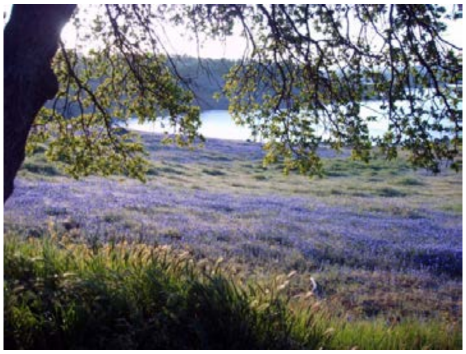
WATER QUALITY ASSESSMENT
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299



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Water Quality Assessment
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
AWQC	Ambient Water Quality Criteria
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 Wildlife (as of January 2013; previously, Department of Fish and Game)
CDMG	California Division of Mines and Geology
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
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
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
DO	Dissolved Oxygen
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
ISR	Initial Study Report
ITA	Indian Trust Assets
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
MPN	Most Probable Number
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
ppb	parts per billion
ppm	parts per million
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
SM	Standard Methods
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
su	standard unit
SWAMP	Surface Water Ambient Monitoring Program
SWE	Snow-Water Equivalent
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
TPH	Total Petroleum Hydrocarbon
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	microSeimens per centimeter

1.0 INTRODUCTION

1.1 Background

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 has a 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). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

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. The “water bank” within Don Pedro Reservoir provides significant benefits for CCSF’s 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 RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at an elevation corresponding to the 845 ft contour (31 FPC 510 [1964]). 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) 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.

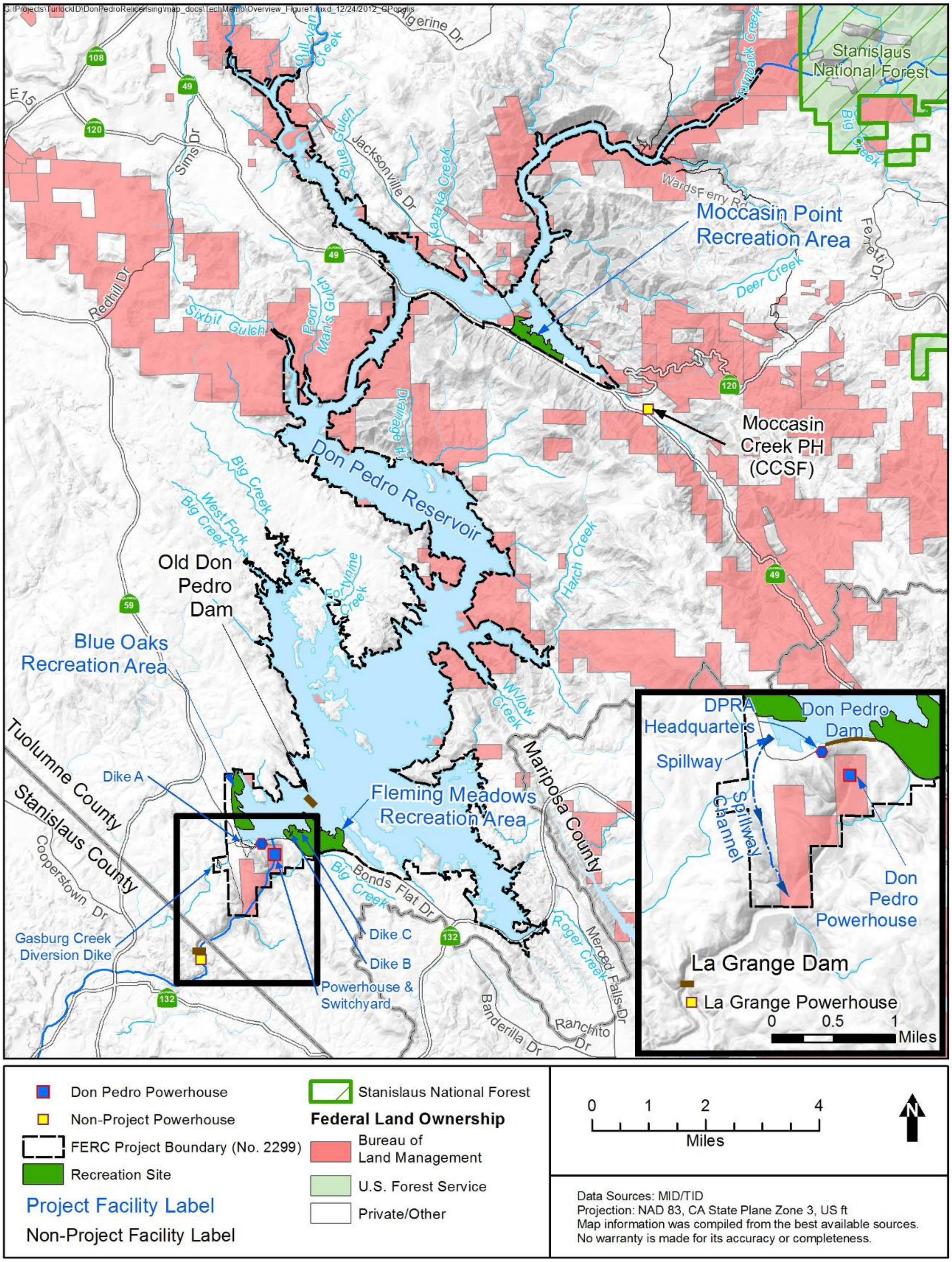

Figure 1.1-1. Don Pedro Project location.

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 Water Quality Assessment Study (W&AR-01) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. On January 17, 2013, the Districts filed the Initial Study Report for the Don Pedro Project. In response to a request made by the State Water Resources Control Board in a letter to FERC dated March 11, 2013, the Districts have edited the Water Quality Assessment Report to add a description of the Hydro Units (Hus), update the reference to the most recent Basin Plan (CVRWQCB 1998 with amendments), and remove the reference to temperature benchmark values; temperature analysis will be conducted in consultation with relicensing participants using the W&AR-03 Reservoir Temperature Model. No other comments were received. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

The ongoing operation and maintenance (O&M) of the Project may affect water quality. The effect may be direct (e.g., release of a pollutant from a Project facility), indirect (e.g., due to public recreation), or cumulative (i.e., combined effect of a Project-related activity with a non-Project activity).

In accordance with the FERC-approved study plan, Water Quality Assessment (W&AR-01), the Districts investigated the quality of surface water potentially affected by the Project, including water within Don Pedro Reservoir and in the Tuolumne River immediately downstream of Don Pedro Dam. A sample was collected downstream of La Grange Dam. Background conditions were also sampled, by sampling the Tuolumne River upstream of the Project. Woods Creek and Sullivan Creek, both tributaries to Don Pedro Reservoir, were dry during the sampling period and were not sampled.

The water quality investigation consisted of two elements: (1) a general water quality element and (2) a recreation-related water quality element. Each element of the study was conducted at the time and place where Project effects were expected to be most pronounced, if they occur. During the 2012 late summer season, surface water samples were collected from five locations upstream, within, and downstream of the Project and samples were analyzed for 55 general physical water quality parameters and chemical constituents. In-reservoir sites were sampled at two depths: within 1-2 meters of the reservoir's surface and within 1-2 meters of the bottom. During the 30 days surrounding and including the 2012 Independence Day holiday, five episodes of surface water samples were collected adjacent to 12 reservoir recreation sites and analyzed for bacteria and hydrocarbons.

This study addresses the following issues identified in Section 6.0 of the PAD:

- **Issue:** Effects of the Project and Project recreation on water quality (excluding water temperature) and compliance with the Central Valley Regional Water Quality Control Board's (CVRWQCB) Water Quality Control Plan for the Sacramento River and San Joaquin River Basins, fourth edition (Basin Plan).
- **Issue:** Effect of the Project on compliance with the SWRCB's CWA Section 303(d) List of TMDL Priority Schedule.
- The water quality parameter temperature was addressed through other studies. Water temperature in the reservoir is the subject of the W&AR-03 Reservoir Temperature Model Study Plan, while water temperature modeling downstream of Don Pedro Reservoir is the subject of the Lower Tuolumne River Temperature Model Study Plan (W&AR-16).

2.0 STUDY GOALS AND OBJECTIVES

This technical memorandum presents the results for the Water Quality Assessment consistent with the requirements set forth in FERC's Study Plan Determination. The goals of this study were (1) to characterize existing water quality conditions in Don Pedro Reservoir and the lower Tuolumne River, as measured at the point of discharge from the Project and (2) to determine the water's consistency with the CVRWQCB's Basin Plan Objectives (CVRWQCB 1998[1]). The objective of the study was to determine whether or not Project operations and maintenance (O&M) activities are in compliance with Basin Plan objectives.

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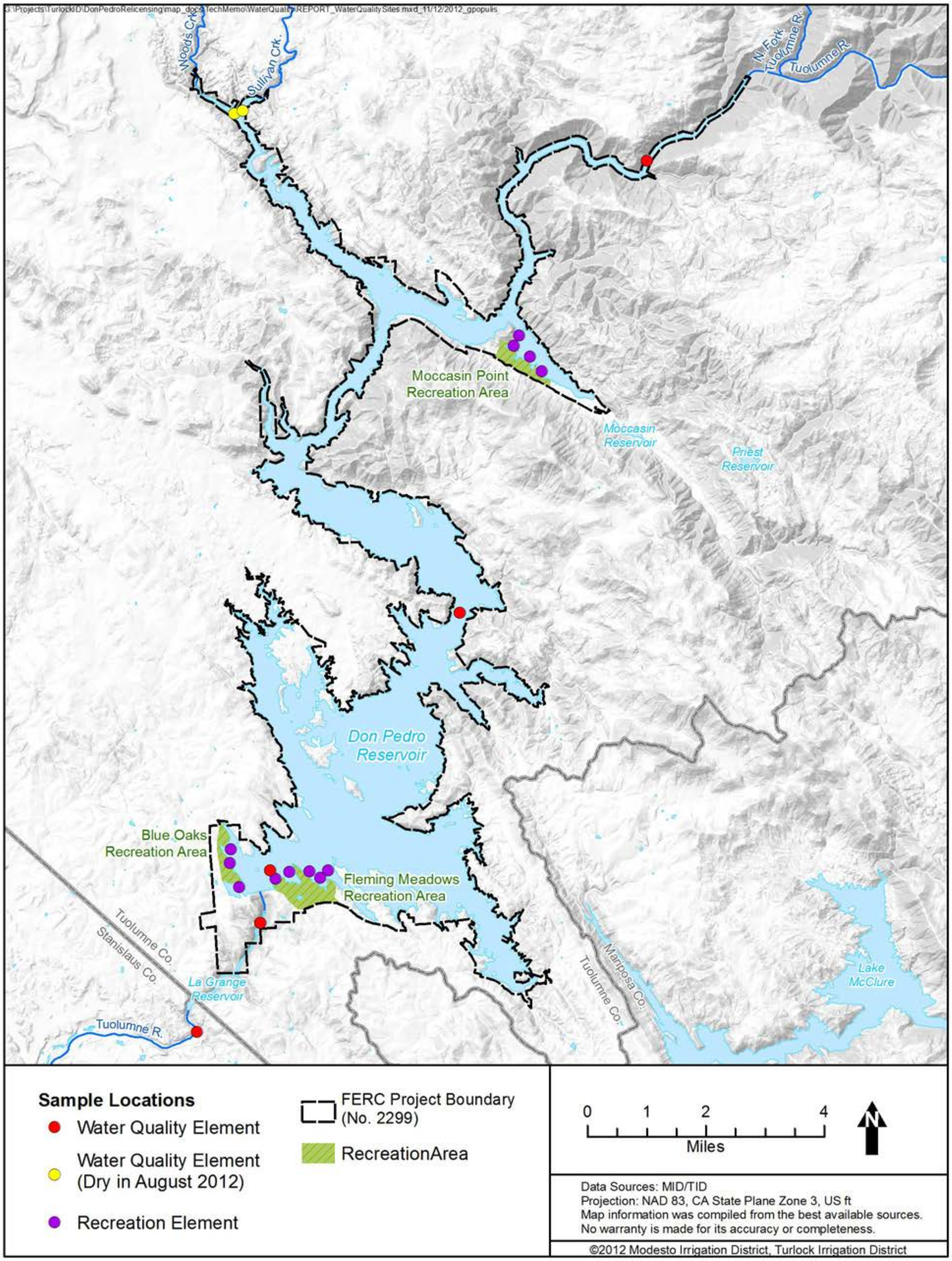
[1] With amendments through October 2011. See Section 8.0 References.

3.0 STUDY AREA

The study area includes the Project Boundary and tributaries upstream of Don Pedro Reservoir, surface waters within the Don Pedro Reservoir, and the Tuolumne River immediately below Don Pedro Dam (Figure 3.0-1). Although no point-source discharges occur in or immediately downstream of the reservoir, the study area encompasses recreation-related facilities and Project O&M activities. Water quality just downstream of La Grange Dam, was also assessed.



Data Sources: MID/TID
Projection: NAD 83, CA State Plane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

Figure 3.0-1. Study area.

4.0 METHODOLOGY

In 2012, the Districts investigated the quality of surface water potentially affected by Project O&M and recreation activities during periods when water quality effects are expected to be most pronounced, if they occur. The study consisted of two elements: a Water Chemistry Element and a Recreation Activity Element. Each is described below.

4.1 Water Chemistry Element

Water quality samples were collected between August 22 and 24, 2012, during summer low-inflow and high temperature conditions.

4.1.1 Sample Locations

The FERC-approved sampling plan called for sampling the locations listed in Table 4.1-1 and shown in Figure 3.0-1. Sampling occurred upstream, within, and downstream of Don Pedro Reservoir.

Table 4.1-1. Reservoir and stream reach sample locations.

Reservoir/Stream Reach	Sample Depth	Location
Woods Creek[1]	Just below surface	Just prior to entering Don Pedro Reservoir
Sullivan Creek[1]	Just below surface	Just prior to entering Don Pedro Reservoir
Tuolumne River above Don Pedro Reservoir	Just below surface	Upstream of Ward's Ferry Bridge at the first riffle
Don Pedro Reservoir	One meter below surface	Between Upper and Middle Bays (co-located with current CDFG temperature profile location)
	One meter above bottom	
Don Pedro Reservoir - near Dam	One meter below surface	At deepest point in the reservoir near the dam (co-located with current CDFG temperature profile location)
	One meter above bottom	
Tuolumne River just below Don Pedro Dam	Just below surface	Below Don Pedro powerhouse (co-located with current TID/MID water quality sonde)
Tuolumne River below La Grange Dam	Just below surface	Below La Grange at USGS gage USGS Gage 11289651 (about 0.5 miles below the dam)

[1] Location was either dry of had no flowing water between August 22 and 24, 2012.

Key:

CDFG = California Department of Fish and Game

USGS = U.S. Geological Survey

Of the three upstream sample locations, only the mainstem Tuolumne sample could be collected during the season investigated, as Woods and Sullivan Creeks were dry at that time. In-reservoir samples were collected at the deepest point near the dam and about 2/3 of the way upstream, between Upper Bay and Middle Bay. At each reservoir location, water quality samples were collected for laboratory analysis at two depths: within the hypolimnion and just below the surface in the epilimnion. *In situ* water quality measurements were made at the same depths using a Hydrolab DataSonde 5.

In-stream samples were taken upstream and downstream of Don Pedro Reservoir. Upstream sampling locations were limited to the Tuolumne River site, upstream of Ward's Ferry. Woods Creek and Sullivan Creek were not sampled because they either contained no flowing water or were dry during the sampling period. Water quality grab samples were collected for laboratory analysis from the moving water. *In situ* measurements were collected from the same locations using a Hydrolab Quanta or Hydrolab DataSonde 5.

4.1.2 In-Situ and Laboratory Analyses

Table 4.1-2 shows the method, target reporting limit,[2] method detection limit[3] and hold time associated with each constituent measured for this study. Water temperature, dissolved oxygen (DO), pH, specific conductance, and turbidity were measured in the field using a Hydrolab DataSonde 5 or Quanta. Laboratory analyses were conducted using U.S. Environmental Protection Agency (EPA) Analytical Methods (EPA 2010), Standard Methods (SM, APHA et al. 2010), or an equivalent method sufficiently sensitive to detect and report levels necessary for evaluation against state and federal water quality standards.

Table 4.1-2. Water quality parameters.

Parameter		**Method**	**Target Reporting Limit/Method Detection Limit µg/L (or other)[1]**	**Hold Time**
Dissolved Oxygen	DO	SM 4500-O	0.1 mg/L	Field (*in situ*)
Specific conductance		SM 2510A	0.001 µmhos	Field (*in situ*)
pH		SM 4500-H	0.1 su	Field (*in situ*)
Turbidity		SM 2130 B	0.1 NTU	Field (*in situ*)
Basic Water Quality – Laboratory				
Total Organic Carbon	TOC	SM 5310	0.5/0.02 mg/L	28 d
Dissolved Organic Carbon	DOC	EPA 415.1 D	0.5/0.02 mg/L	28 d
Total Dissolved Solids	TDS	EPA 2540 C/SM 2340 C	1 mg/L	7d
Total Suspended Solids	TSS	EPA 2520 D SM 2340 D	1 mg/L	7d
Inorganic Ions				
Total Alkalinity	--	SM 2340 B	1000	14 d
Hardness (measured value)	--	EPA 2340 B/SM 2340 C	2 mg/L as $CaCO_3$	14 d
Calcium	Ca	EPA 6010 B	100	180 d
Magnesium	Mg	EPA 6010 B	100	180 d
Potassium	K	EPA 6010 B	500	180 d
Sodium	Na	EPA 6010 B	500	180 d
Chloride	Cl	EPA 300.0	1000 mg/L	28 d
Nutrients				
Nitrate-Nitrite	--	EPA 300.0	100	28 d <pH 2
Total Ammonia as N	--	EPA 4500-NH3/ SM 4500-NH3	100	28 d <pH 2
Total Kjeldahl Nitrogen as N	TKN	SM 4500 N	500	28 d <pH 2
Total Phosphorous	TP	SM 4500-P	100	28 d <pH 2
Dissolved Orthophosphate	PO_4	EPA 365.1/EPA 300.0	100	48 h at 4°C

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[2] The reporting limit is the lowest concentration at which an analyte can be detected with a reliable precision and accuracy. At this concentration, both the identity of the analyte and its quantity are certain.

[3] The method detection limit is the lowest concentration that an analyte can be detected and distinguished from other chemicals. At this concentration, the identity of the analyte is certain, but its quantity is uncertain.

