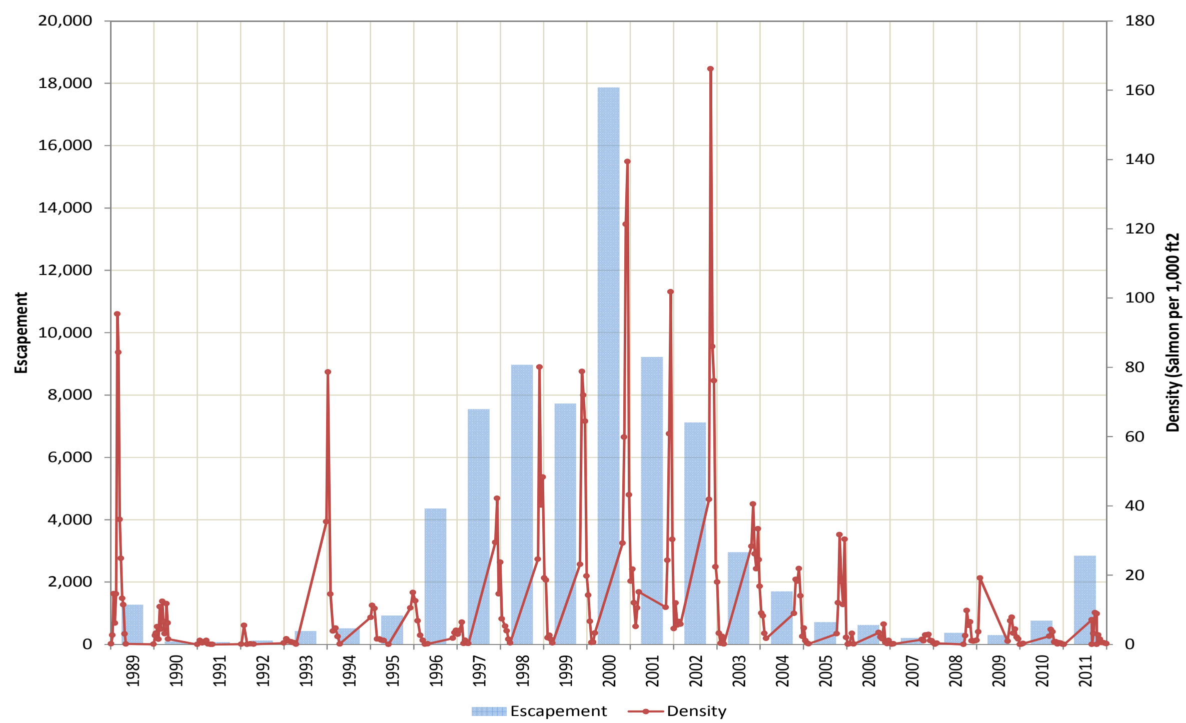

Figure B-9. Average juvenile salmon density in all seine hauls by survey with estimated escapement (1989–2011).

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.