Parameter		Method	Target Reporting Limit/Method Detection Limit µg/L (or other)[1]	Hold Time
Dissolved Oxygen	DO	SM 4500-O	0.1 mg/L	Field (*in situ*)
Specific conductance		SM 2510A	0.001 µmhos	Field (*in situ*)
pH		SM 4500-H	0.1 su	Field (*in situ*)
Turbidity		SM 2130 B	0.1 NTU	Field (*in situ*)
Metals (Total and Dissolved)				
Arsenic (total and dissolved)	As	EPA 200.8/1632	0.15/0.04	180 d
Cadmium (total and dissolved)	Cd	EPA 200.8/1638	0.020/0.004	180 d
Copper (total and dissolved)	Cu	EPA 200.8/1638	0.10/0.010	180 d
Iron (total and dissolved)	Fe	EPA 200.8/1638	10/3.2	180 d
Lead (total and dissolved)	Pb	EPA 1638	0.040/0.003	180 d
Mercury (total)	Hg	EPA 1631	0.0005/0.00008	28 d
Methylmercury (total and dissolved)	CH_3Hg	EPA 1630	0.00005/0.00002	90 d
Selenium (total)	Se	EPA 200.8/1638	0.60/0.2	180 d
Silver (total and dissolved)	Ag	EPA 200.8/1638	0.020/0.006	180 d
Zinc (total and dissolved)	Zn	EPA 200.8/1638	0.20/0.10	180 d
Herbicides and Pesticides				
Aldrin	--	EPA 8081A	3.0	7d
Alpha-BHC (=alpha-HCH)	--	EPA 8081A	0.08	7d
Beta-BHC (=beta-HCH)	--	EPA 8081A	0.08	7d
Chlordane	--	EPA 8081A	0.0043	7d
Chlorpyrifos	--	EPA 8141A	0.014	7d
Delta-BHC (=delta-HCH)	--	EPA 8081A	0.08	7d
Dieldrin	--	EPA 8081A	0.056	7d
Diazinon	--	EPA 8141A	0.05	7d
Endosulfan I	--	EPA 8081A	0.056	7d
Endosulfan II	--	EPA 8081A	0.056	7d
Endrin	--	EPA 8081A	0.036	7d
Gamma-BHC (=gamma-HCH)	--	EPA 8081A	0.08	7d
Heptachlor	--	EPA 8081A	0.0038	7d
Heptachlor Epoxide	--	EPA 8081A	0.0038	7d
Toxaphene	--	EPA 8081A	0.0002	7d

[1] When only one number is provided, it is the method detection limit.

Key:

Field = in situ
d = days
h = hours
µg/L = micrograms per liter
mg/L = milligrams per liter
SM = Standard Method
EPA= Environmental Protection Agency

California-certified laboratories analyzed the water samples for basic water chemistry, inorganic ions, metals, nutrients, herbicides, and pesticides. Frontier Geosciences, Inc., Seattle, Washington, conducted laboratory analyses for trace metals. CalScience Environmental Laboratories, Inc., Garden Grove, California, conducted all other laboratory analyses.

4.1.3 Sample Collection

Sample and data collection procedures were detailed in the Water Quality Assessment Study Plan or Quality Assurance Project Plan (QAPP) provided as Attachment A, Part 1 to this document. Hydrolab sondes were rented from Hach Hydromet in Loveland, Colorado. Calibration of each sonde was performed by Hach Hydromet prior to deployment (Attachment A Part 1). Calibration was also verified in the field using the manufacturer's recommended calibration methods. The study team noted relevant conditions during each sampling event on the field data sheet (i.e., air temperature, water flow, description of location, floating material, and evidence of oil and grease).

Each laboratory sample was collected into laboratory-supplied clean containers. Water samples to be analyzed for metals were taken using "clean hands" methods consistent with the EPA Method 1669 sampling protocol as described in *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria* (EPA 1996). Samples collected for dissolved metals analysis were filtered in the field in accordance with standard protocols.

All sample containers were labeled with the date and time that the sample was collected, assigned a sample number, and handled in a manner consistent with appropriate chain-of-custody protocols. Samples were preserved as appropriate, stored, and delivered to a California-certified water quality laboratory for analyses of the parameters listed in Table 4.1-2 in accordance with maximum holding periods for each parameter. A chain-of-custody record was maintained with the samples at all times. The sampling site location was recorded using a hand-held Global Positioning System (GPS) unit and the coordinates were recorded in a field logbook.

4.1.4 Quality Assurance

As part of the field quality assurance program defined in the Quality Assurance Project Plan (QAPP) (Attachment A, Part 1), duplicate samples, field blanks and equipment rinsate samples were collected and submitted to the laboratory for analysis (Attachment B). A duplicate sample is a sample co-located with an investigation sample and the two are sent to the laboratory together. For homogenous matrices such as water, comparing laboratory results from the duplicate and investigation samples provides a way to assess the laboratory's consistency. A field blank is a sample of analyte-free water poured into a sample container in the field, preserved, and shipped to the laboratory along with collected samples. A field blank assesses sample contamination from field methods and conditions during sampling. An equipment rinsate is a sample of analyte-free water poured over or through decontaminated field sampling equipment prior to the collection of samples. Testing of this sample assesses the adequacy of the decontamination processes. Only equipment used for reservoir sampling was used for more than one sample site; stream samples did not require sharing equipment.

All field and laboratory data were verified and/or validated as appropriate. Following field surveys and laboratory analysis, which included the laboratory's own Quality Assurance/Quality Control (QA/QC**)** analysis, QA/QC procedures were applied to all data, including, but not limited to: spot-checks of transcription; review of electronic data submissions for completeness; comparison of Geographic Information System maps with field notes on locations; comparison of results to field blank and rinsate results; and, identification of any data that seemed inconsistent with expectations and requiring resolution.

All verified chemical detections, including data whose results are "J" qualified,[4] were used for this assessment. Field-sampling conditions, as measured by the field blank and the rinsate sample results, were reviewed by the study scientist and, if appropriate, used to qualify detected concentrations.

4.2 Recreation Element

For the recreation element of the study, bacteria and total petroleum hydrocarbon (TPH) samplings were conducted at near-shore locations adjacent to recreation facilities receiving relatively lower levels of active management as identified by the recreation facility reconnaissance survey. During the survey, these locations were identified to have the potential to affect water quality. In accordance with bacteria sampling protocols (CVRWQCB 1998), bacteria samples were collected on five different days within a 30-day period including a holiday weekend. For this study, samples were collected in the 30 days surrounding and including the 2012 Independence Day holiday weekend. A single TPH sample was also collected at each location during the Independence Day holiday weekend.

4.2.1 Recreation Sample Locations

Recreation sample locations are listed in Table 4.2-1 and shown in Figure 3.0-1. At each sample location, water samples were collected from the near surface[5] for bacteria and at the surface for TPH.

Table 4.2-1. Recreation sample locations on Don Pedro Reservoir.

Recreation Area	Bacteria and TPH Sampling Site
Fleming Meadows	Marina
	Houseboat marina
	Boat launch
	Main campground loop
	Small campground loop
Blue Oaks	Boat ramp
	Picnic area
	Loop of campground
Moccasin Point	Boat ramp
	Marina
	Main campground loop
	Picnic area

TPH = Total Petroleum Hydrocarbon

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[4] Results with a "J" qualifier are results where the chemical was detected, but there is uncertainty in the reported concentration. The quantity is above the method detection limit, but below the reporting limit.

[5] Approximately 6 inches below the surface.

4.2.2 Laboratory Analyses

Water samples associated with recreation activities were analyzed for bacteria and TPH (Table 4.2-2). Bacteria samples were delivered to JL Analytical, Inc., Modesto, California for analysis. TPH samples were sent to CalScience Environmental Laboratories, Inc., Garden Grove, California.

Table 4.2-2. Water quality parameters addressed in the Recreation Element of the study.

Parameter	Symbol or Abbreviation	Method	Target Reporting Limit/ Method Detection Limit	Hold time
Bacteria				
Total coliform	--	SM 9221B	2/100 mL	24 h
Fecal coliform	--	SM 9221E	2 MPN/100 mL	24 h
Escherichia coli	E. coli	SM 9221F	2 MPN/100 mL	24 h
Petroleum Hydrocarbons				
Total Petroleum Hydrocarbon—gasoline	TPH-g	EPA 8015B(Modified)	50/48 µg/L	14 d
Oil & Grease	O&G	Visual Observation	--	--

Key:
d = days
h = hours
ml= milliliters
µg/L = micrograms per liter
MPN = Most Probable Number
SM = Standard Method
EPA= Environmental Protection Agency

At each location, visual observations of oil and grease were recorded in the field notebook, if present.

4.2.3 Sample Collection

The Recreation Element followed the same sampling protocols as the Water Quality Element (Section 4.1.3).

4.2.4 Quality Assurance

All data were verified and/or validated as defined in the Study QAPP (Attachment A, Part 1). In brief, following field surveys and laboratory analysis, which included the laboratory's own QA/QC analysis, the Districts subjected all data to QA/QC procedures including, but not limited to: spot-checks of transcription; review of electronic data submissions for completeness; comparison of Geographic Information System (GIS) maps with field notes on locations; and, identification of any inconsistent data.

4.3 Consistency with Water Quality Objectives

Beneficial uses of surface water in the vicinity of the Project are designated by the CVRWQCB and listed in the Basin Plan (CVRWQCB 1998). The designated beneficial uses for Hydro Units in the Project Boundary and vicinity consist of municipal and domestic supply (MUN);

agricultural supply (AGR); hydropower generation (POW); water contact recreation (REC-1); water non-contact recreation (REC-2); cold freshwater habitat (COLD); warm freshwater habitat (WARM); migration of aquatic organisms (MIGR), spawning, reproduction and/or early development (SPAWN), and wildlife habitat (WILD).

Specifically, the Don Pedro Project and the areas upstream and downstream of the Project fall within three Basin Plan Hydro Units: (1) Hydro Unit 536, which includes the Tuolumne River upstream of the Project; (2) Hydro Unit 536.32, which includes Don Pedro Reservoir; and (3) Hydro Unit 535, which includes the Tuolumne River from Don Pedro Dam to the San Joaquin River. Designated beneficial uses in Hydro Unit 535 consist of municipal and domestic supply, agricultural supply, industrial process supply, industrial service supply, water contact recreation, water non-contact recreation, warm freshwater habitat, cold freshwater habitat, migration of aquatic organisms, spawning habitat, and wildlife habitat.

Because most Water Quality Objectives provided in the Basin Plan are narrative, to assess the consistency of analytical data with these beneficial uses, the Districts selected numeric standards, criteria, or benchmarks correlated with each beneficial use to compare to this study's results. Provided in Table 4.3-1, selected values were primarily taken from the California Toxics Rule (CTR) (EPA 2000) and the Basin Plan itself (CVRWQCB 1998), which incorporates Title 22 drinking water standards. When a study parameter did not have a corresponding value in one of these preferred sources, values were taken from *A Compilation of Water Quality Goals* (Marshack 2008), *Water Quality Standards for Recreational Waters* (EPA 2003, another compilation with multiple regional sources), and others as cited.

Table 4.3-1. Benchmark values suggested for evaluating the protection of designated beneficial uses of Project waters.[1]

Basin Plan Water Quality Objective (Potentially Affected Beneficial Uses)	Symbol or Abbreviation	Benchmark Values	Reference	Notes
Bacteria (MUN, REC-1)				
Total coliform	--	< 10,000 MPN per 100 mL < 240 MPN per 100 mL (geometric mean);	EPA 2003	Water contact recreation, single-day sample; Water contact recreation, 30-day geometric mean
Fecal coliform	--	< 200 MPN per 100 mL (geometric mean); < 10% of samples > 400 MPN per 100 mL	CVRWQCB 1998	Water contact recreation, 30-day geometric mean; with individual samples not > 400 MPN/100 mL
Escherichia coli	E. coli	<126 MPN per 100 mL (geometric mean) <235 MPN per 100 mL in any single sample	EPA 2003	Water contact recreation, 30-day geometric mean
Biostimulatory Substances (COLD, SPAWN)				
Total Kjeldahl Nitrogen	TKN	None	--	--
Total Phosphorous	TP	None	--	--
Chemical Constituents (AGR, COLD, MUN)				
Alkalinity	--	20 mg/L (minimum)	Marshack 2008	EPA AWQC; low alkalinity can affect water treatment

Basin Plan Water Quality Objective (Potentially Affected Beneficial Uses)	Symbol or Abbreviation	Benchmark Values	Reference	Notes
Arsenic	As	0.010 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Cadmium	Cd	5 µ/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Calcium	Ca	None	--	--
Chloride	Cl	250 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Chromium (total)	Cr (total)	50 µg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Copper	Cu	1 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Lead	Pb	15 µg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Mercury (inorganic)	Hg	0.002 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Nickel	Ni	0.1 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Nitrate	NO_3	45 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Nitrite	NO_2	1 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Nitrate + Nitrite	$NO_3 + NO_2$	10 mg/L (combined total)	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Potassium	K	None	--	--
Selenium	Se	0.05 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL[2]
Sodium	Na	20 mg/L	Marshack 2008	Sodium Restricted Diet[3]
Specific conductance	--	150 µmhos	CVRWQCB 1998	Aquatic Life Protection
Zinc	Zn	5 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Dissolved Oxygen (COLD, SPAWN)				
Dissolved Oxygen	DO	7.0 mg/L (minimum)	CVRWQCB 1998	Aquatic life protection
Floating Material (REC-1, REC-2)				
Floating Material	--	Narrative Criteria	CVRWQCB 1998	Aesthetics - Absent by visual observation

Basin Plan Water Quality Objective (Potentially Affected Beneficial Uses)	Symbol or Abbreviation	Benchmark Values	Reference	Notes
Oil and Grease (REC-1, REC-2)				
Oil & Grease	--	Narrative Criteria	CVRWQCB 1998	Aesthetics - Absent by visual observation
Total Petroleum Hydrocarbons	TPH	None	--	--
pH (COLD, SPAWN, WILD)				
pH	--	6.5-8.5	CVRWQCB 1998	Aquatic life protection
Sediment and Settleable Solids (REC-2, SPAWN, WILD)				
Sediment	--	Narrative Criteria	CVRWQCB 1998	
Tastes and Odors (MUN)				
Aluminum	Al	0.2 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Chloride	Cl	250 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Copper	Cu	1.3 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Iron	Fe	0.3 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Silver	Ag	0.1 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Specific Conductance	--	900 umhos	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Sulfate	SO_4	250 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Total Dissolved Solids	TDS	500 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Zinc	Zn	5 mg/L	CDPH 2010 cited in CVRWQCB 1998	Title 22 Secondary MCL[2]
Toxicity (COLD, SPAWN, MUN) ***CTR values listed below generally assume Total Recoverable Concentrations (unfiltered)***[4,5]				
Ammonia as N (pH and Temp dependent)	NH_3-N	24.1 mg/L (CMC); 4.1-5.9 mg/L (CCC)	EPA 2000	CTR criteria over 0-20°C assuming pH 7.0
		5.6 mg/L (CMC); 1.7-2.4 mg/L (CCC)	EPA 2000	CTR criteria over 0-20°C assuming pH 8.0
		0.9 mg/L (CMC); 0.3-0.5 mg/L (CCC)	EPA 2000	CTR criteria over 0-20°C assuming pH 9.0
Arsenic	As	0.34 mg/L (CMC); 0.15 mg/L (CCC)	EPA 2000	CTR criteria

Basin Plan Water Quality Objective (Potentially Affected Beneficial Uses)	Symbol or Abbreviation	Benchmark Values	Reference	Notes
Cadmium (hardness dependent)	Cd	0.23 µg/L (CMC); 0.15 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 5 mg/L as $CaCO_3$
		0.4 µg/L (CMC); 0.34 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		0.56 µg/L (CMC); 0.53 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 15 mg/L as $CaCO_3$
		0.83 µg/L (CMC); 0.95 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Copper (hardness dependent)	Cu	0.83 µg/L (CMC); 0.72 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 5 mg/L as $CaCO_3$
		1.6 µg/L (CMC); 1.3 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		2.34 µg/L (CMC); 1.84 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 15 mg/L as $CaCO_3$
		3.79 µg/L (CMC); 2.85 µg/L (CCC)	EPA 2000	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Lead (hardness dependent)	Pb	0.54 µg/L (CCC) 14 µg/L (CMC)	EPA 2000	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Mercury	Hg	0.050 µg/L	EPA 2000 40 CFR 131.38	CTR/Federal Register 5/18/00
Nitrate-Nitrite	NO_3-N+NO_2-N	10 mg/L (combined total)	CDPH 2010 cited in CVRWQCB 1998	Title 22 Primary MCL (“Blue baby Syndrome”)

Basin Plan Water Quality Objective (Potentially Affected Beneficial Uses)	Symbol or Abbreviation	Benchmark Values	Reference	Notes
Silver (hardness dependent)	Ag	0.02 µg/L (CMC) instantaneous	EPA 2000	CTR for unfiltered sample assuming hardness of 5 mg/L as $CaCO_3$
		0.08 µg/L (CMC) instantaneous	EPA 2000	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		0.16 µg/L (CMC) instantaneous	EPA 2000	CTR for unfiltered sample assuming hardness of 15 mg/L as $CaCO_3$
		0.37 µg/L (CMC) instantaneous	EPA 2000	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Zinc (hardness dependent)	Zn	9.47 µg/L	EPA 2000	CTR for unfiltered sample assuming hardness of 5 mg/L as $CaCO_3$
		17.03 µg/L	EPA 2000	CTR for unfiltered sample assuming hardness of 10 mg/L as $CaCO_3$
		24.01 µg/L	EPA 2000	CTR for unfiltered sample assuming hardness of 15 mg/L as $CaCO_3$
		37.02 µg/L	EPA 2000	CTR for unfiltered sample assuming hardness of 25 mg/L as $CaCO_3$
Aldrin	--	3.0 µg/L	Marshack 2008	AWQC
Chlordane	--	0.0043 µg/L	Marshack 2008	AWQC
Chlorpyrifos	--	0.014 µg/L	Marshack 2008	AWQC
Diazinon	--	0.05 µg/L[5]	Marshack 2008	AWQC
Dieldrin	--	0.056 µg/L	Marshack 2008	AWQC
Endosulfan	--	0.056 µg/L	Marshack 2008	AWQC
Endrin	--	0.036 µg/L	Marshack 2008	AWQC
Heptachlor	--	0.0038 µg/L	Marshack 2008	AWQC
Heptachlor epoxide	--	0.0038 µg/L	Marshack 2008	AWQC
alpha-Hexachlorocyclohexane	--	0.08 µg/L	Marshack 2008	AWQC
beta-Hexachlorocyclohexane	--	0.08 µg/L[6]	Marshack 2008	AWQC
delta-Hexachlorocyclohexane	--	0.08 µg/L[6]	Marshack 2008	AWQC
gamma-Hexachlorocyclohexane	--	0.08 µg/L	Marshack 2008	AWQC
Toxaphene	--	0.0002 µg/L	Marshack 2008	AWQC

Basin Plan Water Quality Objective (Potentially Affected Beneficial Uses)	Symbol or Abbreviation	Benchmark Values	Reference	Notes
Turbidity (COLD, SPAWN, WILD, MUN)				
Turbidity	NTU	increase < 1 NTU for 1-5 NTU background; increase < 20% for 5-50 NTU background	CVRWQCB 1998	Aesthetics, disinfection, egg incubation

[1] Note a chemical may be listed under more than one beneficial use.
[2] CDPH Title 22 identified as minimum water quality thresholds, but acknowledged as insufficiently protective in some cases (CVRWQCB 1998).
[3] Guidance level to protect those individuals restricted to a total sodium intake of 500 mg/day (Marshack 2008).
[4] CMC: Criterion Maximum Concentration (one-hour acute exposure) for aquatic toxicity as defined by EPA (2000).
[5] CCC: Criterion Continuous Concentration (four-day chronic exposure) for aquatic toxicity as defined by EPA (2000).
[6] Value is for gama-hexachlorocyclohexane.

Key:
AGR = agricultural supply
AWQC = Ambient Water Quality Criteria
EPA = Environmental Protection Agency
$CaCO_3$ = Calcium carbonate
CMC = Criterion Maximum Concentration (1-hour acute exposure) for aquatic toxicity as defined by EPA (2000)
CCC = Criterion Continuous Concentration (4-day chronic exposure) for aquatic toxicity as defined by EPA (2000)
COLD = cold freshwater habitat
CTR = California Toxics Rule
MCL = Maximum Contaminant Level
MUN = municipal and domestic supply
REC-1 = water contact recreation
REC-2 = water non-contact recreation
µmhos = micromhos
µg/L = micrograms per liter
mg/L = milligrams per liter
MPN = Most Probable Number
NTU = Nephelometric turbidity units
SM = Standard Method
SPAWN = spawning, reproduction and/or early development
WILD = wildlife habitat

The CVRWQCB has adopted, by reference, California Title 22 maximum contaminant levels (MCL) for drinking water as Basin Plan objectives (CVRWQCB 1998), with the exception that more stringent criteria may apply as necessary for protection of specific beneficial uses. Hence, these values are adopted herein. It should be noted, however, that chemical concentrations that were originally intended to apply to finished tap water, rather than to untreated sources of drinking water, would be applied to the untreated reservoir or river water.

For water quality objectives related to aquatic toxicity,[6] the CTR (EPA 2000) will be evaluated. Section 131.38 of 40 California Code of Regulations (CCR) establishes Criterion Maximum Concentrations (CMC) as the highest concentration to which aquatic life can be exposed for a short period without deleterious effects and must be based on extended sample collection and one-hour averaging. The Criterion Continuous Concentration (CCC) is defined as the highest concentration to which aquatic life can be exposed for an extended period of time (i.e., four days) without deleterious effects. When single grab samples are collected, it is assumed that constituent concentrations are representative of the continuous ambient condition, and CCC

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[6] Ammonia, nitrate, and trace metals.

values are therefore used as the appropriate criteria to compare against environmental samples. Because of differences in acute and chronic toxicity to aquatic organisms of many elements and compounds in Table 4.3-1 as well as variations with ambient water quality such as pH or hardness, several entries have multiple benchmarks to assist with their evaluation. The benchmarks for five of the metals addressed in this study plan (i.e., cadmium, copper, lead, silver and zinc) are reported for unfiltered (i.e., total metals) samples from the CTR (EPA 2000), and calculated in 5 mg/L increments of hardness since the level at which each of these metals is reportedly toxic to aquatic life is lower at lower hardness levels. In addition, the CMC and CCC levels for ammonia are a function of both pH and temperature and are presented over a range of 0 to 20°C in pH increments of 1 standard unit (su).

5.0 RESULTS

Study results are provided below by Water Quality Study Element and Recreation Water Quality Study Element. Analytical results are provided in their entirety, by reservoir and stream reach, in Attachment C.

5.1 Data Representativeness, Accuracy and Completeness

The QAPP specifies representativeness, completeness, and accuracy objectives for analytical data acquisition (Attachment A, Part 1). Representativeness was ensured via the location of sample sites as well as the season. Representative locations and measurement intervals were specified in the FERC-approved Study Plan and described above in Section 4.1 for the Water Quality Study Element and Section 4.2 for the Recreation Water Quality Study Element. The sampling design ensured representativeness of the data.

Accuracy for field and laboratory measurements is defined as the degree of conformity of a measured/calculated quantity to its actual (true) value. The accuracy objective provided in the QAPP for the study was 90 percent (Attachment A, Part 1). Calibration records for the field instruments are provided in Attachment B and show that field instruments were within acceptable limits. Though field filters and the vast majority of other sampling equipment were not shared between sites, rinsate and field blank data indicate that at the low detection and reporting limits used, some trace metals concentrations may have been introduced by the filters used for in-field filtration, field handling, or laboratory handling[7] (Attachment B). Data were not modified to reflect this observation; however, results were used to qualify the discussion in Section 6.0. For the laboratory data, quality assurance samples (method blanks, laboratory control samples, method spikes, and others) were analyzed as appropriate for each method. All quality control analyses were within acceptable limits for the laboratory data; some data are flagged, however, to account for concentrations found below reporting limits, but above detection limits, or when method blanks had detected concentrations. All verified chemical detections, including data whose results are “J” qualified,[8] were used in this assessment.

The completeness objective provided in the QAPP for the study was 90 percent (Attachment A, Part 1), and is defined as the number of valid measurements divided by the number of measurements collected. Though one non-conformance resulted in data loss—turbidity was not measured downstream of La Grange Dam-- the completeness objective for water quality sampling was met: valid results were obtained for > 99 percent of the data collection effort.

5.2 Water Quality Element

Analytical results and comparisons to their associated standards, criteria, and/ or benchmarks are provided in Attachment C and summarized below in Table 5.2-1. The summary consists of the parameter’s frequency of detection, range of results (minimum, maximum) and average value by

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[7] Filtering was performed in the field and not in the laboratory to address preservation and holding time concerns when sampling sites are remote from shipping sites.

[8] Results with a “J” qualifier are results where the chemical was detected, but there is uncertainty in the quantity. The quantity is above the method detection limit, but below the reporting limit.

season. The standard, criterion, or benchmark used for the comparison (from Table 4.3-1) and the location(s) of any value above or below the standard, criterion, or benchmark (as defined) were excerpted from Attachment C and are provided in the summary tables, as well. For completeness, analytes that were not detected in any sample are also listed in Table 5.2-1.

Results that exceeded the standards, criteria, or benchmarks of Table 4.3-1 are discussed in section 6.0.

Table 5.2-1. Summer 2012 summary of water quality element results.[1]

Analyte	Units	Detection Frequency[2,3]	Concentration Range			Standard, Criterion, or Benchmark[4]	Location(s) of Benchmark Exceedance(s)
			min	max	average		
In Situ Measurements							
Temperature	°C	7/7	9.67	27.13	17.00	--	--
Specific Conductance	μSiemans/cm	7/7	20	44	33.7	150	None
pH	stnd units	7/7	**6.40**	7.95	6.94	6.5-8.5	6.40 – Tuolumne River above Don Pedro 6.47 – Mid-reservoir (Bottom) 6.42 – Near Don Pedro Dam (Bottom)
Dissolved Oxygen	mg/L	7/7	**3.15**	12.6	7.85	7 (minimum)	3.2 – Mid-reservoir (Bottom) 4.8 – Near Don Pedro Dam (Bottom)
Turbidity	NTU	2/6	0	282	49	--	--
Basic Water Quality, Inorganic ions and Nutrients							
Alkalinity, Total (as $CaCO_3$)	mg/L	8/8	**3.5**	**15.5**	12.2	20 (minimum)	All results—upstream, downstream and within Don Pedro Reservoir
Ammonia (as N)	mg/L	0/8	0.10 ND	0.10 ND	0.10 ND	Temp & pH Dep't[6]	None
Calcium	mg/L	8/8	2.12	3.95	2.98	--	--
Carbon, Dissolved Organic	mg/L	8/8	3.1B	4.7	3.8	--	--
Carbon, Total Organic	mg/L	8/8	2.6B	4.6	3.5	--	--
Chloride	mg/L	8/8	0.58 J	0.83 J	0.70 J	230	None
Hardness, Total	mg/L	8/8	6	15	11.5	--	--
Magnesium	mg/L	8/8	0.443	1.55	1.26	--	--
Nitrate (as N)	mg/L	5/8	0.037 J	0.11	0.08	10	None
Nitrite (as N)	mg/L	0/8	0.10 ND	0.10 ND	0.10 ND	1	None
o-Phosphate (as P)	mg/L	1/8	0.051 J	0.10 ND	0.09	--	--
Phosphorus, Total	mg/L	6/8	0.025 J	0.10 ND	0.06	--	--
Potassium	mg/L	8/8	0.534	0.69	0.60	--	--
Sodium	mg/L	8/8	1.2	2.3	1.9	20	None
Solids, Total Dissolved	mg/L	8/8	20	47	29	500	None
Solids, Total Suspended	mg/L	4/8	0.10 ND	16.00	2.98	--	--
Total Kjeldahl Nitrogen	mg/L	8/8	0.50 ND	0.50 ND	0.50 ND	--	--

Analyte	Units	Detection Frequency[2,3]	Concentration Range			Standard, Criterion, or Benchmark[4]	Location(s) of Benchmark Exceedance(s)
			min	max	average		
Herbicides and Pesticides							
Aldrin	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	3.0	None
Alpha-BHC	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.08	None
Beta-BHC	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.08	None
Chlordane	µg/L	0/8	0.025 ND	0.025 ND	0.025 ND	0.0043	None[8]
Chlorpyrifos	µg/L	0/8	0.005 ND	0.010 ND	0.006 ND	0.014	None
Delta-BHC	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.08	None
Diazinon	µg/L	0/8	0.005 ND	0.010 ND	0.006 ND	0.05	None
Dieldrin	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.056	None
Endosulfan I	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.056	None
Endosulfan II	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.056	None
Endrin	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.036	None
Gamma-BHC	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.08	None
Heptachlor	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.0038	None
Heptachlor Epoxide	µg/L	0/8	0.010 ND	0.010 ND	0.010 ND	0.0038	None
Toxaphene	µg/L	0/8	0.12 ND	0.12 ND	0.12 ND	0.0002	None[8]
Metals (Total)							
Arsenic	µg/L	8/8	0.25	0.33	0.29	10	None
Cadmium	µg/L	8/8	0.003 J	0.006 J	0.004 J	5	None
Copper	µg/L	8/8	0.48	1.18	0.71	1000	None
Iron	µg/L	8/8	18	**314**	72.50	300	314 – Tuolumne River above Don Pedro
Lead	µg/L	8/8	0.005 J	0.142 J	0.02 J	15	None
Mercury	ng/L	8/8	0.08 J	4.57	1.43	50	None
Methyl Mercury	ng/L	3/8	0.029 J	0.053	0.05 ND	--	--
Selenium	µg/L	0/8	0.6	0.60	0.60	50	None
Silver	µg/L	4/8	0.002 J	0.02 ND	0.01 J	100	None
Zinc	µg/L	8/8	0.14 J	6.35	1.07	5000	None
Metals (Dissolved)							
Arsenic	µg/L	8/8	0.23	0.34	0.28	--	--
Cadmium	µg/L	3/8	0.003 J	0.020 ND	0.01 J	Hardness Dep't[6]	None

Analyte	Units	Detection Frequency[2,3]	Concentration Range			Standard, Criterion, or Benchmark[4]	Location(s) of Benchmark Exceedance(s)
			min	max	average		
Copper	µg/L	8/8	0.4	**8.16**	2.25	Hardness Dep't[6]	6.25 – Mid-reservoir (Bottom) 8.16 – Near Don Pedro Dam (Bottom)
Iron	µg/L	8/8	1 J	96	18	--	--
Lead	µg/L	5/8	0.008 J	0.04 ND	0.02 J	Hardness Dep't[6]	None
Methyl Mercury	ng/L	2/8	0.05 ND	0.35	0.12	--	--
Silver	µg/L	0/8	0.02 ND	0.02 ND	0.02 ND	Hardness Dep't[6]	None
Zinc	µg/L	8/8	0.18 J	0.90	0.46	Hardness Dep't[6]	None

[1] All data are provided in Attachment C.
[2] Five locations were sampled. Two locations were sampled at two depths.
[3] For duplicate sample results, the highest concentration of the two samples was used for benchmark comparisons. A duplicate sample was collected downstream of Don Pedro Dam.
[4] The most protective standard, criterion, or benchmark of those given in Table 4.3-1 was used for this analysis. With few exceptions, aquatic life protective benchmarks were the most protective number.
[5] Minimum concentration except where natural concentrations are less (Marshack 2008).
[6] See Attachment C for sample specific criteria. Ammonia criteria are temperature and pH dependent. Metals Criteria are hardness dependent for cadmium, copper, lead, silver, and zinc.
[7] The gamma-BHC benchmark was selected as the alpha-, beta-BHC, and delta-BHC benchmarks.
[8] Benchmark is below the method detection limit for this analyte.

Key:
B = Analyte was present in the associated method blank
J = Analyte was detected at a concentration below the reporting limit and above the laboratory method detection limit. Reported value is estimated.
ND = Analyte was not detected at the reporting limit.

µg/L	micrograms per Liter
mg/L	milligrams per Liter
ng/L	nanograms per liter
<	less than the reporting limit for this analysis
--	not available or not applicable

5.3 Recreation Element

Bacteria samples were collected in surface water adjacent to 12 recreation sites five times within 30 days, including one day of the Independence Day holiday weekend (See Figure 3.0-1). The geometric mean was then calculated from the five results to allow comparison with the Water Quality Objective (fecal coliform) or benchmark (total coliform, e coli). TPH samples and visual observations for oil and grease were also recorded. Results of these comparisons are shown in Table 5.3-1.

Table 5.3-1. 2012 Independence Day bacteria sampling results and oil and grease observations.[1,2]

Sample Date	Sample Location											
	Fleming Meadows					Blue Oaks			Moccasin Point			
	Marina	Houseboat Marina	Boat Launch	Main camp loop	Small Camp loop	Boat Launch	Picnic Area	Camp Loop	Boat Launch	Marina	Main camp loop	Picnic Area
TOTAL COLIFORM < 240 MPN per 100 mL (geometric mean)												
6/14/12	230	220	23	79	3500	2800	220	940	7.8	2	17	33
	--	--	--	--	--	1300	--	--	--	10	--	--
7/2/12	22	7.8	7.8	2	7.8	14	4.5	7.8	23	33	2	7.8
	--	--	--	--	--	170	--	--	4.5	--	--	--
7/4/12	49	13	46	17	33	< 1.8	< 1.8	< 1.8	11	33	4.5	13
	7.8	--	--	--	--	--	--	--	--	--	4.5	--
7/7/12	70	49	26	17	130	7.8	11	23	14	23	4.5	13
	--	--	--	9.3	--	--	--	--	--	34	--	--
7/18/12	4.5	23	4	7.8	49	33	2	4.5	4.5	2	11	< 1.8
	--	--	6.8	--	--	--	2	--	--	--	--	--
Geometric Mean[1]	29	30	13	12	89	63	7	17	9	12	6	10
FECAL COLIFORM < 200 MPN per 100 mL (geometric mean)												
6/14/12	1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	4.5	2	6.8	6.8
	--	--	--	--	--	< 1.8	--	--	--	< 1.8	--	--
7/2/12	< 1.8	2	< 1.8	< 1.8	< 1.8	4.5	< 1.8	< 1.8	< 1.8	2	2	< 1.8
	--	--	--	--	--	170	--	--	< 1.8	--	--	--
7/4/12	< 1.8	2	4.5	4.5	7.8	< 1.8	< 1.8	< 1.8	11	4.5	2	7.8
	2	--	--	--	--	--	--	--	--	--	2	--
7/7/12	11	49	14	11	79	< 1.8	4	4.5	14	4.5	2	7.8
	--	--	--	4.5	--	--	--	--	--	15	--	--
7/18/12	4	< 1.8	4	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	2	< 1.8	4	< 1.8
	--	--	6.8	--	--	--	< 1.8	--	--	--	--	--
Geometric Mean[1]	2.8	3.6	4.2	3.3	5.1	3.9	2.1	2.2	4.1	3.3	2.8	4.2

Sample Date	**Sample Location**											
	Fleming Meadows					**Blue Oaks**			**Moccasin Point**			
	Marina	**Houseboat Marina**	**Boat Launch**	**Main camp loop**	**Small Camp loop**	**Boat Launch**	**Picnic Area**	**Camp Loop**	**Boat Launch**	**Marina**	**Main camp loop**	**Picnic Area**
ESCHERICHIA COLI ***< 126 MPN per 100 mL (geometric mean)***												
6/14/12	1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	4.5	< 1.8
	--	--	--	--	--	< 1.8	--	--	--	< 1.8	--	--
7/2/12	< 1.8	2	< 1.8	< 1.8	< 1.8	4.5	< 1.8	< 1.8	< 1.8	2	2	< 1.8
	--	--	--	--	--	170	--	--	< 1.8	--	--	--
7/4/12	< 1.8	< 1.8	2	4.5	< 1.8	< 1.8	< 1.8	< 1.8	2	1.8	< 1.8	< 1.8
	< 1.8	--	--	--	--	--	--	--	--	--	< 1.8	--
7/7/12	2	< 1.8	< 1.8	< 1.8	2	< 1.8	< 1.8	2	< 1.8	< 1.8	< 1.8	< 1.8
	--	--	--	< 1.8	--	--	--	--	--	< 1.8	--	--
7/18/12	< 1.8	< 1.8	4	< 1.8	< 1.8	< 1.8	< 1.8	< 1.8	2	< 1.8	4	< 1.8
	--	--	< 1.8	--	--	--	< 1.8	--	--	--	--	--
Geometric Mean[1]	1.8	1.8	2.1	2.1	1.8	3.9	1.8	1.8	1.9	1.8	2.4	1.8
OIL AND GREASE ***Aesthetics – Present or absent by visual observation***												
6/14/12	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
7/2/12	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
7/4/12	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
7/7/12	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
7/18/12	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Total Petroleum Hydrocarbons (µ/L) ***Reporting Limit = 50 µ/L (micrograms per Liter)***												
7/4/12	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50

[1] Geometric mean values in bold were greater than the water quality objective or benchmark.

[2] Duplicate sample results are provided below original sample results.

Key:
-- = No count performed for this location and time
MPN – Most Probable Number.

6.0 DISCUSSION AND FINDINGS

When developing the Pre-Application Document, the Districts found that limited analyses had been performed on water samples collected in the Project Area, but those existing data indicated that surface water is of low specific conductivity and hardness, prone to acidification, and with limited potential sources of local contamination. This study confirms those results. Water quality in the Project Area is very good, i.e., most analytes were reported from non-detectable to just above reporting limit concentrations. Further, there does not appear to be a pattern of increasing chemical concentrations from upstream to downstream of Don Pedro Dam.

Beneficial uses of surface water in the vicinity of the Project are designated by the CVRWQCB and listed in the Basin Plan (CVRWQCB 1998). The designated beneficial uses for the Project Area were introduced above Section 4.3 and consist of municipal and domestic supply; agricultural supply; hydropower generation; water contact recreation; water non-contact recreation; cold freshwater habitat; warm freshwater habitat; migration of aquatic organisms; spawning; reproduction and/or early development; and wildlife habitat.

To assess the consistency of analytical data with these beneficial uses, the Basin Plan's Water Quality Objectives were compared to the results of the study. Basin Plan Water Quality Objectives and beneficial uses were linked to each other above in Table 4.3-1 where, for situations where the Basin Plan does not provide a numeric Water Quality Objective, a pertinent regulatory standard, criteria or benchmark was selected for this evaluation. Results of these comparisons are provided in Attachment C, summarized in Section 5, and discussed below.