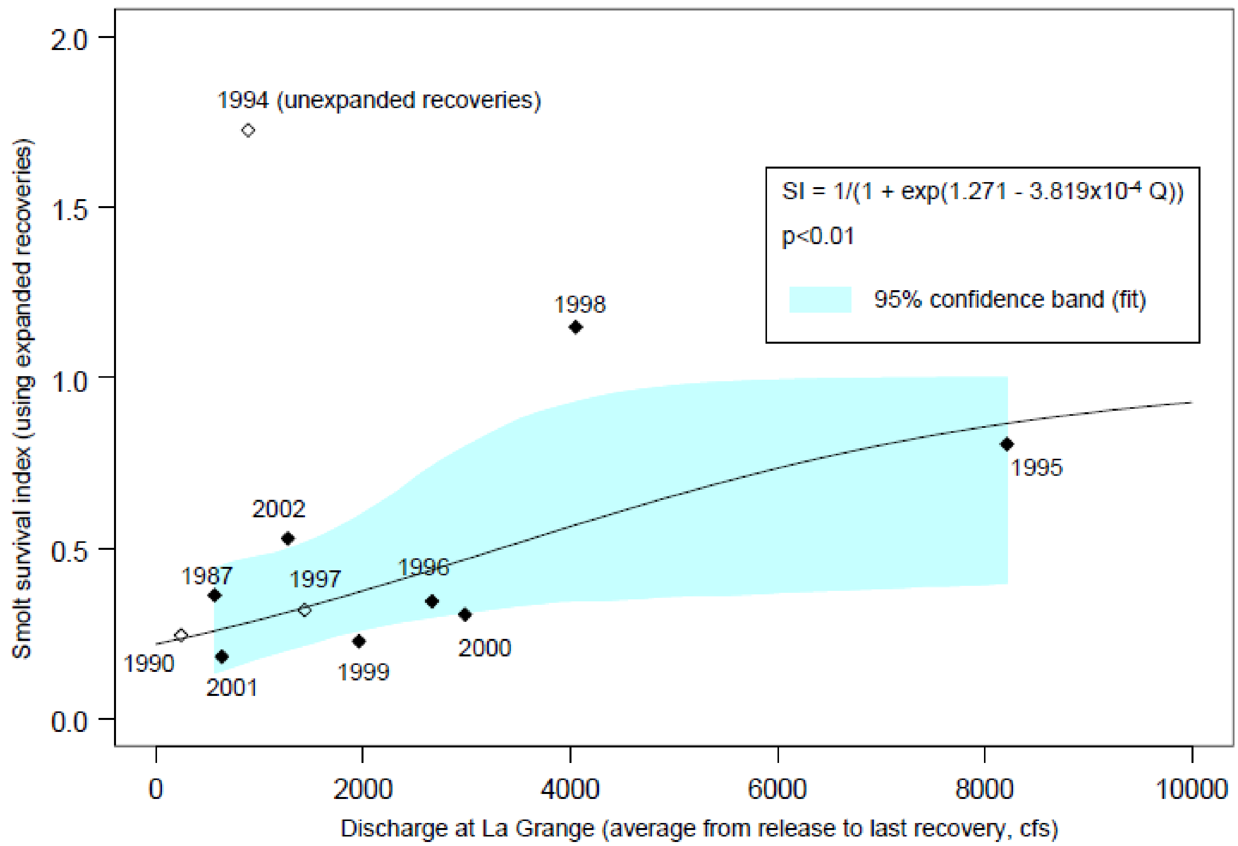

Figure B-10. Logistic regression of validated smolt survival indices by the recovery-weighted flow (cfs) at La Grange from release to last recapture at Mossdale Trawl.

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.

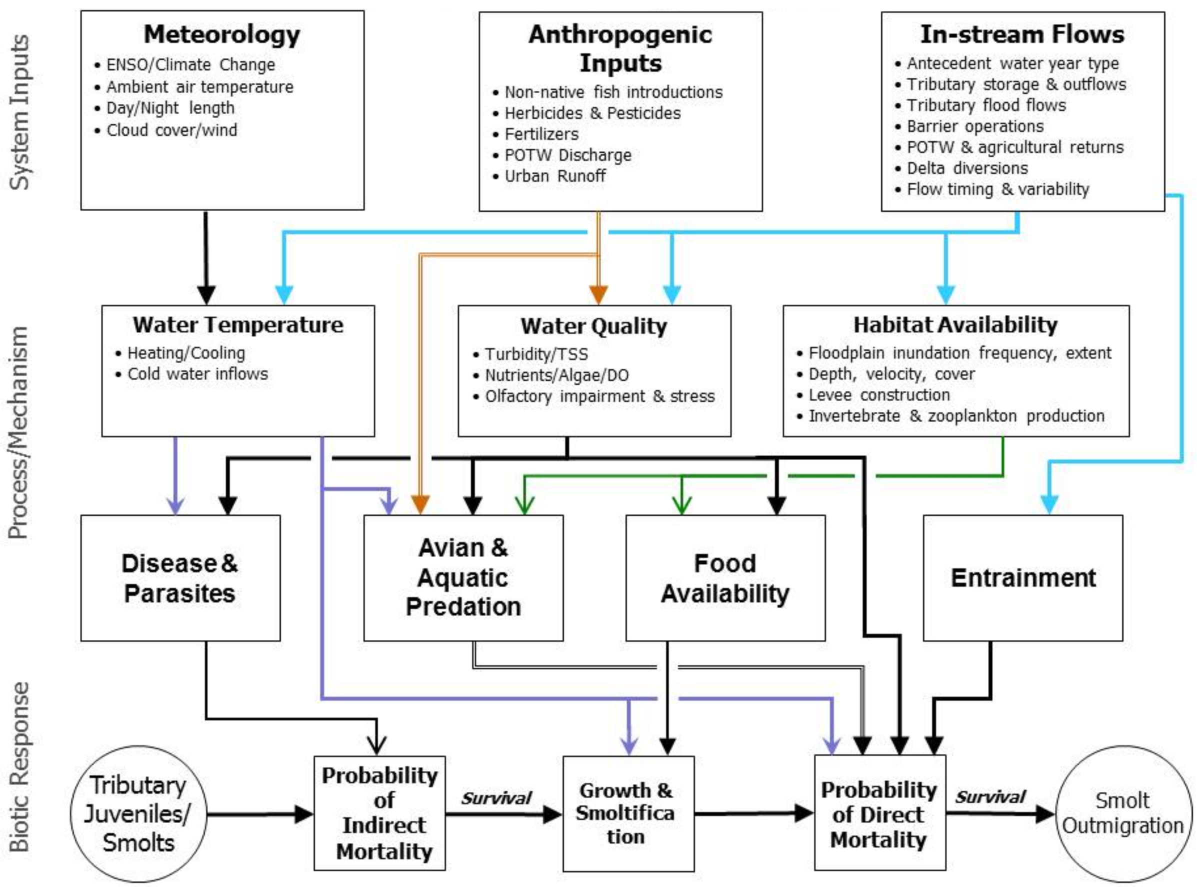

Figure B-11. Potential issues affecting Tuolumne River fall-run Chinook salmon juvenile rearing and smolt emigration from the Delta.

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.