6.1 Biostimulatory Substances

The Basin Plan requires that water shall not contain biostimulatory substances which promote aquatic growth in concentrations that cause nuisance or adversely affect designated beneficial uses.

In August 2012, nitrate concentrations ranged between 0.037 mg/L (estimated) and 0.11 mg/L, while nitrite concentrations and Total Kjeldahl Nitrogen were not detectable. Total phosphorous levels were similarly low, ranging between 0.025 mg/L (estimated) and the reporting limit of 0.10 mg/L. Orthophosphate concentrations were only detected in one sample at 0.051 mg/L (estimated). These low nutrient levels suggest that biostimulatory substances are not currently present in sufficient quantities to cause nuisance conditions related to algal blooms or decreased water clarity. The Districts are unaware of any instances where algal bloom or decreased water clarity has been reported as a nuisance.

6.2 Chemical Constituents

The Basin Plan requires that water shall not contain chemical constituents in concentrations that adversely affect designated beneficial uses. The Basin Plan requires that water designated for use as domestic or municipal supply shall not contain concentrations of chemical constituents in excess of the MCLs specified in the provisions of Title 22 of the CCR (CDPH 2010).

MCLs are intended to be applied to finished tap water, but were applied to untreated water in this study. Samples collected in August 2012 had concentrations less than the primary MCLs for all analytes; water quality was found to be consistent with drinking water standards (See Attachment C). Analytes with secondary MCLs for tastes and odors are addressed below under "Taste & Odor." Aquatic toxicity is discussed below under "Toxicity."

6.3 Color

The Basin Plan includes a narrative Water Quality Objective regarding color.

The FERC-approved study did not require sampling for color. The Districts are unaware of any instances where the color of the water in the vicinity of the Project has been reported as a nuisance or has adversely affected designated beneficial uses.

6.4 pH

The Basin Plan requires that pH shall not be depressed below 6.5 nor raised above 8.5.

During August 2012 sampling, three locations had a pH value outside of these limits: the inflow sample of the Tuolumne River above Don Pedro Reservoir (6.40 su), the mid-reservoir hypolimnion of Don Pedro Reservoir (6.47 su), and the near-dam hypolimnion of Don Pedro Reservoir (6.43 su). Not unexpected for a low nutrient snow-melt derived reservoir, these values are within the sonde's measurement error of ± 0.1 mg/L and are considered consistent with the objective.

6.5 Pesticides

The Basin Plan includes extensive discussions related to Water Quality Objectives for pesticides. Significant pesticide use does not occur within the study area, or in association with Project O&M activities. Further, the Districts are unaware of any instances where pesticide use in the vicinity of the Project has been reported to cause a nuisance or adversely affect designated beneficial uses.

Downstream of the Project, the section of the Tuolumne River from Don Pedro Reservoir to the San Joaquin River is included in the State of California's CWA § 303(d) list regarding the non-point discharge of some agricultural pesticides (SWRCB 2010). Agricultural chemicals on the 303(d) list are chlorpyrifos, diazinon, and the Group A Pesticides—aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexanes (including lindane), endosulfan, and toxaphene.

Pesticides on the 303(d) list for the lower Tuolumne River were not detected in any of the August 2012 samples analyzed at the commercially available reporting limits. However, because the detection limits for chlordane and toxaphene exceeded the reporting limits for those analytes (See Attachment C), consistency with benchmarks could not be determined. However, as stated above, since significant pesticide use does not occur in association with the Project, these non-detects are considered applicable—chlordane and toxaphene are not present in Project waters.

6.6 Sediment and Settleable Solids

The Basin Plan requires that suspended sediment load and suspended sediment discharge to surface waters shall not alter surface waters in such a manner as to cause a nuisance or adversely affect beneficial uses of Project or other water.

Total dissolved solids and total suspended solids were low in August 2012 (10 to 38 mg/L and 1.0 to 3.1 mg/L, respectively). The Districts are unaware of any sediment discharges to surface water related to the Project. Additionally, the Districts are unaware of any circumstances that suspended sediment levels or discharges of such cause a nuisance or adversely affect any designated beneficial uses of Project or other water.

6.7 Tastes and Odor

The Basin Plan requires that waters shall not contain taste- or odor-producing substances in concentrations that impart undesirable tastes or odors to domestic or municipal water supplies or to fish flesh or other edible products of aquatic origin, or that cause nuisance, or otherwise adversely affect beneficial uses of Project or other water.

During the 2012 sampling, iron was measured at a level less than its secondary MCL of 0.3 mg/L for taste and odors at all locations, but one. Above Don Pedro, the inflow sample had an iron concentration of 3.14 mg/L. Secondary MCLs are routinely applied at the point of use (i.e., “at the tap”) and existing water treatment methods appear to be adequate to meet these secondary water quality criteria. The Districts are unaware of any reports that taste or odor of water or fish caught in Don Pedro Reservoir cause a nuisance or otherwise adversely affect designated beneficial uses of Project or other water.

6.8 Toxicity

The Basin Plan requires that waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life.

The FERC-approved study states that study water quality data would be compared to the aquatic life protective benchmarks from the EPA (2000) *California Toxics Rule (CTR)* or benchmarks excerpted from Marshack (2008) *A Compilation of Water Quality Goals*. The low levels of hardness found throughout the study area are expected to increase the aquatic toxicity of some metals due to the greater proportion of free ions found in many trace metals. At the low hardness levels found in the study (i.e., 6 to 15 mg/L), sample specific dissolved cadmium, copper, lead, silver, and zinc CTR criteria were calculated (see Attachment C, Table C.2**)**. Of these five metals, only copper exhibited a concentration greater than its sample specific CTR—and only in two samples. The mid-reservoir hypolimnion of Don Pedro Reservoir had copper (dissolved) concentration of 6.25 micrograms per liter (µg/L), as compared to a CTR guideline of 1.8 µg/L, and the near-dam hypolimnion of Don Pedro Reservoir had copper (dissolved) concentration of 8.16 µg/L, as compared to a CTR guideline of 1.8 µg/L.

The Districts are unaware of any Project O&M activity that may affect levels of copper. As reported in the PAD, algaecides are not used to manage algae in project waters.

6.8.1 Mercury and Methylmercury

Downstream of the Project, the section of the Tuolumne River included in the State of California's CWA Section 303(d) list regarding the non-point discharge of pollutants/stressors is the section below the outlet of Don Pedro Reservoir to the San Joaquin River. The pollutant stressors identified in the 303(d) list are primarily related to agricultural use, but the list also includes mercury, a legacy contaminant of the gold mining era (SWRCB 2010). Mercury can affect the nervous system of higher trophic organisms and is bioaccumulated and transferred to higher trophic organisms through the food-web.

In August 2012, mercury was detected at all locations at concentrations that ranged between 0.08 J and 4.57 nanograms per Liter (ng/L). These total mercury concentrations were far less than the MCL of 0.002 mg/L (2,000 ng/L) indicating that drinking water beneficial use is being met everywhere in the Project area for mercury. In addition, the samples were below the CTR benchmark of 50 ng/L.

However, even in trace quantities, mercury is bioaccumulative in its methylated form; samples were also analyzed for methylmercury (total) and methylmercury (dissolved). Methylmercury (total) was detected in three of the eight samples. Samples that contained methylmercury were collected from the Tuolumne River inflow sample, above Don Pedro Reservoir (0.029 J ng/L), the mid-reservoir hypolimnion of Don Pedro Reservoir (0.042 J ng/L), and the near-dam hypolimnion of Don Pedro Reservoir (0.053 ng/L), while methylmercury (dissolved) was detected at higher concentrations in the mid-reservoir hypolimnion of Don Pedro Reservoir (0.293 ng/L), and the near-dam hypolimnion of Don Pedro Reservoir (0.394 ng/L). These data show that methylmercury is present; however the exact concentration is uncertain. The reported dissolved concentrations are greater than total concentrations and the laboratory cannot explain why, other than the results reflecting the difficulty of measuring methylmercury near its reporting limits.

These data are consistent with reports of water quality and fish tissue data collected by Stillwater Sciences between fall 2008 and spring 2009 in which water quality samples and higher trophic level fish species were collected from nines sites within Don Pedro Reservoir and upstream and downstream of the reservoir (TID/MID 2009). Like this study, methylmercury was not detected below either the Don Pedro or La Grange dams and methylmercury was detected in hypolimnetic samples in the Moccasin Creek arm (0.15 ng/L) and Woods Creek (0.145 ng/L) arm of Don Pedro Reservoir. However, unlike this study, no mercury was detected in water samples collected from the Tuolumne River upstream of Don Pedro Reservoir.

In addition, Stillwater Sciences (TID/MID 2009) found evidence of fish mercury bioaccumulation. Concentrations in excess of the EPA (2001) fish tissue residue criterion (0.3 mg/kg[9]) were found at all sites with Don Pedro Reservoir, as well as downstream of La Grange

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[9] Since 2001, the California Office of Environmental Health Hazard Assessment (OEHHA) has issued Advisory Tissue Levels (ATLs) that are lower than the EPA (2001) mercury criterion. ATLs are screening values developed by OEHHA to help public

Dam in the lower Tuolumne River, with the highest fish tissue mercury concentrations (0.29 to 0.99 milligrams/kilogram [mg/kg]) observed in largemouth bass sampled from the shallow Moccasin Creek and Woods Creek arms of Don Pedro Reservoir. OEHHA has not issued a fish ingestion advisory for Don Pedro Reservoir (OEHHA 2009).

The Districts are unaware of any Project O&M activity that may affect mercury methylation and do not propose any activities associated with the release or mobilization of mercury.

6.9 Turbidity

The Basin Plan requires that waters be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. This objective is expressed in terms of changes in turbidity (NTU) in the receiving water body: where natural turbidity is 0 to 5 NTUs, increases shall not exceed 1 NTU; where natural turbidity is 5 to 50 NTUs, increases shall not exceed 20 percent; where natural turbidity is 50 to 100 NTUs, increases shall not exceed 10 NTUs; and where natural turbidity is greater than 100 NTUs, increase shall not exceed 10 percent.

Spatial upstream-to-downstream turbidity trends are best seen in the data as it is presented in Attachment C, which provides sample results by location. In August 2012, turbidity was 8.6 NTU upstream of the Project (Tuolumne River above Don Pedro) and 0 NTU downstream of the Project (Below Don Pedro Dam). Three of the four intermediate locations also exhibited no turbidity. The Mid-reservoir (surface) sample had a turbidity reading of 283 NTU; review of temperature profiles indicated that this reading was near the thermocline, a location where plankton reportedly accumulate. Downstream of the La Grange Dam, turbidity data were not recorded when the sonde's probe did not properly record).

The Districts are unaware of any reports that turbidity causes a nuisance or adversely affects beneficial uses in the study area or immediately downstream of the Project.

6.10 Bacteria

The Basin Plan includes a Water Quality Objective (< 200 MPN per 100 mL) for fecal coliform in waters designated for contact recreation (Table 5.3-1), but does not provide a Water Quality Objective for total coliform or *Escherichia coli* (*E. coli*).

In 2012, all twelve recreation sites sampled had fecal coliform counts below the Water Quality Objective for the time surrounding and including Independence Day. Likewise, all total coliform counts and *E. coli* levels were below their respective benchmarks. *E. coli* counts are thought to be better indicators of human impacts (EPA 2003).

6.11 Floating Material

The Basin Plan includes a narrative Water Quality Objective regarding floating material that states water shall be free of floating material in amounts that cause nuisance or adversely affect

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health managers decide whether or not to ask OEHHA to evaluate the need for a fish ingestion advisory for water bodies under the manager's jurisdiction (Klasing and Brodberg 2008).

beneficial uses. The FERC-approved study did not include a provision for measuring floating material. The Districts are unaware of any instances where floating material in Project waters has been reported as a potential problem.

6.12 Oil and Grease

The Basin Plan requires that the water not contain oils, greases, waxes or other material in concentrations that cause nuisance, result in visible film or coating on the surface of the water or on objects in the water, or otherwise adversely affect beneficial uses. In 2012, the Districts looked for and did not observe any oil and grease in Don Pedro Reservoir. Samples collected adjacent to 12 recreation sites on and around the Independence Day holiday and analyzed for TPH. TPH was not detected at any of the sites.

6.13 Dissolved Oxygen

The general DO Water Quality Objective of 7.0 mg/L applies to the Tuolumne River and its tributaries (CVRWQCB 1998).

Synoptic measurements of DO in August 2012 samples were all above Basin Plan numerical limits except the mid-reservoir hypolimnion of Don Pedro Reservoir (3.2 mg/L), and the near-dam hypolimnion of Don Pedro Reservoir (4.8 mg/L). These results were expected, since large, deep reservoirs/lakes generally form strong thermoclines with oxygen poor hypolimnions in the late summer/fall period and Don Pedro Reservoir is no exception to this rule (See PAD Section 5.2.1.5, Water Temperature). DO values were above the Basin Plan Objective in all surface samples.

7.0 STUDY VARIANCES AND MODIFICATIONS

The study was conducted in conformance to the FERC-approved Water Quality Assessment Study Plan (W&AR-01), with one variance. The FERC-approved study required collection of single samples at nine sites. During the sampling period, two of the three sites upstream of Don Pedro, Woods Creek and Sullivan Creek (Figure 3.0-1), contained no flowing water. However, the Tuolumne River above Don Pedro sample was collected and reflected inflow water quality conditions.

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STUDY REPORT W&AR-01
WATER QUALITY ASSESSMENT

ATTACHMENT A

QUALITY ASSURANCE PROJECT PLAN

PART 1

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GROUP A ELEMENTS:
PROJECT MANAGEMENT

1.0 TITLE AND APPROVAL SHEET

This Quality Assurance Program Plan (QAPP) is to be used by HDR, Inc. when implementing Water Quality Assessment stud(ies) in support of the Federal Energy Regulatory Commission (FERC) approved Water Quality Assessment study developed to support the relicensing of Turlock Irrigation District's (TID) and Modesto Irrigation District's (MID) (collectively, the Districts), Don Pedro Project (Project), FERC Project No. 2299.

This document is a supporting document to:

- Study W&AR-01 Water Quality Assessment (TID and MID 2011)

Prepared by: ______________________________ ______________
(Name) (Date)

Approved by: ______________________________ ______________
(Name) (Date)

2.0 DISTRIBUTION LIST

This document will be distributed to the key personnel listed in Table 2.0-1 and will be provided as an attachment to relevant reports and upon request.

Table 2.0-1. Personnel Responsibilities.

Name	Affiliation	Title	Contact Information
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TBD	IEH JL Analytical Services	Laboratory Project Manager	217 Primo Way Modesto, CA 95358 Phone: (209) 538-8111

3.0 PROJECT/TASK ORGANIZATION

3.1 Involved Parties and Roles

This QAPP has been prepared for the Water Quality Assessment investigation component(s) of the Project's relicensing. Within this QAPP are descriptions of methods, procedures, and practices that will be used to assure and control the quality of chemical data.

Key personnel who will be involved in the project are listed above in Table 3.0-1. Under contract to the TID and MID, HDR will be responsible for all aspects of the Water Quality Assessment study(ies) including the organization of field staff, scheduling of sampling days, field quality assurance/quality control (QA/QC), coordination with the off-site laboratory, and reporting. Laboratory analytical services will be provided by a California certified laboratory.

The Study Lead is responsible for monitoring and verifying implementation of the QA/QC procedures found in this QAPP. Key personnel assigned to the project will have reviewed the QAPP and will be instructed by Study Lead regarding the requirements of the QA/QC program. The Study Lead will work directly with the Field Coordinator or other designee and Laboratory Project Managers to ensure that QAPP objectives are being met. All members of the team will continually assess the effectiveness of the QA/QC program and recommend modifications, as needed.

3.2 Quality Assurance Officer Role

The QA Officer is familiar with the study, but not involved in day-to-day implementation. The QA officer is versed in HDR policies, Water Quality Assessment field sampling, and laboratory procedures. The QA officer will review the study's intermediate and final products, and work with the Study Lead to ensure they are of high quality when complete.

3.3 Persons Responsible for QAPP Update and Maintenance

The Study Lead is responsible for keeping the QAPP up-to-date. Modifications may be instigated by any member of the study team—the Study Lead, the Field Coordinator, the QA Officer, the laboratory project manager, or others. Exceptions to the content of this document will be formalized in the table following the title page. New versions of the QAPP will be available to project personnel and attached to subsequent reports. Variances and non-conformances with the QAPP will be documented in applicable project reports.

3.4 Organizational Chart and Responsibilities

The organizational chart for implementation of the Water Quality Assessment investigation component of the Project relicensing is presented in Figure 3.4-1.

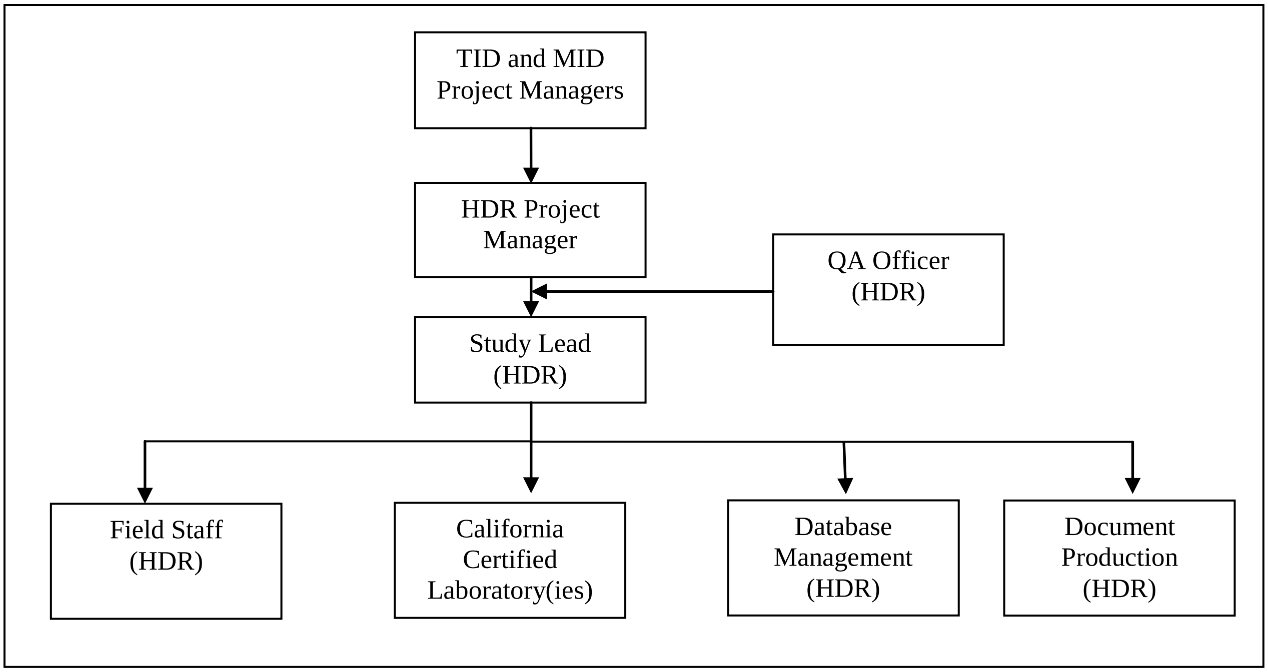

Figure 3.4-1. Organizational Chart

4.0 PROBLEM DEFINITION/BACKGROUND

4.1 Problem Statement

This QAPP has been developed to provide guidance and quality assurance for Water Quality Assessment sampling and analyses conducted to implement the FERC-approved Water Quality Assessment study plan(s) developed to support the Project's FERC relicensing.

4.2 Decisions or Outcomes

The collected data will provide one or more "snap-shots" of the physical and/or chemical state of surface water in the study area, defined in the study plan. The data will be filed with FERC in the Initial Study Report and in other relicensing documents, as needed, and will be suitable to compare to applicable regulatory standards and criteria. The data may be integrated with other information or data and used for trend analyses or for modeling. Additional information and detail can be found in the FERC-approved study plan(s).

4.3 Water Quality Assessment Regulatory Criteria

Water Quality Assessment objectives for Project reservoirs and Project affected stream reaches are established in Central Valley Regional Water Quality Assessment Control Board's (CVRWQCB) Water Quality Assessment Control Plan (Basin Plan) for the Sacramento and San Joaquin Rivers, the fourth edition of which was initially adopted in 1998 and most recently revised in 2011 (CVRWQCB 1998). The standards are composed of designated existing and potential beneficial uses and Water Quality Assessment objectives to protect the beneficial uses. Additional information and detail can be found in the FERC-approved study plan(s).

5.0 PROJECT/TASK DESCRIPTION

5.1 General Work Statement

Each FERC-approved study plan details the scope of the Water Quality Assessment investigation. Chemical constituents and characteristics of surface water will be measured both in the field and through collection of Water Quality Assessment samples for off-site analyses by a California certified laboratory. Examples of in situ water field measurements that may be performed include pH, specific conductivity, instantaneous water temperature, dissolved oxygen (DO), DO percent saturation, turbidity, and Secchi disk. Examples of analyses that may be performed on samples sent to an off-site California certified laboratory are trace metals, hardness, bacteria, sediment, nutrients, minerals, chlorophyll, pesticides, total petroleum hydrocarbons or other organics.

Refer to the “Group B Element: Data Generation and Acquisition” section of this QAPP for quality assurance practices associated with sample collection, instrument calibration, and so forth.

5.2 Project Schedule

The study schedule is specified in the FERC-approved study plan.

5.3 Geographical Setting

The Project is located in Tuolumne County, California, on the Tuolumne River, in the foothills of the Sierra Nevada.

5.4 Constraints

Water Quality Assessment sample collection will occur at elevations ranging from 44.4 to 2238.5 feet above sea level and may occur over a wide range of weather conditions (rain, snow, sun, wind, high heat, and cold weather). Stream flows may be high or low. Lake and reservoir sampling may require the use of a boat and occur at different stages of lake or reservoir surface elevation. Remote sites may require 4-wheel driving or long hikes carrying heavy bottles and equipment. Permission may need to be received from landowners prior to any work on private lands. Due to the distances covered, only five to nine locations may be visited in a single day and still meet the laboratory’s hours of operation or shipping deadlines.

Many of the watersheds where HDR works have extremely low naturally occurring levels of trace metals and waters are free or nearly free of contaminants. Hence, samples are highly susceptible to contamination during sampling and handling activities by both the field personnel and the analytical laboratory and the lowest possible method detection limits and reporting limits are required.

6.0 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

Data quality objectives (DQOs) are a set of performance or acceptance criteria that the collected data should achieve in order to minimize the possibility of either making a decision error or failing to keep uncertainty in estimates to within acceptable levels. DQOs are defined in terms of five parameters: precision, accuracy, representativeness, completeness, and comparability (PARCC) and differ with different measurement techniques.

DQOs for relicensing Water Quality Assessment studies are presented in Table 6.0-1.

Table 6.0-1. Data Quality Objectives, by Measurement Type and Sampling Event

Precision	Accuracy	Representativeness	Completeness	Comparability
FIELD MEASUREMENTS (e.g. pH, specific conductivity, temperature, dissolved oxygen)				
--	Instrument calibration meets manufacturers' requirements	Sample locations, sampling frequency and analytical methods follow study plan.	90%	Meets Target Reporting Limits provided in the study plan.
ANALYTICAL LABORATORY ANALYSES (e.g. metals, nutrients)				
Field duplicates within10%; Laboratory QA/QC meet method requirements.	Laboratory QA/QC meets method requirements.	Sample locations, sampling frequency and analytical methods follow study plan.	90%	Meets Target Reporting Limits provided in the study plan.
BACTERIA ANALYSES (e.g. fecal coliform, total coliform, e. coli)				
Field duplicates within 10%; Laboratory QA/QC meet method requirements.	Laboratory QA/QC meets method requirements.	Sample locations, sampling frequency and analytical methods follow study plan.	100%	Meets Target Reporting Limits provided in the study plan.

-- not applicable

Precision is a measure of the reproducibility of analyses under a given set of conditions. In other words, precision describes how well repeated measurements agree. Precision is typically evaluated by comparing analytical results from duplicate samples and calculating the relative percent difference (RPD), where RPD is defined as:

$$RPD = \left(\frac{|C_1 - C_2|}{\left(\frac{C_1 + C_2}{2} \right)} \right) \times 100$$

, where C_1 and C_2 are the analyte's concentrations in each duplicate

Precision will be determined through the use of field duplicates, laboratory matrix spike/matrix spike duplicates and laboratory duplicate quality control samples.

Accuracy is a measure of the bias that exists in a measurement system. In other words, accuracy describes how close an analytical measurement is to its "true" value. For analytical samples, accuracy is typically measured by analyzing a sample of known concentration (prepared using analytical-grade standards) and comparing the analytical result with the known concentration. For bacteria samples, accuracy is evaluated by comparing results to a laboratory reference sample.

Representativeness is the degree sampling data accurately and precisely depict selected characteristics. The representativeness of the data is mainly dependent on the sample design, such as locations (spatial), sampling frequency (temporal), and sample collection procedures, as well as analytical constituents and methods. The FERC-approved study plan presents the study design.

Completeness, which is expressed as a percentage, is calculated by subtracting the number of rejected and unreported results from the total planned results and dividing by the total number of planned results. Estimated results do not count against completeness because they are considered usable as long as any limitations are identified. Results rejected because of out-of-control analytical conditions, severe matrix effects, broken or spilled samples, or samples that could not be analyzed for any other reason are subtracted from the total planned number of results to calculate completeness. Though regulations currently do not require a specific percentage of data completeness, it is expected that the measurement techniques selected for use in this project are capable of generating data that is of 90% of more completeness for field and laboratory analyses.

Comparability is the degree of confidence with which one data set can be compared to another. A broad spectrum of analytical constituents has been selected to characterize Water Quality Assessment and the use of approved/documented analytical methods will ensure that analytical results adequately represent the true concentrations of constituents within these samples. In addition, Target Reporting Limits (TRLs) have been selected for each analyte, where appropriate, to ensure that the analytical methods used are of adequate sensitivity to generate useful data for the purposes of this project. Presented in the FERC-approved study plan, selection of appropriate TRLs was based on a review the CVWRCB's numeric and narrative Water Quality Assessment objectives and other regulatory standards, criteria and benchmarks, as well as the capabilities of commercial laboratories.

7.0 SPECIAL TRAINING NEEDS/CERTIFICATION

Proper training of field and laboratory personnel represents a critical aspect of quality control.

All field personnel that participate in Water Quality Assessment monitoring will have reviewed this QAPP. Field personnel will have also been trained in Water Quality Assessment sample collection (including QA/QC, grab sampling techniques, flow measurement techniques, completing laboratory chain-of-custody forms, ordering correct laboratory analyses, and proper handling of water samples), field analysis (including instrument calibration, data recording procedures, and interpretation of collected data), and GPS use. All samplers will be provided hands-on training in the “clean hands-dirty hands” technique by the QA Officer or his designee when trace metals are constituents of interest (See Section 11). The QA Officer or his designee will provide training to field personnel. Documentation of training will be will be maintained in the project file.

All laboratories utilized to perform analytical services will be certified by the State of California, The certification includes requirements that laboratory personnel will be certified and trained. Certification and training is documented in the laboratory’s quality assurance manual and verified during the State audit[1].

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[1] http://www.cdph.ca.gov/certlic/labs/Pages/default.aspx

8.0 DOCUMENTS AND RECORDS

8.1 Project Documents, Records, and Electronic Files

The documents and records that will be used or generated during this project include the following:

Study Plan. The FERC-approved study plan contains information regarding sampling locations, frequencies, sample collection methods, analytical methods, target reporting limits, and Water Quality Assessment objectives.

Quality Assurance Project Plan. The QAPP (this document) contains details on the quality assurance and quality control procedures that will be implemented throughout the Water Quality Assessment study(ies).

Field records. The Study Lead or designee will maintain all field records, including field data sheets documenting results of field analyses and QC samples, equipment maintenance and calibration documentation, and sample collection and handling documentation (copies of chain-of-custody forms, shipping receipts, etc.).

Laboratory records. The analytical laboratory will generate records for sample receipt and storage, instrument calibration, analytical QC, and reporting. Lab reports summarizing analytical results and QC results will be provided to HDR both in hard-copy and electronic formats. The information contained within and the format of the data report package will include at a minimum the sample identification number (ID), sampling date/time, test method, extraction date/time, analysis date/time, analytical result, QA sample results, instrument and equipment calibration information, and a description of any corrective action taken to resolve data quality issues.

Data verification records. Field data sheets, field QC results, chain-of-custody forms, and lab reports from each sampling event will be reviewed by the Study Lead and documented for the project file.

Project database. Microsoft Excel spreadsheets will be used to store all Water Quality Assessment data gathered during this project.

8.2 Retention of Project Documentation

Throughout the relicensing, the original field notebooks and forms, equipment maintenance and calibration documentation, chain-of-custody forms, laboratory reports, and data verification records will be stored at the HDR office at 2379 Gateway Oaks Drive, Suite 200, Sacramento, CA 95833. Records will be transferred to the Districts upon license receipt or earlier, at the Districts's discretion.

8.3 Electronic File Back-up

All electronic files will be stored on HDR network servers and will be backed-up on a regular basis by the HDR information technology staff

8.4 Distribution of QAPP Revisions

Revisions that occur after the original QAPP is approved will be indicated on the QAPP title page and will be distributed in subsequent deliverables and upon request.

GROUP B ELEMENTS:
DATA GENERATION AND ACQUISITION

9.0 SAMPLING PROCESS DESIGN

The FERC-approved study plan presents the study design, including sample locations, frequency of sample collection, analytical parameters, and laboratory methods.

10.0 SAMPLING METHODS

Data will be obtained in the field and in the laboratory.

The field sampler will maintain a field notebook and will note relevant conditions during each sampling event on the field data sheet. At a minimum, the following information pertaining to each sample will be recorded: date, time, weather conditions, name(s) of people collecting samples, units of measurements, depth, GPS coordinates for sample site, and river flow or reservoir water level.

Gloves and other appropriate personal protective equipment will be worn during sample and data collection activities. Observations of any field conditions that could affect sample results will be recorded in the field notebook, such as the concentrated presence of domestic animals or wildlife. Digital photo documentation of sampling conditions may also be performed. All field notes will be clearly written in a format that can be reproduced (i.e. scanned (pdf)) and entered into electronic format (Word or Excel).

10.1 Field Data Collection

The field measurement equipment that may be used during this project includes the following:

- Handheld multi-parameter meter (Hydrolab^{TM} DataSonde 5) or equivalent. A sonde will be used to measure water temperature (±0.1°C), dissolved oxygen (±0.2 mg/L), pH (±0.2 standard unit, or su), specific conductance (±0.001 µmhos/cm), and turbidity (±1 NTU) and depth.

Prior to each use, the instrument will be calibrated using manufacturer's recommended calibration methods (See Section 16). Any variances will be noted on the field data sheet and final report. If necessary to obtain a complete dataset, re-sampling within the FERC-approved study window will be performed. Non-disposable sampling equipment will be thoroughly cleaned between sampling sites.

Any field collected data that are not already in electronic format (Excel) will be hand entered into an electronic format and checked by a second-party.

10.2 Analytical Sample Collection

Surface samples will be collected using a grab sampling technique. Hypolimnetic samples will be collected using a Kemmerer bottle or equivalent. Each laboratory sample will be collected using laboratory-supplied clean containers, certified to meet the reporting limits specified in the study plan. Water samples to be analyzed for metals will be collected using "clean hands-dirty hands" method[2] consistent with the EPA Method 1669 sampling protocol as described in

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[2] One member of a two-person sampling team is designated as "dirty hands"; the second member is designated as "clean hands." All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handled by the individual designated as "clean hands." "Dirty hands" is all other activities that do not involve direct contact with the sample.

Sampling Ambient Water for Trace Metals at EPA Water Quality Assessment Criteria Levels (EPA 1996; Appendix A).

Samples requiring filtration before metals analysis will be filtered in accordance with standard protocols. Whether filtering is done in the field or the laboratory, samples will be filtered with a 0.45 micro millimeter (µm) diameter pore-membrane filter, prior to preservation. Filters used in the field will be disposable and certified clean at the desired reporting limits, specified in the study plan.

As part of the field quality assurance program, field blanks and equipment rinsates will also be collected and submitted to the laboratory for analysis (See Section 13). While still in the field, full sample containers will be labeled, placed in re-sealable plastic bags (e.g. Ziploc®), and stored in a cooler on ice to maintain a temperature of approximately 4º C.

11.0 SAMPLE HANDLING AND CUSTODY

A chain-of-custody record will be maintained with the laboratory samples at all times.

A chain-of-custody form that identifies the sample bottles, date and time of sample collection, and analyses requested will be initiated at the time of sample collection and prior to sample shipment or release. Identification information for each sample will be consistent with the information entered in the field notebook. The samples will be transported or shipped to the analytical lab in insulated containers within the appropriate holding time and will be accompanied by the chain-of-custody form. If shipment is needed, the samples will be packaged and shipped in accordance with U.S. Department of Transportation standards. The original chain-of-custody will be given to the lab with the samples and HDR will retain a copy for their records.

Once received by the laboratory, a sample receipt and storage record will be generated. The laboratory will perform all analyses within the constituent- or method- specific holding times.

After analyses, all samples will be disposed of in accordance with federal, state, and local requirements.

12.0 ANALYTICAL METHODS

The FERC-approved study plan presents the laboratory methods that will be employed. Containers, preservatives, holding times, and QA/QC requirements are specified in the analytical methods and/or in the laboratory's own standard operating procedures. Analytical methods are preferentially U.S. Environmental Protection Agency (EPA) or American Society for Testing and Materials (ASTM) methods and are detailed in the laboratory's own quality assurance manual.

For each analyte, the laboratory must be able to achieve target reporting limits and method detection limits that will allow consistency with the Basin Plan's Water Quality Assessment Objectives to be assessed. Because many of the watersheds where HDR works are free or nearly free of contaminants, low method detection limits and reporting limits are often required. Though not preferred, it may be necessary for the commercial laboratory to report estimated or "J-flagged" data to meet target reporting limits for some analytes.

13.0 QUALITY CONTROL

13.1 In Situ Data Collection

Projects that require pH and DO sampling also require a method of back-up or corrective action for inconsistent or questionable measurements collected in the field. For example, if pH is measured at less than 6 or greater than 8.5 in the field, a second measurement must be taken to verify the value. The second measurement could consist of ensuring that pH is included in the analyses of grab samples submitted to the California-certified laboratory, recalibrating the probe and re-measuring in the field, or returning to the site with a calibrated probe within the study window specified within the FERC-approved study plan. This information must be recorded in the field notes as well with explanations for the activity.

Projects that require DO sampling also require methods for back-up or corrective action measurements. For example, if a DO reading of less than 7 mg/L, for waters designated as COLD in the Basin Plan, is measured; then the instrument should be recalibrated and the sample collected again. If the reading is still questionable, then a sample must be collected for Winkler titration to verify the DO content of the water. Accurate field notes must be kept for any additional or back-up monitoring required in the field.

13.2 Sample Collection

QA/QC activities for sampling processes include the collection of field duplicates for bacterial and chemical testing, and the preparation of field blanks and/or equipment blanks as necessary. The number of duplicates should be one per every ten stations sampled or one per field visit.

Blanks will be prepared by pouring water known to be free of the substance of interest into a sample collection container then subsampling into the appropriate number of replicate sample containers. Ultrapure certified metals-free water will be used for hardness and metals.

13.3 Analytical Laboratory

All laboratories providing analytical support for this project will have the appropriate facilities to store, prepare, and process samples and appropriate instrumentation and staff to provide data of the required quality within the time period dictated by the project. The California certified laboratory will have a quality assurance plan in place and will adhere to standard protocols for accuracy, precision, instrument bias, and analytical bias.

The laboratory's deliverable (i.e. data package) will include information documenting their ability to conduct the analyses with the required level of data quality. Such information may include results from inter-laboratory calibration studies, control charts, and summary data from internal QA/QC checks, and results from analyses of certified reference materials. Additionally, the laboratory will report any inconsistencies or problems associated with any sample run(s) to HDR, who will document the situation as a variance or non-conformance, as appropriate (e.g., contaminated reagents, equipment malfunction, lost or broken sample bottles upon receipt, etc.).

14.0 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

14.1 Field Equipment

The field measurement equipment that may be used during this project includes the following:

- Handheld multi-parameter meter (Hydrolab DataSonde 5). This sonde will be used to measure dissolved oxygen, temperature, pH, and conductivity in the field.

Prior to each field visit, the sonde will be rented from and calibrated by the manufacturer. Upon receipt of the Hydrolab and prior to leaving for the field, the Field Lead or his designee will confirm the probe is working. Written documentation of calibration will be maintained in the project file, attached to relevant reports, and provided upon request.

In the event that the sonde shows signs of malfunction or drift in readings during fieldwork, basic diagnostics will be performed. At a minimum, the following will be checked: batteries, computer connection, and software. The probes will be examined for obstructions, such as algae, or physical damage. The Hydrolab user manual will be taken into the field that includes some basic trouble shooting. If basic trouble shooting is not successful, the sampling team will order a replacement rental unit and return to sample the site in a few days and within the sample period specified in the FERC-approved Study Plan.

14.2 Laboratory Equipment

All laboratories utilized to perform analytical services will be certified by the State of California. The certification includes requirements that the laboratory maintain their analytical equipment in accordance with manufactures instructions and analytical method requirements. Instrument testing, inspection and maintenance procedures are documented in the laboratory's quality assurance manual and verified during the State's audit.[3] Records will be kept at the laboratory and available upon request.