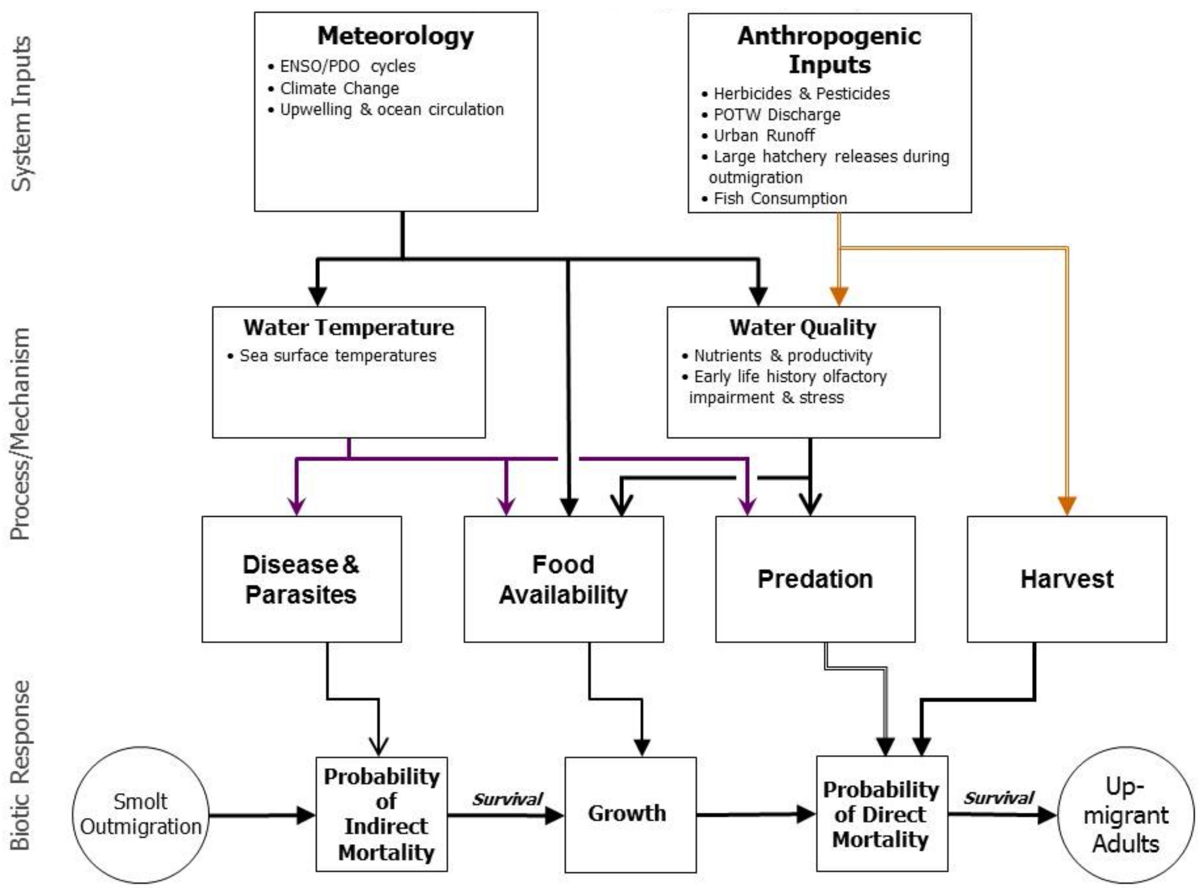

Figure B-12. Potential issues affecting Tuolumne River fall-run Chinook salmon during adult rearing in the Pacific Ocean.

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.

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 (Sep-Nov)			Winter (Dec-Feb)			Spring (Mar-May)			Summer (Jun-Aug)		
Adult Upstream Migration	grey	grey	grey	dark grey	dark grey	dark grey	grey				grey	grey
Adult Spawning				grey	grey	dark grey	dark grey	grey				
Egg Incubation and Fry Emergence					grey	grey	dark grey	dark grey	grey			
In-River Rearing (Age 0+, 1+ and older)	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey
Smolt Outmigration (Riverine/Delta)					grey	grey	dark grey	dark grey	dark grey	grey		
Ocean Rearing and Adult Residency	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey

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

[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.