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[3] http://www.cdph.ca.gov/certlic/labs/Pages/default.aspx

15.0 INSTRUMENT/EQUIPMENT CALIBRATION AND FREQUENCY

Field instruments will be calibrated according to manufacturer's instructions immediately before use in the field. Sondes will be rented from and calibrated by the manufacturer immediately before use in the field. Documentation of calibration prior to each field visit will be maintained in the project file.

16.0 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

Project supplies and consumables that may directly or indirectly affect the quality of results include filters, samplers, gloves, bottles and more. To avoid contaminating samples through supplies, supply selection will be made the meet the needs of the study plan. Supplies will be examined for damage as they are received and consumables will be replaced no later than the date recommended in the manufacturer's instructions.

The California-certified laboratory will provide all bottles used for sample collection and cleanliness certification will be provided. Specifically, all equipment used for trace metals sample collection will be certified clean and double-bagged, allowing for the measurement at the concentrations required for the study plan using the clean hands-dirty hands technique described in EPA Method 1669 (Appendix A).

A small inventory of critical spare parts for field equipment (DO membranes, o-rings, and temperature and conductivity probes) will be kept by HDR and brought in the field if needed; however, perishable supplies or expensive parts may not be kept on hand, and will need to be ordered when needed. All spare parts and supplies will be obtained through the equipment manufacturer or other reputable sources.

17.0 NON-DIRECT MEASUREMENTS (EXISTING DATA)

Water Quality Assessment data has been previously collected in the study area. Though it is unknown at this time what existing data may be incorporated into relicensing documents, if any, the level of review of all incorporated existing data will be disclosed.

18.0 DATA MANAGEMENT

Field and laboratory data will be entered and maintained in Excel spreadsheets. The contract laboratory will provide an electronic data deliverable and an electronic narrative that includes, at a minimum, Level II documentation.

Throughout the relicensing, the original field notebooks and forms, equipment maintenance and calibration documentation, chain-of-custody forms, laboratory reports, and data verification records will be stored at the HDR office at 2379 Gateway Oaks Drive, Suite 200, Sacramento, CA 95833. Records will be transferred to the Districts upon license receipt or earlier, at the Districts' discretion.

GROUP C ELEMENTS:
ASSESSMENT AND OVERSIGHT

19.0 ASSESSMENTS AND RESPONSE ACTIONS

Periodic assessments will be conducted to ensure that data collection is conducted according to requirements presented in this QAPP. The Study Lead will have the primary responsibility for assessing compliance with the QAPP requirements pertaining to sample collection and handling procedures, field analytical procedures, laboratory analytical procedures, and communicating project status to the QA Officer and Project Manager. The QA Officer or his designee will conduct reviews of field sampling and analysis procedures at the beginning of each field season. The reviews may be performed at a demonstration site or involve accompanying sampling personnel to determine whether sampling activities are being conducted in accordance with the QAPP and Study Plan. Laboratory analyses will be assessed through evaluating results of QC samples and compliance with DQOs.

If a non-conformance is identified, the QA Officer and/or Study Lead, will notify the Project Manager immediately. The Project Manager, QA Office, and Study Lead will discuss the observed discrepancy with the appropriate person responsible for the activity to determine whether the information collected can still be considered accurate, what the cause(s) were leading to the deviation, how the deviation might impact data quality, and what corrective actions might be considered. The QA Officer and Study Lead will then follow up to ensure that corrective actions have been implemented.

20.0 REPORTS TO MANAGEMENT

The study schedule is specified in the FERC-approved study plan. As described in the study plan, the primary deliverable will be a technical memorandum, transmitting the data collected.

GROUP D ELEMENTS:
DATA VALIDATION AND USABILITY

21.0 DATA REVIEW, VERIFICATION, AND VALIDATION REQUIREMENTS

Data review, verification and validation are steps in the transition between data collection via sampling and analysis and data use and interpretation. Although data review, verification and data validation are commonly used terms, they are defined and applied differently in various organizations and quality systems. For the purposes of relicensing, the terms will be generally defined as follows:

- Data review ensures the data have been recorded, transmitted, and processed correctly. That includes, ensuring the data are sensible and checking for data entry, transcription, calculation, reduction, and transformation errors.
- Data verification is the process for evaluating the completeness, correctness, and conformance/compliance of a specific data set against the method, procedural, or contractual specifications (EPA 2002).
- Data validation is an analyte and sample specific process that extends the evaluation of data beyond method, procedure, or contractual compliance to determine the quality of a specific data set relative to the end use (EPA 2002). Data validation begins with the output from data verification.

22.0 VERIFICATION AND VALIDATION METHODS

Documentation of review, verification, and/or validation will be maintained in the project file.

For the relicensing, all data will be reviewed and verified. In brief, following the field sampling and laboratory analyses, which includes the laboratories’ own QA/QC analyses, HDR will subject all data to QA/QC procedures including, but not limited to: spot-checks of transcription; review of electronic data submissions for completeness; comparison of results to field blank and rinsate results; and, identification of any data that seem inconsistent. If any inconsistencies are found, HDR will consult with the laboratory to identify any potential sources of error before concluding that the data is correct.

All verified chemical detections, including data whose results are “J” qualified, will be used for this assessment. Should the laboratory need to re-extract samples and re-run the sample under different calibration conditions, the data identified by the laboratory, as the most certain, will be used. If field-sampling conditions, as measured by the field blank and the rinsate sample results, indicate that samples have been corrupted, HDR will identify the data accordingly.

23.0 RECONCILIATION WITH USER REQUIREMENTS

To fulfill the Districts' data needs, it is important that the data collected during this project are accurate, precise, representative, and complete, and can therefore be used to characterize Water Quality Assessment within the the Districts Project area. These data requirements will be assessed by ensuring that DQOs are met throughout the project.

After each discrete sampling event, the Study Lead will evaluate if the data quality objectives (DQOs) of Table 7.0-1 have been met. Results of the evaluation will be documented on the Data Review and Verification Form provided in Appendix B. If the impact of the QC failure on data quality is minimal, the data will be flagged and included with in the database. If a greater impact is found, the Study Lead will work with the QA Officer to determine the next steps. Data that does not meet the DQOs listed in Section 7 will be evaluated to 1) determine the cause of the problem; 2) determine whether corrective actions can be implemented so that DQOs are met in the future; and/or 3) determine if re-sampling is necessary to meet completeness or other PARCC objectives.

At the end of the monitoring program, the data generated under this project will be given to the Districts.

24.0 REFERENCES

Central Valley Regional Water Quality Control Board (CVRWQCB). 1998. The Water Quality Control Plan (Basin Plan) for the Sacramento River Basin and the San Joaquin River Basin. 4th ed. California Regional Water Quality Control Board, Central Valley Region. Revised in September 2009 with the Approved Amendments.

EPA 2002. United States Environmental Protection Agency. 2002. Guidance on Environmental Data Verification and Data Validation (EPA QA/G-8), November 2002.

QUALITY ASSURANCE PROJECT PLAN

APPENDIX A

SAMPLING AMBIENT WATERS FOR TRACE METALS AT EPA WATER QUALITY LEVELS

Method 1669

Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels

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July 1996

U.S. Environmental Protection Agency
Office of Water
Engineering and Analysis Division (4303)
401 M Street S.W.
Washington, D.C. 20460

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Disclaimer

This sampling method has been reviewed and approved for publication by the Analytical Methods Staff within the Engineering and Analysis Division of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Further Information

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Introduction

This sampling method was designed to support water quality monitoring programs authorized under the Clean Water Act. Section 304(a) of the Clean Water Act requires EPA to publish water quality criteria that reflect the latest scientific knowledge concerning the physical fate (e.g., concentration and dispersal) of pollutants, the effects of pollutants on ecological and human health, and the effect of pollutants on biological community diversity, productivity, and stability.

Section 303 of the Clean Water Act requires states to set a water quality standard for each body of water within its boundaries. A state water quality standard consists of a designated use or uses of a waterbody or a segment of a waterbody, the water quality criteria that are necessary to protect the designated use or uses, and an antidegradation policy. These water quality standards serve two purposes: (1) they establish the water quality goals for a specific waterbody, and (2) they are the basis for establishing water quality-based treatment controls and strategies beyond the technology-based controls required by Sections 301(b) and 306 of the Clean Water Act.

In defining water quality standards, the state may use narrative criteria, numeric criteria, or both. However, the 1987 amendments to the Clean Water Act required states to adopt numeric criteria for toxic pollutants (designated in Section 307(a) of the Act) based on EPA Section 304(a) criteria or other scientific data, when the discharge or presence of those toxic pollutants could reasonably be expected to interfere with designated uses.

In some cases, these water quality criteria are as much as 280 times lower than those achievable using existing EPA methods and required to support technology-based permits. Therefore, this sampling method, and the analytical methods referenced in Table 1 of this document, were developed by EPA to specifically address state needs for measuring toxic metals at water quality criteria levels, when such measurements are necessary to protect designated uses in state water quality standards. The latest criteria published by EPA are those listed in the National Toxics Rule (57 *FR* 60848) and the Stay of Federal Water Quality Criteria for Metals (60 *FR* 22228). These rules include water quality criteria for 13 metals, and it is these criteria on which this sampling method and the referenced analytical methods are based.

In developing these methods, EPA found that one of the greatest difficulties in measuring pollutants at these levels was precluding sample contamination during collection, transport, and analysis. The degree of difficulty, however, is highly dependent on the metal and site-specific conditions. This method, therefore, is designed to provide the level of protection necessary to preclude contamination in nearly all situations. It is also designed to provide the procedures necessary to produce reliable results at the lowest possible water quality criteria published by EPA. In recognition of the variety of situations to which this method may be applied, and in recognition of continuing technological advances, the method is performance-based. Alternative procedures may be used, so long as those procedures are demonstrated to yield reliable results.

Requests for additional copies of this method should be directed to:

U.S. EPA NCEPI
11029 Kenwood Road
Cincinnati, OH 45242
513/489–8190

Note: This document is intended as guidance only. Use of the terms "must," "may," and "should" are included to mean that EPA believes that these procedures must, may, or should be followed in order to produce the desired results when using this guidance. In addition, the guidance is intended to be performance-based, in that the use of less stringent procedures may be used so long as neither samples nor blanks are contaminated when following those modified procedures. Because the only way to measure the performance of the modified procedures is through the collection and analysis of uncontaminated blank samples in accordance with this guidance and the referenced methods, it is highly recommended that any modifications be thoroughly evaluated and demonstrated to be effective before field samples are collected.

Method 1669

Sampling Ambient Water for Determination of Metals at EPA Water Quality Criteria Levels

1.0 Scope and Application

1.1 This method is for the collection and filtration of ambient water samples for subsequent determination of total and dissolved metals at the levels listed in Table 1. It is designed to support the implementation of water quality monitoring and permitting programs administered under the Clean Water Act.

1.2 This method is applicable to the metals listed below and other metals, metals species, and elements amenable to determination at trace levels.

Analyte	Symbol	Chemical Abstract Services Registry Number (CASRN)
Antimony	(Sb)	7440-36-0
Arsenic	(As)	7440-38-2
Cadmium	(Cd)	7440-43-9
Chromium (III)	Cr^{+3}	16065-83-1
Chromium (VI)	Cr^{+6}	18540-29-9
Copper	(Cu)	7440-50-8
Lead	(Pb)	7439-92-1
Mercury	(Hg)	7439-97-6
Nickel	(Ni)	7440-02-0
Selenium	(Se)	7782-49-2
Silver	(Ag)	7440-22-4
Thallium	(Tl)	7440-28-0
Zinc	(Zn)	7440-66-6

1.3 This method is accompanied by the 1600 series methods listed in Table 1. These methods include the sample handling, analysis, and quality control procedures necessary for reliable determination of trace metals in aqueous samples.

1.4 This method is not intended for determination of metals at concentrations normally found in treated and untreated discharges from industrial facilities. Existing regulations (40 *CFR* Parts 400-500) typically limit concentrations in industrial discharges to the mid to high part-per-billion (ppb) range, whereas ambient metals concentrations are normally in the low part-per-trillion (ppt) to low ppb range. This guidance is therefore directed at the collection of samples to be measured at or near the levels listed in Table 1. Actual concentration ranges to which this guidance is applicable will be dependent on the sample matrix, dilution levels, and other laboratory operating conditions.

1.5 The ease of contaminating ambient water samples with the metal(s) of interest and interfering substances cannot be overemphasized. This method includes sampling techniques that should maximize the ability of the sampling team to collect samples reliably and eliminate sample contamination. These techniques are given in Section 8.0 and are based on findings of researchers performing trace metals analyses (References 1-9).

1.6 Clean and Ultraclean—The terms "clean" and "ultraclean" have been used in other Agency guidance to describe the techniques needed to reduce or eliminate contamination in trace metals determinations. These terms are not used in this sampling method due to a lack of exact definitions. However, the information provided in this method is consistent with summary guidance on clean and ultraclean techniques (Reference 10).

1.7 This sampling method follows the EPA Environmental Methods Management Council's "Format for Method Documentation" (Reference 11).

1.8 Method 1669 is "performance-based"; i.e., an alternate sampling procedure or technique may be used, so long as neither samples nor blanks are contaminated when following the alternate procedures. Because the only way to measure the performance of the alternate procedures is through the collection and analysis of uncontaminated blank samples in accordance with this guidance and the methods referenced in Table 1, it is highly recommended that any modifications be thoroughly evaluated and demonstrated to be effective before field samples are collected. Section 9.2 provides additional details on the tests and documentation required to support equivalent performance.

1.9 For dissolved metal determinations, samples must be filtered through a 0.45 µm capsule filter at the field site. The filtering procedures are described in this method. The filtered samples may be preserved in the field or transported to the laboratory for preservation. Procedures for field preservation are detailed in this sampling method; procedures for laboratory preservation are provided in the methods referenced in Table 1. Preservation requirements are summarized in Table 2.

1.10 The procedures in this method are for use only by personnel thoroughly trained in the collection of samples for determination of metals at ambient water quality control levels.

2.0 Summary of Method

2.1 Before samples are collected, all sampling equipment and sample containers are cleaned in a laboratory or cleaning facility using detergent, mineral acids, and reagent water as described in the methods referenced in Table 1. The laboratory or cleaning facility is responsible for generating an acceptable equipment blank to demonstrate that the sampling equipment and containers are free from trace metals contamination before they are shipped to the field sampling team. An acceptable blank is one that is free from contamination below the minimum level (ML) specified in the referenced analytical method (Section 9.3).

2.2 After cleaning, sample containers are filled with weak acid solution, individually double-bagged, and shipped to the sampling site. All sampling equipment is also bagged for storage or shipment.

NOTE: *EPA has found that, in some cases, it may be possible to empty the weak acid solution from the bottle immediately prior to transport to the field site. In this case, the bottle should be refilled with reagent water (Section 7.1).*

2.3 The laboratory or cleaning facility must prepare a large carboy or other appropriate clean container filled with reagent water (Section 7.1) for use with collection of field blanks during sampling activities. The reagent-water-filled container should be shipped to the field site and handled as all other sample containers and sampling equipment. At least one field blank should be processed per site, or one per every ten samples, whichever is more frequent (Section 9.4). If samples are to be collected for determination of trivalent chromium, the sampling team processes additional QC aliquots are processed as described in Section 9.6.

2.4 Upon arrival at the sampling site, one member of the two-person sampling team is designated as "dirty hands"; the second member is designated as "clean hands." All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handled by the individual designated as "clean hands." "Dirty hands" is responsible for preparation of the sampler (except the sample container itself), operation of any machinery, and for all other activities that do not involve direct contact with the sample.

2.5 All sampling equipment and sample containers used for metals determinations at or near the levels listed in Table 1 must be nonmetallic and free from any material that may contain metals.

2.6 Sampling personnel are required to wear clean, nontalc gloves at all times when handling sampling equipment and sample containers.

2.7 In addition to processing field blanks at each site, a field duplicate must be collected at each sampling site, or one field duplicate per every 10 samples, whichever is more frequent (Section 9.5). Section 9.0 gives a complete description of quality control requirements.

2.8 Sampling

2.8.1 Whenever possible, samples are collected facing upstream and upwind to minimize introduction of contamination.

2.8.2 Samples may be collected while working from a boat or while on land.

2.8.3 Surface samples are collected using a grab sampling technique. The principle of the grab technique is to fill a sample bottle by rapid immersion in water and capping to minimize exposure to airborne particulate matter.

2.8.4 Subsurface samples are collected by suction of the sample into an immersed sample bottle or by pumping the sample to the surface.

2.9 Samples for dissolved metals are filtered through a 0.45 µm capsule filter at the field site. After filtering, the samples are double-bagged and iced immediately. Sample containers are shipped to the analytical laboratory. The sampling equipment is shipped to the laboratory or cleaning facility for recleaning.

2.10 Acid preservation of samples is performed in the field or in the laboratory. Field preservation is necessary for determinations of trivalent chromium. It has also been shown that field preservation can increase sample holding times for hexavalent chromium to 30 days; therefore it is recommended that preservation of samples for hexavalent chromium be performed in the field. For other metals, however, the sampling team may prefer to utilize laboratory preservation of samples to expedite field operations and to minimize the potential for sample contamination.

2.11 Sampling activities must be documented through paper or computerized sample tracking systems.

3.0 Definitions

3.1 Apparatus—Throughout this method, the sample containers, sampling devices, instrumentation, and all other materials and devices used in sample collection, sample processing, and sample analysis activities will be referred to collectively as the Apparatus.

3.2 Definitions of other terms are given in the Glossary (Section 15.0) at the end of this method.

4.0 Contamination and Interferences

4.1 Contamination Problems in Trace Metals Analysis

4.1.1 Preventing ambient water samples from becoming contaminated during the sampling and analytical process is the greatest challenge faced in trace metals determinations. In recent years, it has been shown that much of the historical trace metals data collected in ambient water are erroneously high because the concentrations reflect contamination from sampling and analysis rather than ambient levels (Reference 12). Therefore, it is imperative that extreme care be taken to avoid contamination when collecting and analyzing ambient water samples for trace metals.

4.1.2 There are numerous routes by which samples may become contaminated. Potential sources of trace metals contamination during sampling include metallic or metal-containing sampling equipment, containers, labware (e.g. talc gloves that contain high levels of zinc), reagents, and deionized water; improperly cleaned and stored equipment, labware, and reagents; and atmospheric inputs such as dirt and dust from automobile exhaust, cigarette smoke, nearby roads, bridges, wires, and poles. Even human contact can be a source of trace metals contamination. For example, it has been demonstrated that dental work (e.g., mercury amalgam fillings) in the mouths of laboratory personnel can contaminate samples that are directly exposed to exhalation (Reference 3).

4.2 Contamination Control

4.2.1 Philosophy—The philosophy behind contamination control is to ensure that any object or substance that contacts the sample is nonmetallic and free from any material that may contain metals of concern.

4.2.1.1 The integrity of the results produced cannot be compromised by contamination of samples. Requirements and suggestions for controlling sample contamination are given in this sampling method and in the analytical methods referenced in Table 1.

4.2.1.2 Substances in a sample or in the surrounding environment cannot be allowed to contaminate the Apparatus used to collect samples for trace metals measurements. Requirements and suggestions for protecting the

Apparatus are given in this sampling method and in the methods referenced in Table 1.

4.2.1.3 While contamination control is essential, personnel health and safety remain the highest priority. Requirements and suggestions for personnel safety are given in Section 5 of this sampling method and in the methods referenced in Table 1.

4.2.2 Avoiding contamination—The best way to control contamination is to completely avoid exposure of the sample and Apparatus to contamination in the first place. Avoiding exposure means performing operations in an area known to be free from contamination. Two of the most important factors in avoiding/reducing sample contamination are (1) an awareness of potential sources of contamination and (2) strict attention to work being performed. Therefore, it is imperative that the procedures described in this method be carried out by well trained, experienced personnel. Documentation of training should be kept on file and readily available for review.

4.2.2.1 Minimize exposure—The Apparatus that will contact samples or blanks should only be opened or exposed in a clean room, clean bench, glove box, or clean plastic bag, so that exposure to atmospheric inputs is minimized. When not being used, the Apparatus should be covered with clean plastic wrap, stored in the clean bench or in a plastic box or glove box, or bagged in clean, colorless zip-type bags. Minimizing the time between cleaning and use will also reduce contamination.

4.2.2.2 Wear gloves—Sampling personnel must wear clean, nontalc gloves (Section 6.7) during all operations involving handling of the Apparatus, samples, and blanks. Only clean gloves may touch the Apparatus. If another object or substance is touched, the glove(s) must be changed before again handling the Apparatus. If it is even suspected that gloves have become contaminated, work must be halted, the contaminated gloves removed, and a new pair of clean gloves put on. Wearing multiple layers of clean gloves will allow the old pair to be quickly stripped with minimal disruption to the work activity.

4.2.2.3 Use metal-free Apparatus—All Apparatus used for metals determinations at the levels listed in Table 1 must be nonmetallic and free of material that may contain metals. When it is not possible to obtain equipment that is completely free of the metal(s) of interest, the sample should not come into direct contact with the equipment.

4.2.2.3.1 Construction materials—Only the following materials should come in contact with samples: fluoropolymer (FEP, PTFE), conventional or linear polyethylene, polycarbonate, polysulfone, polypropylene, or ultrapure quartz. PTFE is less desirable than FEP because the sintered material in PTFE may contain contaminants and is susceptible to serious memory effects (Reference 6). Fluoropolymer or glass containers should be used for samples that will be analyzed for mercury because mercury vapors can diffuse in or out of other materials, resulting either in contamination or low-biased results (Reference 3). Metal must not be used under any circumstance. Regardless of construction, all materials that will directly or indirectly contact the sample must be cleaned using the procedures described in the referenced analytical methods (see Table 1) and must be known to be clean and metal-free before proceeding.

4.2.2.3.2 The following materials have been found to contain trace metals and must not be used to hold liquids that come in contact with the sample or must not contact the sample, unless these materials have been shown to be free of the metals of interest at the desired level: Pyrex, Kimax, methacrylate, polyvinylchloride, nylon, and Vycor (Reference 6). In addition, highly colored plastics, paper cap liners, pigments used to mark increments on plastics, and rubber all contain trace levels of metals and must be avoided (Reference 13).

4.2.2.3.3 Serialization—Serial numbers should be indelibly marked or etched on each piece of Apparatus so that contamination can be traced, and logbooks should be maintained to track the sample from the container through the sampling process to shipment to the laboratory. Chain-of-custody procedures may also be used if warranted so that contamination can be traced to particular handling procedures or lab personnel.

4.2.2.3.4 The Apparatus should be clean when the sampling team receives it. If there are any indications that the Apparatus is not clean (e.g., a ripped storage bag), an assessment of the likelihood of contamination must be made. Sampling must not proceed if it is possible that the Apparatus is contaminated. If the Apparatus is contaminated, it must be returned to the laboratory or cleaning facility for proper cleaning before any sampling activity resumes.

4.2.2.3.5 Details for recleaning the Apparatus between collection of individual samples are provided in Section 10.0.

4.2.2.4 Avoid sources of contamination—Avoid contamination by being aware of potential sources and routes of contamination.

4.2.2.4.1 Contamination by carryover—Contamination may occur when a sample containing low concentrations of metals is processed immediately after a sample containing relatively high concentrations of these metals. At sites where more than one sample will be collected, the sample known or expected to contain the lowest concentration of metals should be collected first with the sample containing the highest levels collected last (Section 8.1.4). This will help minimize carryover of metals from high- concentration samples to low- concentration samples. If the sampling team does not have prior knowledge of the waterbody, or when necessary, the sample collection system should be rinsed with dilute acid and reagent water between samples and followed by collection of a field blank (Section 10.3).

4.2.2.4.2 Contamination by samples—Significant contamination of the Apparatus may result when untreated effluents, in-process waters, landfill leachates, and other samples containing mid- to high-level concentrations of inorganic substances are processed. As stated in Section 1.0, this sampling method is not intended for application to these samples, and samples containing high concentrations of metals must not be collected, processed, or shipped at the same time as samples being collected for trace metals determinations.

4.2.2.4.3 Contamination by indirect contact—Apparatus that may not directly contact samples may still be a source of contamination. For example, clean tubing placed in a dirty plastic bag may pick up contamination from the bag and subsequently transfer the contamination to the sample. Therefore, it is imperative that every piece of the Apparatus that is directly or indirectly used in the collection of ambient water samples be cleaned as specified in the analytical method(s) referenced in Table 1.

4.2.2.4.4 Contamination by airborne particulate matter—Less obvious substances capable of contaminating samples include airborne particles. Samples may be contaminated by airborne dust, dirt, particulate matter, or vapors from automobile exhaust; cigarette smoke; nearby corroded or rusted bridges, pipes, poles, or wires; nearby roads; and even human breath (Section 4.1.2). Whenever possible, the sampling activity should occur as far as possible from sources of airborne contamination (Section 8.1.3). Areas where nearby soil is bare and subject to wind erosion should be avoided.

4.3 Interferences—Interferences resulting from samples will vary considerably from source to source, depending on the diversity of the site being sampled. If a sample is suspected of containing substances that may interfere in the determination of trace metals, sufficient sample should be collected to allow the laboratory to identify and overcome interference problems.

5.0 Safety

5.1 The toxicity or carcinogenicity of the chemicals used in this method has not been precisely determined; however, these chemicals should be treated as a potential health hazard. Exposure should be reduced to the lowest possible level. Sampling teams are responsible for maintaining a current awareness file of OSHA regulations for the safe handling of the chemicals specified in this method. A reference file of Material Safety Data Sheets should also be made available to all personnel involved in sampling. It is also suggested that the organization responsible perform personal hygiene monitoring of each sampling team member who uses this method and that the results of this monitoring be made available to the member.

5.2 Operating in and around waterbodies carries the inherent risk of drowning. Life jackets must be worn when operating from a boat, when sampling in more than a few feet of water, or when sampling in swift currents.

5.3 Collecting samples in cold weather, especially around cold water bodies, carries the risk of hypothermia, and collecting samples in extremely hot and humid weather carries the risk of dehydration and heat stroke. Sampling team members should wear adequate clothing for protection in cold weather and should carry an adequate supply of water or other liquids for protection against dehydration in hot weather.

6.0 Apparatus and Materials

NOTE: *Brand names, suppliers, and part numbers are for illustration only and no endorsement is implied. Equivalent performance may be achieved using apparatus and materials other than those specified here. Meeting the performance requirements of this method is the responsibility of the sampling team and laboratory.*

6.1 All sampling equipment and sample containers must be precleaned in a laboratory or cleaning facility, as described in the methods referenced in Table 1, before they are shipped to the field site. Performance criteria for equipment cleaning is described in the referenced methods. To minimize difficulties in sampling, the equipment should be packaged and arranged to minimize field preparation.

6.2 Materials such as gloves (Section 6.7), storage bags (Section 6.8), and plastic wrap (Section 6.9), may be used new without additional cleaning unless the results of the equipment blank pinpoint any of these materials as a source of contamination. In this case, either a different supplier must be obtained or the materials must be cleaned.

6.3 Sample Bottles—Fluoropolymer (FEP, PTFE), conventional or linear polyethylene, polycarbonate, or polypropylene; 500 mL or 1 L with lids. If mercury is a target analyte, fluoropolymer or glass bottles should be used. Refer to the methods referenced in Table 1 for bottle cleaning procedures.

6.3.1 Cleaned sample bottles should be filled with 0.1% HCl (v/v). In some cases, it may be possible to empty the weak acid solution from the sample bottle immediately prior to transport to the field site. In this case, the bottle should be refilled with reagent water (Section 7.1).

6.3.2 Whenever possible, sampling devices should be cleaned and prepared for field use in a class 100 clean room. Preparation of the devices in the field should be done within the glove bag (Section 6.6). Regardless of design, sampling devices must be constructed of nonmetallic material (Section 4.2.2.3.1) and free from material that contains metals. Fluoropolymer or other material shown not to adsorb or contribute mercury must be used if mercury is a target analyte; otherwise, polyethylene, polycarbonate, or polypropylene are acceptable. Commercially available sampling devices may be used provided that any metallic or metal-containing parts are replaced with parts constructed of nonmetallic material.

6.4 Surface Sampling Devices—Surface samples are collected using a grab sampling technique. Samples may be collected manually by direct submersion of the bottle into the water or by using a grab sampling device. Examples of grab samplers are shown in Figures 1 and 2 and may be used at sites where depth profiling is neither practical nor necessary.

6.4.1 The grab sampler in Figure 1 consists of a heavy fluoropolymer collar fastened to the end of a 2-m-long polyethylene pole, which serves to remove the sampling personnel from the immediate vicinity of the sampling point. The collar holds the sample bottle. A fluoropolymer closing mechanism, threaded onto the bottle, enables the sampler to open and close the bottle under water, thereby avoiding surface microlayer contamination (Reference 14). Polyethylene, polycarbonate, and polypropylene are also acceptable construction materials unless mercury is a target analyte. Assembly of the cleaned sampling device is as follows (refer to Figure 1):

6.4.1.1 Thread the pull cord (with the closing mechanism attached) through the guides and secure the pull ring with a simple knot. Screw a sample bottle onto the closing device and insert the bottle into the collar. Cock the closing plate so that the plate is pushed away from the operator.

6.4.1.2 The cleaned and assembled sampling device should be stored in a double layer of large, clean zip-type polyethylene bags or wrapped in two layers of clean polyethylene wrap if it will not be used immediately.

6.4.2 An alternate grab sampler design is shown in Figure 2. This grab sampler is used for discrete water samples and is constructed so that a capped clean bottle can be submerged, the cap removed, sample collected, and bottle recapped at a selected depth. This device eliminates sample contact with conventional samplers (e.g., Niskin bottles), thereby reducing the risk of extraneous contamination. Because a fresh bottle is used for each sample, carryover from previous samples is eliminated (Reference 15).

6.5 Subsurface Sampling Devices—Subsurface sample collection may be appropriate in lakes and sluggish deep river environments or where depth profiling is determined to be necessary. Subsurface samples are collected by pumping the sample into a sample bottle. Examples of subsurface collection systems include the jar system device shown in Figure 3 and described in Section 6.5.1 or the continuous-flow apparatus shown in Figure 4 and described in Section 6.5.2.

6.5.1 Jar sampler (Reference 14)—The jar sampler (Figure 3) is comprised of a heavy fluoropolymer 1-L jar with a fluoropolymer lid equipped with two 1/4 in. fluoropolymer fittings. Sample enters the jar through a short length of fluoropolymer tubing inserted into one fitting. Sample is pulled into the jar by pumping on fluoropolymer tubing attached to the other fitting. A thick fluoropolymer plate supports the jar and provides attachment points for a fluoropolymer safety line and fluoropolymer torpedo counterweight.

6.5.1.1 Advantages of the jar sampler for depth sampling are (1) all wetted surfaces are fluoropolymer and can be rigorously cleaned; (2) the sample is collected into a sample jar from which the sample is readily recovered, and the jar can be easily recleaned; (3) the suction device (a peristaltic or rotary vacuum pump, Section 6.15) is located in the boat, isolated from the sampling jar; (4) the sampling jar can be continuously flushed with sample, at sampling depth, to equilibrate the system; and (5) the sample does not travel through long lengths of tubing that are more difficult to clean and keep clean (Reference 14). In addition, the device is designed to eliminate atmospheric contact with the sample during collection.

6.5.1.2 To assemble the cleaned jar sampler, screw the torpedo weight onto the machined bolt attached to the support plate of the jar sampler. Attach a section of the 1/4 in. o.d. tubing to the jar by inserting the tubing into the fitting on the lid and pushing down into the jar until approximately 8 cm from the bottom. Tighten the fitting nut securely. Attach the solid safety line to the jar sampler using a bowline knot to the loop affixed to the support plate.

6.5.1.3 For the tubing connecting the pump to the sampler, tubing lengths of up to 12 m have been used successfully (Reference 14).

6.5.2 Continuous-flow sampler (References 16-17)—This sampling system, shown in Figure 4, consists of a peristaltic or submersible pump and one or more lengths of precleaned fluoropolymer or styrene/ethylene/butylene/ silicone (SEBS) tubing. A filter is added to the sampling train when sampling for dissolved metals.

6.5.2.1 Advantages of this sampling system include (1) all wetted surfaces are fluoropolymer or SEBS and can be readily cleaned; (2) the suction device is located in the boat, isolated from the sample bottle; (3) the sample does not travel through long lengths of tubing that are difficult to clean and keep clean; and (4) in-line filtration is possible, minimizing field handling requirements for dissolved metals samples.

6.5.2.2 The sampling team assembles the system in the field as described in Section 8.2.8. System components include an optional polyethylene pole to remove sampling personnel from the immediate vicinity of the sampling point and the pump, tubing, filter, and filter holder listed in Sections 6.14 and 6.15.

6.6 Field-Portable Glove Bag—I2R, Model R-37-37H (nontalc), or equivalent. Alternately, a portable glove box may be constructed with a nonmetallic (PVC pipe or other suitable material) frame and a frame cover made of an inexpensive, disposable, nonmetallic material (e.g., a thin-walled polyethylene bag) (Reference 7).

6.7 Gloves—Clean, nontalc polyethylene, latex, vinyl, or PVC; various lengths. Shoulder-length gloves are needed if samples are to be collected by direct submersion of the sample bottle into the water or when sampling for mercury.

6.7.1 Gloves, shoulder-length polyethylene—Associated Bag Co., Milwaukee, WI, 66-3-301, or equivalent.

6.7.2 Gloves, PVC—Fisher Scientific Part No. 11-394-100B, or equivalent.

6.8 Storage Bags—Clean, zip-type, nonvented, colorless polyethylene (various sizes).

6.9 Plastic Wrap—Clean, colorless polyethylene.

6.10 Cooler—Clean, nonmetallic, with white interior for shipping samples.

6.11 Ice or Chemical Refrigerant Packs—To keep samples chilled in the cooler during shipment.

6.12 Wind Suit—Pamida, or equivalent.

NOTE: *This equipment is necessary only for collection of metals, such as mercury, that are known to have elevated atmospheric concentrations.*

6.12.1 An unlined, long-sleeved wind suit consisting of pants and jacket and constructed of nylon or other synthetic fiber is worn when sampling for mercury to prevent mercury adsorbed onto cotton or other clothing materials from contaminating samples.

6.12.2 Washing and drying—The wind suit is washed by itself or with other wind suits only in a home or commercial washing machine and dried in a clothes dryer. The clothes dryer must be thoroughly vacuumed, including the lint filter, to remove all traces of lint before drying. After drying, the wind suit is folded and stored in a clean polyethylene bag for shipment to the sample site.

6.13 Boat

6.13.1 For most situations (e.g., most metals under most conditions), the use of an existing, available boat is acceptable. A flat-bottom, Boston Whaler-type boat is preferred because sampling materials can be stored with reduced chance of tipping.

6.13.1.1 Immediately before use, the boat should be washed with water from the sampling site away from any sampling points to remove any dust or dirt accumulation.

6.13.1.2 Samples should be collected upstream of boat movement.

6.13.2 For mercury, and for situations in which the presence of contaminants cannot otherwise be controlled below detectable levels, the following equipment and precautions may be necessary:

6.13.2.1 A metal-free (e.g., fiberglass) boat, along with wooden or fiberglass oars. Gasoline- or diesel-fueled boat motors should be avoided when possible because the exhaust can be a source of contamination. If the body of water is large enough to require use of a boat motor, the engine should be shut off at a distance far enough from the sampling point to avoid contamination, and the sampling team should manually propel the boat to the sampling point. Samples should be collected upstream of boat movement.

6.13.2.2 Before first use, the boat should be cleaned and stored in an area that minimizes exposure to dust and atmospheric particles. For example, cleaned boats should not be stored in an area that would allow exposure to automobile exhaust or industrial pollution.

6.13.2.3 The boat should be frequently visually inspected for possible contamination.

6.13.2.4 After sampling, the boat should be returned to the laboratory or cleaning facility, cleaned as necessary, and stored away from any sources of contamination until next use.

6.14 Filtration Apparatus—Required when collecting samples for dissolved metals determinations.

6.14.1 Filter—0.45 µm, 15 mm diameter or larger, tortuous-path capsule filters (Reference 18), Gelman Supor 12175, or equivalent.

6.14.2 Filter holder—For mounting filter to the gunwale of the boat. Rod or pipe made from plastic material and mounted with plastic clamps.

NOTE: *A filter holder may not be required if one or a few samples are to be collected. For these cases, it may only be necessary to attach the filter to the outlet of the tubing connected to the pump.*

6.15 Pump and Pump Apparatus—Required for use with the jar sampling system (Section 6.5.1) or the continuous-flow system (Section 6.5.2). Peristaltic pump; 115 V a.c., 12 V d.c., internal battery, variable-speed, single-head, Cole-Parmer, portable, "Masterflex L/S," Catalog No. H-07570-10 drive with Quick Load pump head, Catalog No. H-07021-24, or equivalent.

NOTE: *Equivalent pumps may include rotary vacuum, submersible, or other pumps free from metals and suitable to meet the site-specific depth sampling needs.*

6.15.1 Cleaning—Peristaltic pump modules do not require cleaning. However, nearly all peristaltic pumps contain a metal head and metal controls. Touching the head or controls necessitates changing of gloves before touching the Apparatus. If a submersible pump is used, a large volume of sample should be pumped to clean the stainless steel shaft (hidden behind the impeller) that comes in contact with the sample. Pumps with metal impellers should not be used.

6.15.2 Tubing—For use with peristaltic pump. SEBS resin, approximately 3/8 in. i.d. by approximately 3 ft, Cole-Parmer size 18, Cat. No. G-06464-18, or approximately 1/4 in. i.d., Cole-Parmer size 17, Catalog No. G-06464-17, or equivalent. Tubing is cleaned by soaking in 5-10% HCl solution for 8-24 hours, rinsing with reagent water in a clean bench in a clean room, and drying in the clean bench by purging with mercury-free air or nitrogen. After drying, the tubing is double-bagged in clear polyethylene bags, serialized with a unique number, and stored until use.