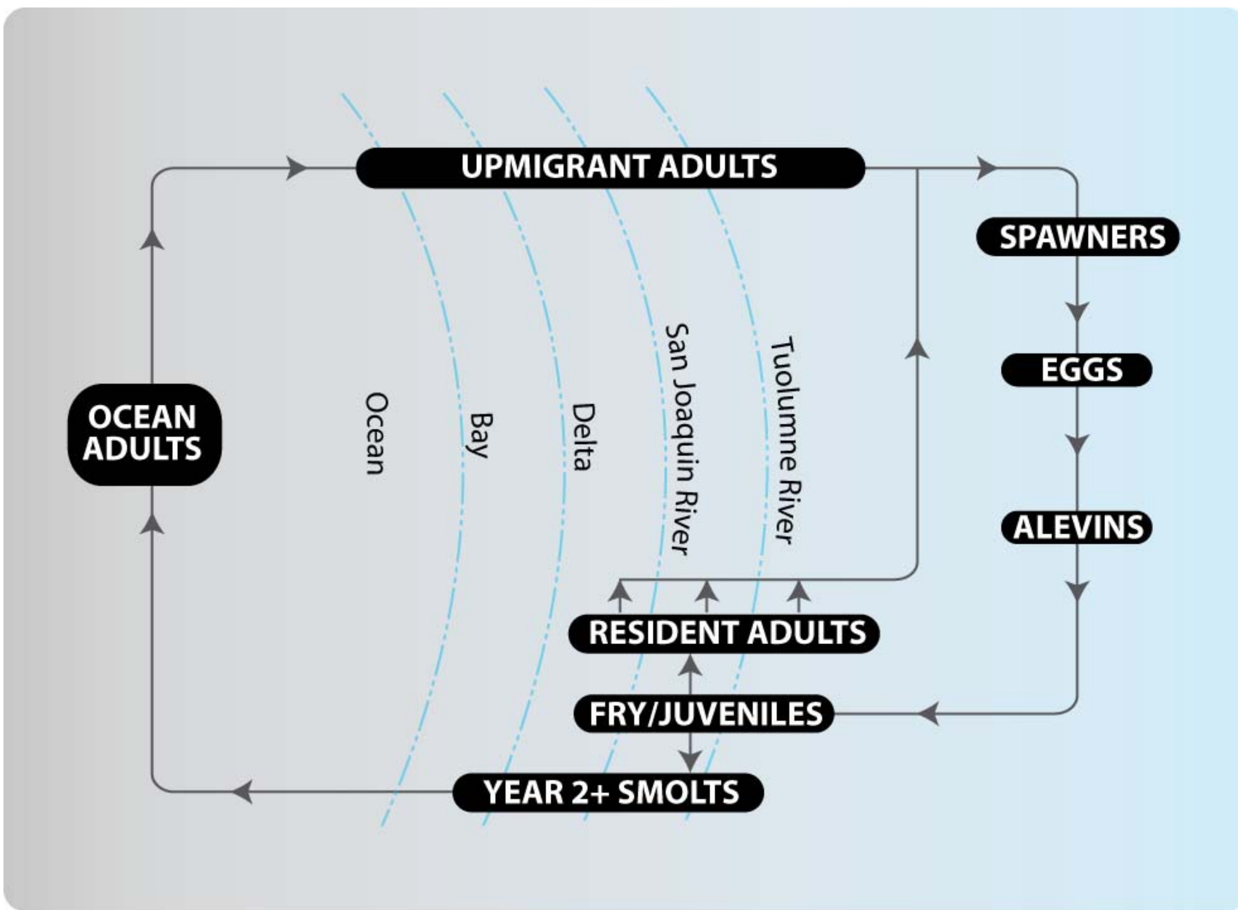

Figure C-1. Central Valley steelhead and rainbow trout life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

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.

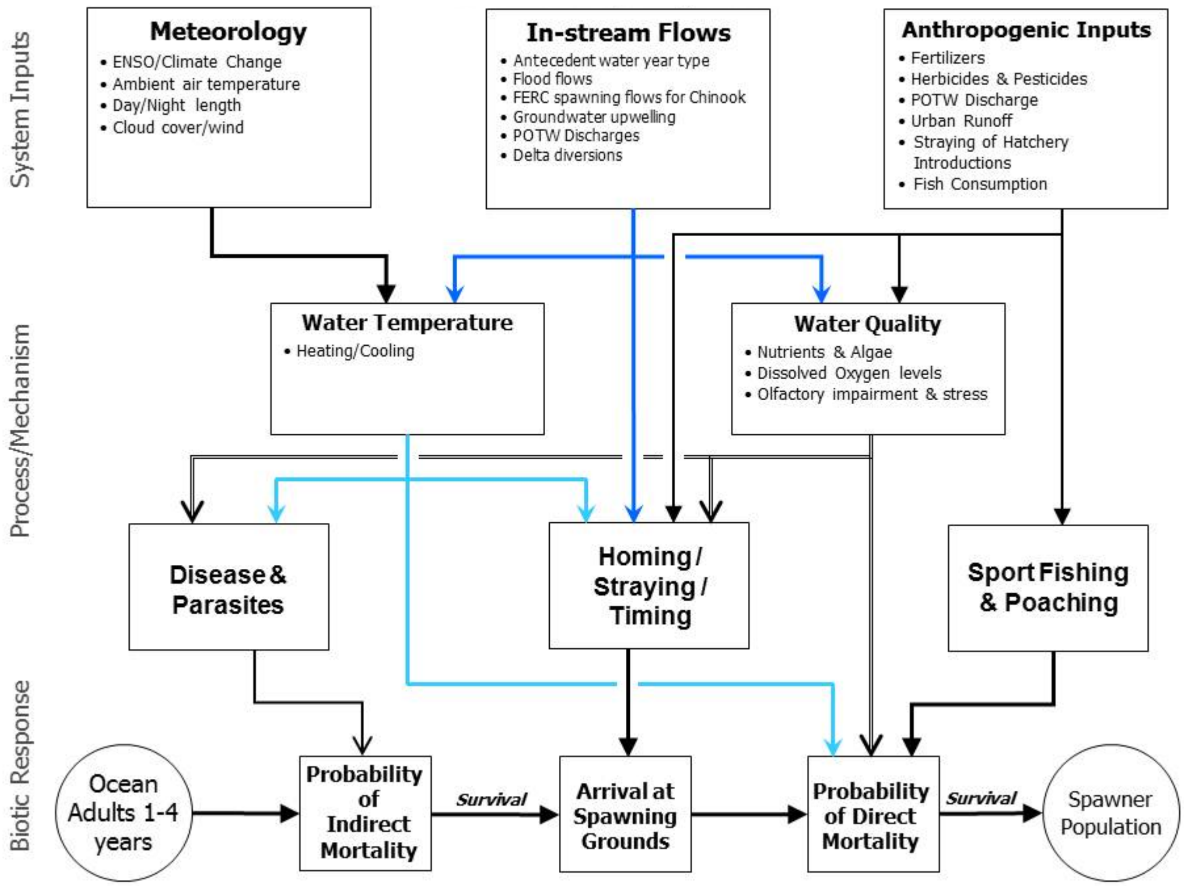

Figure C-2. Potential issues that may affect any Central Valley steelhead upmigration through the San Francisco estuary, Delta, lower San Joaquin River, and arrival in the Tuolumne River.

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.

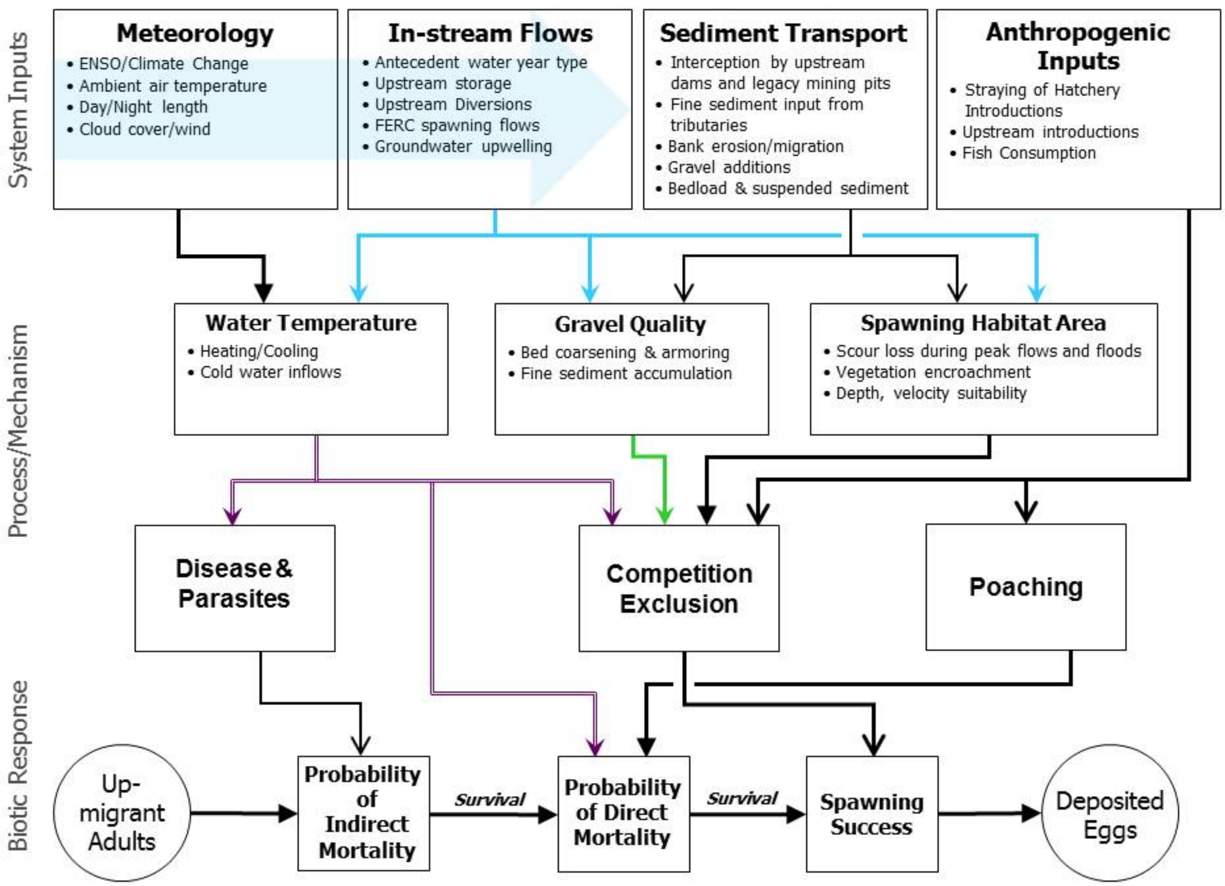

Figure C-3. Potential issues affecting *O. mykiss* spawning in the lower Tuolumne River.

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.

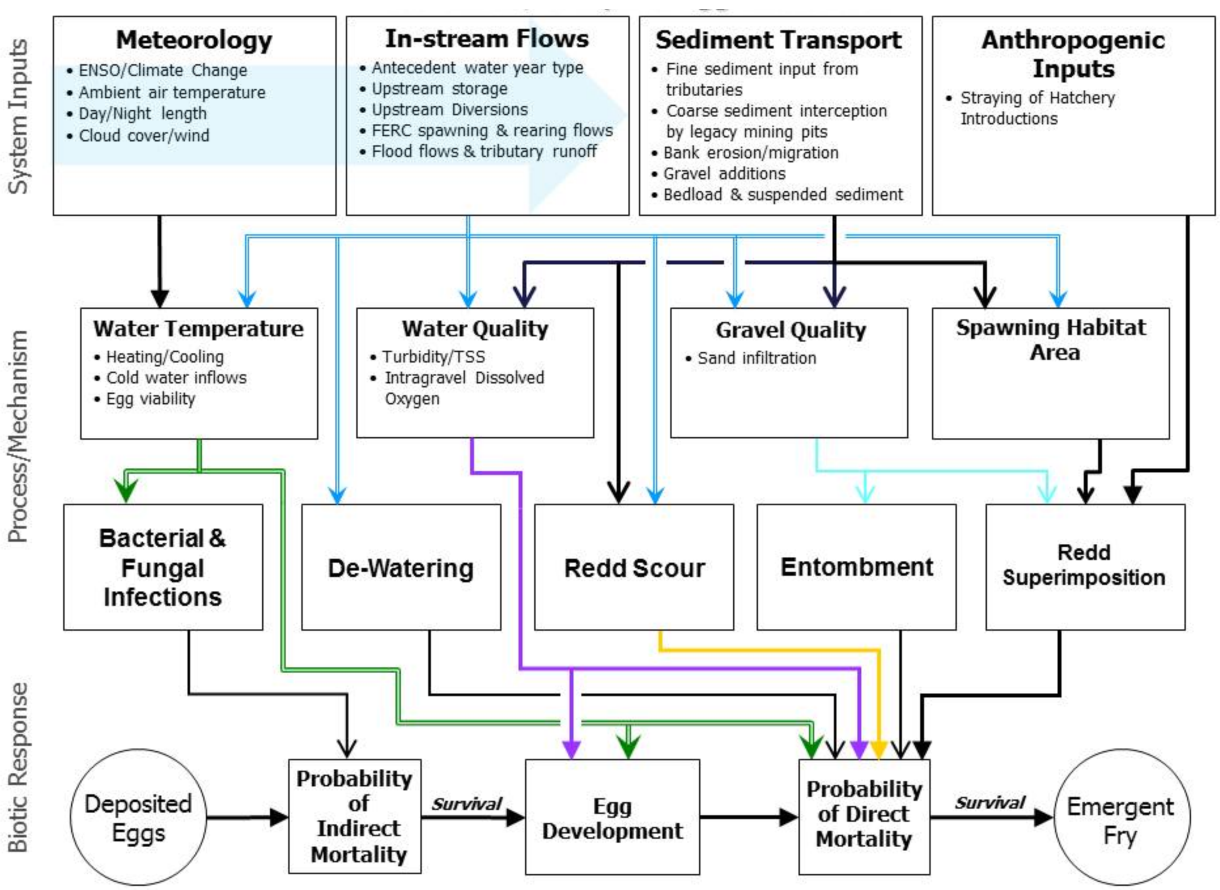

Figure C-4. Potential issues affecting *O. mykiss* egg incubation, alevin development, and fry emergence in the lower Tuolumne River.

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.

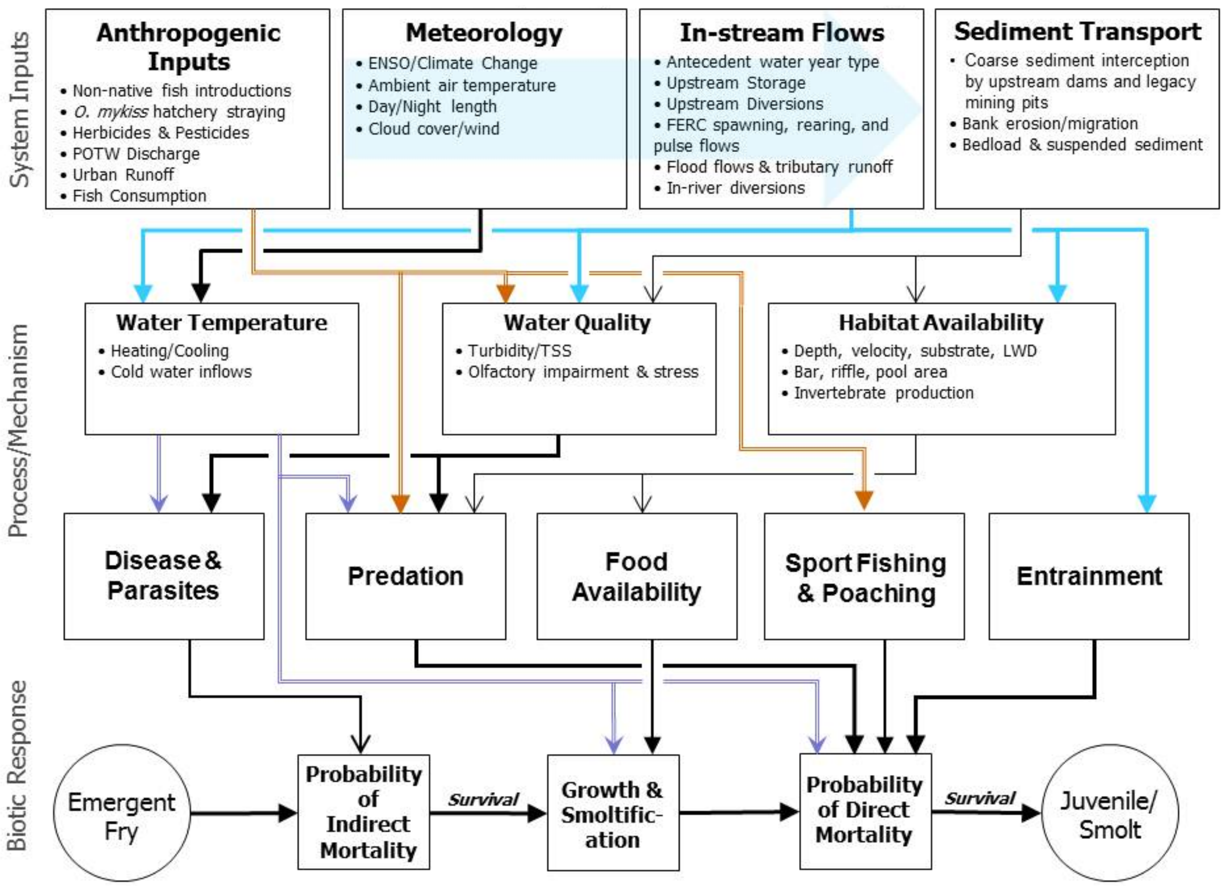

Figure C-5. Potential issues affecting in-river rearing of juvenile *O. mykiss* and smolt emigration of any Central Valley steelhead from the lower Tuolumne River.

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.

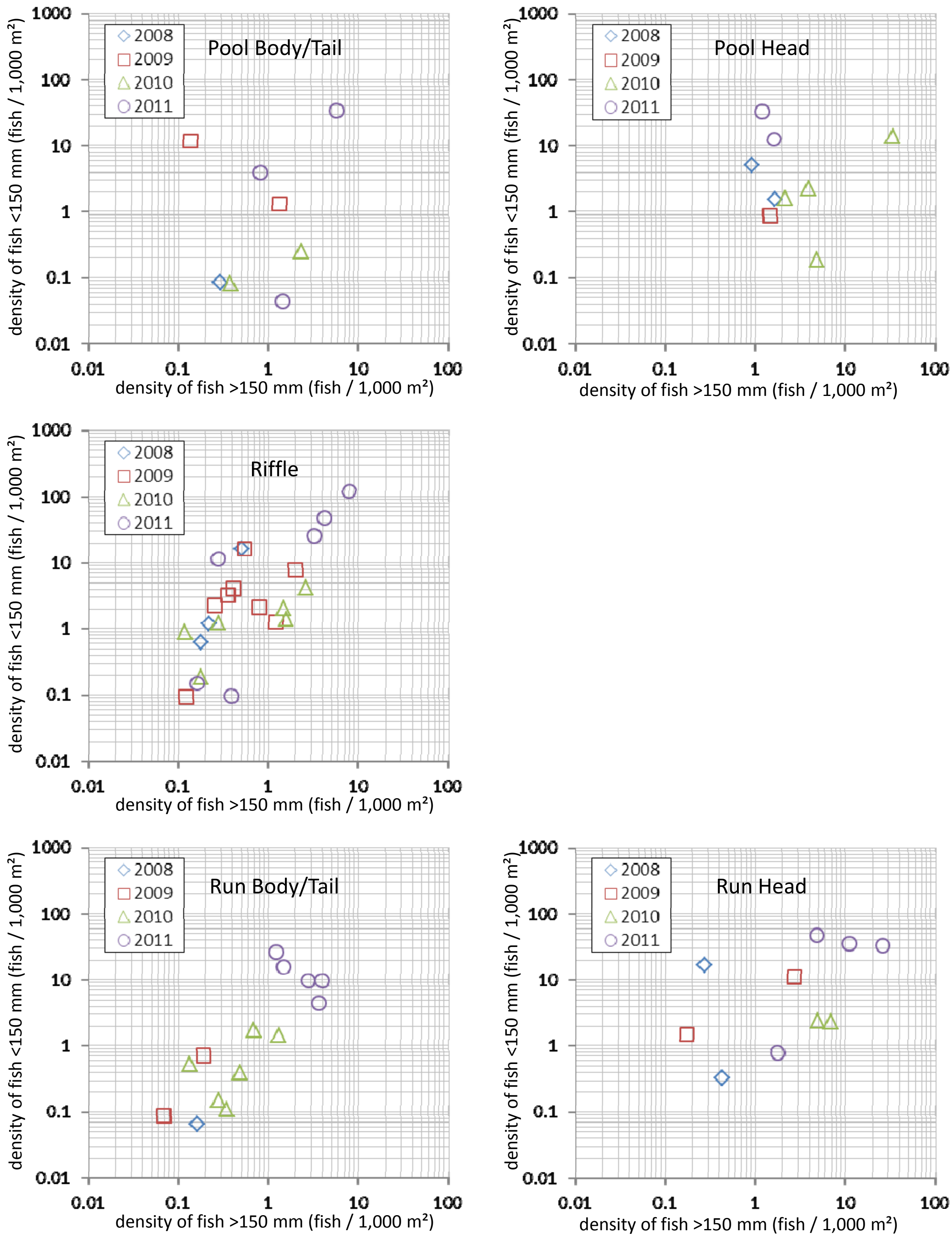

Figure C-6. **Comparison of Age 0+ vs. Age 1+ *O. mykiss* density in various habitat types sampled by snorkeling in the Tuolumne River (2008-2011).**

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

[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.

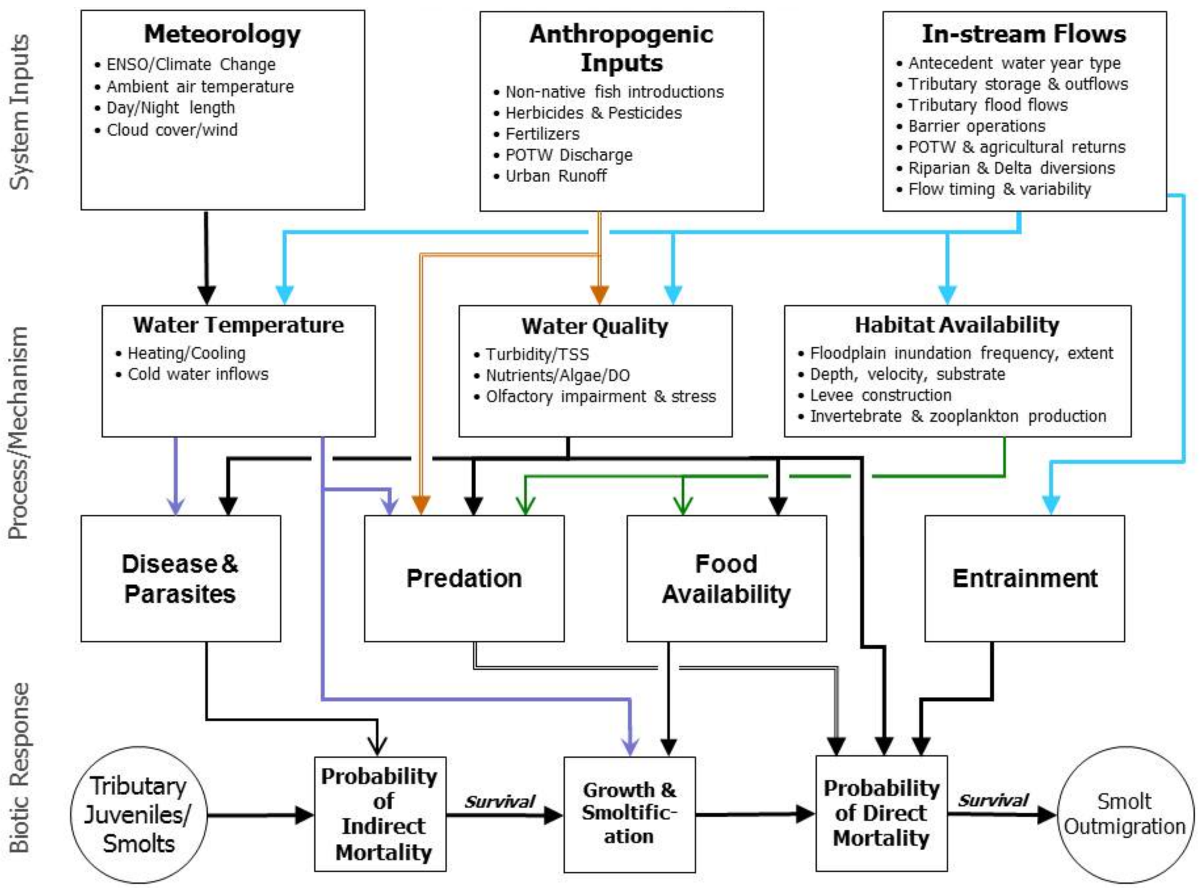

Figure C-7. Potential issues affecting any Central Valley steelhead smolts emigrating from the Tuolumne River through the lower San Joaquin River, Delta, and San Francisco Estuary.

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.

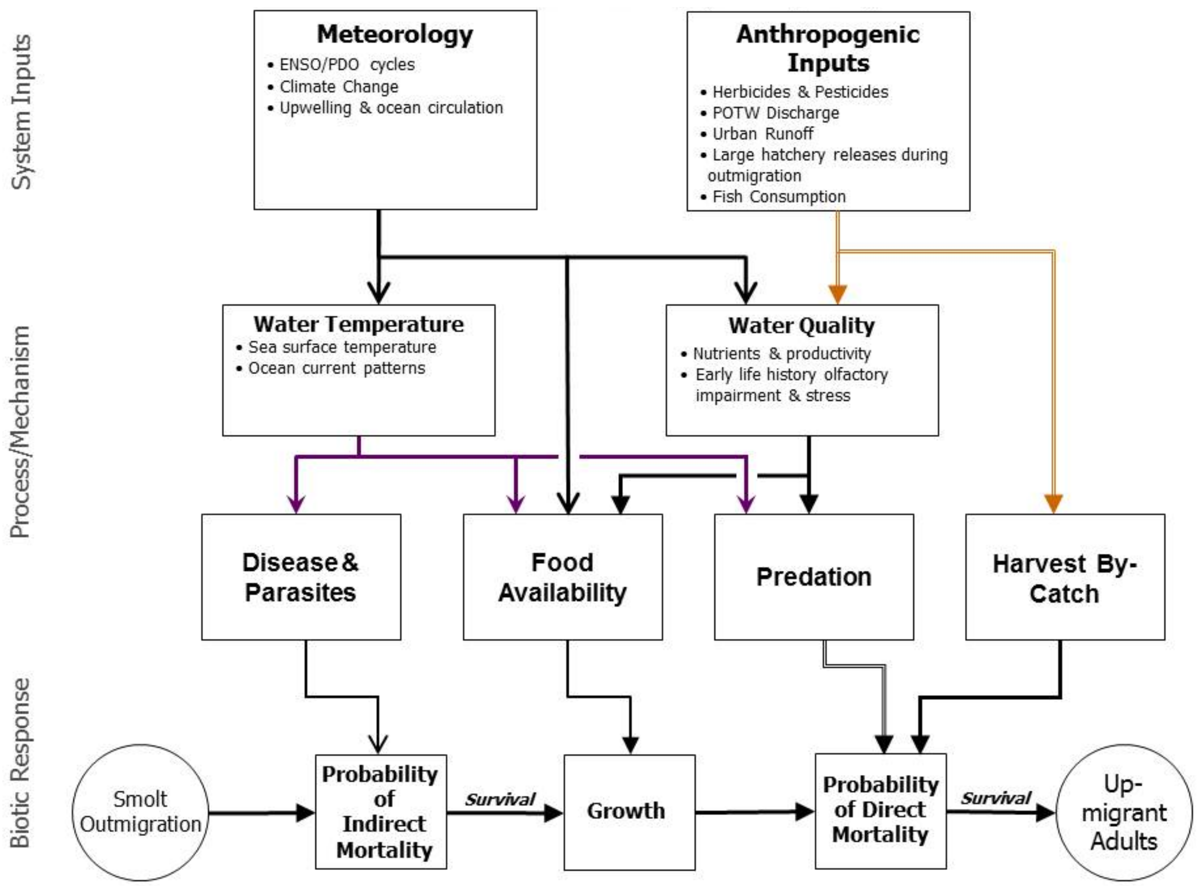

Figure C-8. Potential issues affecting any Central Valley steelhead adults from the Tuolumne River during adult rearing in the Pacific Ocean.

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.