6.15.3 Tubing—For connection to peristaltic pump tubing. Fluoropolymer, 3/8 or 1/4 in. o.d., in lengths as required to reach the point of sampling. If sampling will be at some depth from the end of a boom extended from a boat, sufficient tubing to extend to the end of the boom and to the depth will be required. Cleaning of the fluoropolymer can be the same as cleaning the tubing for the rotary vacuum pump (Section 6.15.1.2). If necessary, more aggressive cleaning (e.g., concentrated nitric acid) may be used.

6.15.4 Batteries to operate submersible pump—12 V, 2.6 amp, gel cell, YUASA NP2.6-12, or equivalent. A 2 amp fuse connected at the positive battery terminal is strongly recommended to prevent short circuits from overheating the battery. A 12 V, lead-acid automobile or marine battery may be more suitable for extensive pumping.

6.15.5 Tubing connectors—Appropriately sized PVC, clear polyethylene, or fluoropolymer "barbed" straight connectors cleaned as the tubing above. Used to connect multiple lengths of tubing.

6.16 Carboy—For collection and storage of dilute waste acids used to store bottles.

6.17 Apparatus—For field preservation of aliquots for trivalent chromium determinations.

6.17.1 Fluoropolymer forceps—1 L fluoropolymer jar, and 30 mL fluoropolymer vials with screw-caps (one vial per sample and blank). It is recommended that 1 mL of ultrapure nitric acid (Section 7.3) be added to each vial prior to transport to the field to simplify field handling activities (See Section 8.4.4.6).

6.17.2 Filters—0.4 µm, 47 mm polycarbonate Nuclepore (or equivalent). Filters are cleaned as follows. Fill a 1 L fluoropolymer jar approximately two-thirds full with 1 N nitric acid. Using fluoropolymer forceps, place individual filters in the fluoropolymer jar. Allow the filters to soak for 48 hours. Discard the acid, and rinse five times with reagent water. Fill the jar with reagent water, and soak the filters for 24 hours. Remove the filters when ready for use, and using fluoropolymer forceps, place them on the filter apparatus (Section 6.17.3).

6.17.3 Vacuum filtration apparatus—Millipore 47 mm size, or equivalent, vacuum pump and power source (and extension cords, if necessary) to operate the pump.

6.17.4 Eppendorf auto pipet and colorless pipet tips (100-1000 µL)

6.17.5 Wrist-action shaker—Burrel or equivalent.

6.17.6 Fluoropolymer wash bottles—One filled with reagent water (Section 7.1) and one filled with high- purity 10% HCl (Section 7.4.4), for use in rinsing forceps and pipet tips.

7.0 Reagents and Standards

7.1 Reagent Water—Water in which the analytes of interest and potentially interfering substances are not detected at the Method Detection Limit (MDL) of the analytical method used for analysis of samples. Prepared by distillation, deionization, reverse osmosis, anodic/cathodic stripping voltammetry, or other techniques that remove the metal(s) and potential interferent(s). A large carboy or other appropriate container filled with reagent water must be available for the collection of field blanks.

7.2 Nitric Acid—Dilute, trace-metal grade, shipped with sampling kit for cleaning equipment between samples.

7.3 Sodium Hydroxide—Concentrated, 50% solution for use when field-preserving samples for hexavalent chromium determinations (Section 8.4.5).

7.4 Reagents—For field-processing aliquots for trivalent chromium determinations

7.4.1 Nitric Acid, Ultrapure—For use when field-preserving samples for trivalent chromium determinations (Sections 6.17 and 8.4.4).

7.4.2 Ammonium Iron (II) Sulfate Solution (0.01M)—Used to prepare the chromium (III) extraction solution (Section 7.4.3) necessary for field preservation of samples for trivalent chromium (Section 8.4.4). Prepare the ammonium iron (II) sulfate solution by adding 3.92 g ammonium iron (II) sulfate (ultrapure grade) to a 1 L volumetric flask. Bring to volume with reagent water. Store in a clean polyethylene bottle.

7.4.3 Chromium (III) extraction solution—For use when field-preserving samples for trivalent chromium determinations (Section 8.4.4). Prepare this solution by adding 100 mL of ammonium iron (II) sulfate solution (Section 7.4.2) to a 125 mL polyethylene bottle. Adjust pH to 8 with approximately 2 mL of ammonium hydroxide solution. Cap and shake on a wrist-action shaker for 24 hours. This iron (III) hydroxide solution is stable for 30 days.

7.4.4 Hydrochloric acid—High-purity, 10% solution, shipped with sampling kit in fluoropolymer wash bottles for cleaning trivalent chromium sample preservation equipment between samples.

7.4.5 Chromium stock standard solution (1000 µg/mL)—Prepared by adding 3.1 g anhydrous chromium chloride to a 1 L flask and diluting to volume with 1% hydrochloric acid. Store in polyethylene bottle. A commercially available standard solution may be substituted.

7.4.6 Standard chromium spike solution (1000 µg/L)—Used to spike sample aliquots for matrix spike/matrix spike duplicate (MS/MSD) analysis and to prepare ongoing precision and recovery standards. Prepared by spiking 1 mL of the chromium stock standard solution (Section 7.4.5) into a 1 L flask. Dilute to volume with 1% HCl. Store in a polyethylene bottle.

7.4.7 Ongoing precision and recovery (OPR) standard (25 µg/L)—Prepared by spiking 2.5 mL of the standard chromium spike solution (Section 7.4.6) into a 100 mL flask. Dilute to volume with 1% HCl. One OPR is required for every 10 samples.

8.0 Sample Collection, Filtration, and Handling

8.1 Site Selection

8.1.1 Selection of a representative site for surface water sampling is based on many factors including: study objectives, water use, point source discharges, non-point source discharges, tributaries, changes in stream characteristics, types of stream bed, stream depth, turbulence, and the presence of structures (bridges, dams, etc.). When collecting samples to determine ambient levels of trace metals, the presence of potential sources of metal contamination are of extreme importance in site selection.

8.1.2 Ideally, the selected sampling site will exhibit a high degree of cross-sectional homogeneity. It may be possible to use previously collected data to identify locations for samples that are well mixed or are vertically or horizontally stratified. Since mixing is principally governed by turbulence and water velocity, the selection of a site immediately downstream of a riffle area will ensure good vertical mixing. Horizontal mixing occurs in constrictions in the channel. In the absence of turbulent areas, the selection of a site that is clear of immediate point sources, such as industrial effluents, is preferred for the collection of ambient water samples (Reference 19).

8.1.3 To minimize contamination from trace metals in the atmosphere, ambient water samples should be collected from sites that are as far as possible (e.g., at least several hundred feet) from any metal supports, bridges, wires or poles. Similarly, samples should be collected as far as possible from regularly or heavily traveled roads. If it is not possible to avoid collection near roadways, it is advisable to study traffic patterns and plan sampling events during lowest traffic flow (Reference 7).

8.1.4 The sampling activity should be planned to collect samples known or suspected to contain the lowest concentrations of trace metals first, finishing with the samples known or suspected to contain the highest concentrations. For example, if samples are collected from a flowing river or stream near an industrial or municipal discharge, the upstream sample should be collected first, the downstream sample collected second, and the sample nearest the discharge collected last. If the concentrations of pollutants is not known and cannot be estimated, it is necessary to use precleaned sampling equipment at each sampling location.

8.2 Sample Collection Procedure—Before collecting ambient water samples, consideration should be given to the type of sample to be collected, the amount of sample needed, and the devices to be used (grab, surface, or subsurface samplers). Sufficient sample volume should be collected to allow for necessary quality control analyses, such as matrix spike/matrix spike duplicate analyses.

8.2.1 Four sampling procedures are described:

8.2.1.1 Section 8.2.5 describes a procedure for collecting samples directly into the sample container. This procedure is the simplest and provides the least potential for contamination because it requires the least amount of equipment and handling.

8.2.1.2 Section 8.2.6 describes a procedure for using a grab sampling device to collect samples.

8.2.1.3 Section 8.2.7 describes a procedure for depth sampling with a jar sampler. The size of sample container used is dependent on the amount of sample needed by the analytical laboratory.

8.2.1.4 Section 8.2.8 describes a procedure for continuous-flow sampling using a submersible or peristaltic pump.

8.2.2 The sampling team should ideally approach the site from down current and downwind to prevent contamination of the sample by particles sloughing off the boat or equipment. If it is not possible to approach from both, the site should be approached from down current if sampling from a boat or approached from downwind if sampling on foot. When sampling from a boat, the bow of the boat should be oriented into the current (the boat will be pointed upstream). All sampling activity should occur from the bow.

If the samples are being collected from a boat, it is recommended that the sampling team create a stable workstation by arranging the cooler or shipping container as a work table on the upwind side of the boat, covering this worktable and the upwind gunnel with plastic wrap or a plastic tablecloth, and draping the wrap or cloth over the gunnel. If necessary, duct tape is used to hold the wrap or cloth in place.

8.2.3 All operations involving contact with the sample bottle and with transfer of the sample from the sample collection device to the sample bottle (if the sample is not directly collected in the bottle) are handled by the individual designated as "clean hands." "Dirty hands" is responsible for all activities that do not involve direct contact with the sample.

Although the duties of "clean hands" and "dirty hands" would appear to be a logical separation of responsibilities, in fact, the completion of the entire protocol may require a good deal of coordination and practice. For example, "dirty hands" must open the box or cooler containing the sample bottle and unzip the outer bag; clean hands must reach into the outer bag, open the inner bag, remove the bottle, collect the sample, replace the bottle lid, put the bottle back into the inner bag, and zip the inner bag. "Dirty hands" must close the outer bag and place it in a cooler.

To minimize unnecessary confusion, it is recommended that a third team member be available to complete the necessary sample documentation (e.g., to document sampling location, time, sample number, etc). Otherwise, "dirty hands" must perform the sample documentation activity (Reference 7).

8.2.4 Extreme care must be taken during all sampling operations to minimize exposure of the sample to human, atmospheric, and other sources of contamination. Care must be taken to avoid breathing directly on the sample, and whenever possible, the sample bottle should be opened, filled, and closed while submerged.

8.2.5 Manual collection of surface samples directly into the sample bottle.

8.2.5.1 At the site, all sampling personnel must put on clean gloves (Section 6.7) before commencing sample collection activity, with "clean hands" donning shoulder-length gloves. If samples are to be analyzed for mercury, the sampling team must also put their precleaned wind suits on at this time. Note that "clean hands" should put on the shoulder-length polyethylene gloves (Section 6.7.1) and both "clean hands" and "dirty hands" should put on the PVC gloves (Section 6.7.2).

8.2.5.2 "Dirty hands" must open the cooler or storage container, remove the double-bagged sample bottle from storage, and unzip the outer bag.

8.2.5.3 Next, "clean hands" opens the inside bag containing the sample bottle, removes the bottle, and reseals the inside bag. "Dirty hands" then reseals the outer bag.

8.2.5.4 "Clean hands" unscrews the cap and, while holding the cap upside down, discards the dilute acid solution from the bottle into a carboy for wastes (Section 6.16) or discards the reagent water directly into the water body.

8.2.5.5 "Clean hands" then submerges the sample bottle, and allows the bottle to partially fill with sample. "Clean hands" screws the cap on the bottle, shakes the bottle several times, and empties the rinsate away from the site. After two more rinsings, "clean hands" holds the bottle under water and allows bottle to fill with sample. After the bottle has filled (i.e., when no more bubbles appear), and while the bottle is still inverted so that the mouth of the bottle is underwater, "clean hands" replaces the cap of the bottle. In this way, the sample has never contacted the air.

8.2.5.6 Once the bottle lid has been replaced, "dirty hands" reopens the outer plastic bag, and "clean hands" opens the inside bag, places the bottle inside it, and zips the inner bag.

8.2.5.7 "Dirty hands" zips the outer bag.

8.2.5.8 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.2.5.9 If the sample is to be analyzed for dissolved metals, it is filtered in accordance with the procedure described in Section 8.3.

8.2.6 Sample collection with grab sampling device—The following steps detail sample collection using the grab sampling device shown in Figure 1 and described in Section 6.4.1. The procedure is indicative of the "clean hands/dirty hands" technique that must be used with alternative grab sampling devices such as that shown in Figure 2 and described in Section 6.4.2.

8.2.6.1 The sampling team puts on gloves (and wind suits, if applicable). Ideally, a sample bottle will have been preattached to the sampling device in the class 100 clean room at the laboratory. If it is necessary to attach a bottle to the device in the field, "clean hands" performs this operation, described in Section 6.4.2, inside the field-portable glove bag (Section 6.6).

8.2.6.2 "Dirty hands" removes the sampling device from its storage container and opens the outer polyethylene bag.

8.2.6.3 "Clean hands" opens the inside polyethylene bag and removes the sampling device.

8.2.6.4 "Clean hands" changes gloves.

8.2.6.5 "Dirty hands" submerges the sampling device to the desired depth and pulls the fluoropolymer pull cord to bring the seal plate into the middle position so that water can enter the bottle.

8.2.6.6 When the bottle is full (i.e., when no more bubbles appear), "dirty hands" pulls the fluoropolymer cord to the final stop position to seal off the sample and removes the sampling device from the water.

8.2.6.7 "Dirty hands" returns the sampling device to its large inner plastic bag, "clean hands" pulls the bottle out of the collar, unscrews the bottle from the sealing device, and caps the bottle. "Clean hands" and "dirty hands" then return the bottle to its double-bagged storage as described in Sections 8.2.5.6 through 8.2.5.7.

8.2.6.8 Closing mechanism—"Clean hands" removes the closing mechanism from the body of the grab sampler, rinses the device with reagent water (Section 7.1), places it inside a new clean plastic bag, zips the bag, and places the bag inside an outer bag held by "dirty hands." "Dirty hands" zips the outer bag and places the double-bagged closing mechanism in the equipment storage box.

8.2.6.9 Sampling device—"Clean hands" seals the large inside bag containing the collar, pole, and cord and places the bag into a large outer bag held by "dirty hands." "Dirty hands" seals the outside bag and places the double-bagged sampling device into the equipment storage box.

8.2.6.10 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.2.6.11 If the sample is to be analyzed for dissolved metals, it is filtered in accordance with the procedures described in Section 8.3.

8.2.7 Depth sampling using a jar sampling device (Figure 3 and Section 6.5.1)

8.2.7.1 The sampling team puts on gloves (and wind suits, if applicable) and handles bottles as with manual collection (Sections 8.2.5.1 through 8.2.5.4 and 8.2.5.6 through 8.2.5.7).

8.2.7.2 "Dirty hands" removes the jar sampling device from its storage container and opens the outer polyethylene bag.

8.2.7.3 "Clean hands" opens the inside polyethylene bag and removes the jar sampling apparatus. Ideally, the sampling device will have been preassembled in a class 100 clean room at the laboratory. If, however, it is necessary to assemble the device in the field, "clean hands" must perform this operation, described in Section 6.5.2, inside a field-portable glove bag (Section 6.6).

8.2.7.4 While "dirty hands" is holding the jar sampling apparatus, "clean hands" connects the pump to the to the 1/4 in. o.d. flush line.

8.2.7.5 "Dirty hands" lowers the weighted sampler to the desired depth.

8.2.7.6 "Dirty hands" turns on the pump allowing a large volume (>2 L) of water to pass through the system.

8.2.7.7 After stopping the pump, "dirty hands" pulls up the line, tubing, and device and places them into either a field-portable glove bag or a large, clean plastic bag as they emerge.

8.2.7.8 Both "clean hands" and "dirty hands" change gloves.

8.2.7.9 Using the technique described in Sections 8.2.5.2 through 8.2.5.4, the sampling team removes a sample bottle from storage, and "clean hands" places the bottle into the glove bag.

8.2.7.10 "Clean hands" tips the sampling jar and dispenses the sample through the short length of fluoropolymer tubing into the sample bottle.

8.2.7.11 Once the bottle is filled, "clean hands" replaces the cap of the bottle, returns the bottle to the inside polyethylene bag, and zips the bag. "Clean hands" returns the zipped bag to the outside polyethylene bag held by "dirty hands."

8.2.7.12 "Dirty hands" zips the outside bag. If the sample is to be analyzed for dissolved metals, it is filtered as described in Section 8.3.

8.2.7.13 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.2.8 Continuous-flow sampling (Figure 4 and Section 6.5.2)—The continuous-flow sampling system uses peristaltic pump (Section 6.15) to pump sample to the boat or to shore through the SEBS-resin or PTFE tubing.

8.2.8.1 Before putting on wind suits or gloves, the sampling team removes the bags containing the pump (Section 6.15), SEBS-resin tubing (Section 6.15.2), batteries (Section 6.15.4), gloves (Section 6.7), plastic wrap (Section 6.9), wind suits (Section 6.12), and, if samples are to be filtered, the filtration apparatus (Section 6.14) from the coolers or storage containers in which they are packed.

8.2.8.2 "Clean hands" and "dirty hands" put on the wind suits and PVC gloves (Section 6.7.2).

8.2.8.3 "Dirty hands" removes the pump from its storage bag, and opens the bag containing the SEBS-resin tubing.

8.2.8.4 "Clean hands" installs the tubing while "dirty hands" holds the pump. "Clean hands" immerses the inlet end of the tubing in the sample stream.

8.2.8.5 Both "clean hands" and "dirty hands" change gloves. "Clean hands" also puts on shoulder length polyethylene gloves (Section 6.7.1).

8.2.8.6 "Dirty hands" turns the pump on and allows the pump to run for 5-10 minutes or longer to purge the pump and tubing.

8.2.8.7 If the sample is to be filtered, "clean hands" installs the filter at the end of the tubing, and "dirty hands" sets up the filter holder on the gunwale as shown in Figure 4.

NOTE: *The filtration apparatus is not attached until immediately before sampling to prevent buildup of particulates from clogging the filter.*

8.2.8.8 The sample is collected by rinsing the sample bottle and cap three times and collecting the sample from the flowing stream.

8.2.8.9 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.3 Sample Filtration—The filtration procedure described below is used for samples collected using the manual (Section 8.2.5), grab (Section 8.2.6), or jar (Section 8.2.7) collection systems (Reference 7). In-line filtration using the continuous-flow approach is described in Section 8.2.8.7. Because of the risk of contamination, it is recommended that samples for mercury be shipped unfiltered by overnight courier and filtered when received at the laboratory.

8.3.1 Set up the filtration system inside the glove bag, using the shortest piece of pump tubing as is practicable. Place the peristaltic pump immediately outside of the glove bag and poke a small hole in the glove bag for passage of the tubing. Also, attach a short length of tubing to the outlet of the capsule filter.

8.3.2 "Clean hands" removes the water sample from the inner storage bag using the technique described in Sections 8.2.5.2 through 8.2.5.4 and places the sample inside the glove bag. "Clean hands" also places two clean empty sample bottles, a bottle containing reagent water, and a bottle for waste in the glove bag.

8.3.3 "Clean hands" removes the lid of the reagent water bottle and places the end of the pump tubing in the bottle.

8.3.4 "Dirty hands" starts the pump and passes approximately 200 mL of reagent water through the tubing and filter into the waste bottle. "Clean hands" then moves the outlet tubing to a clean bottle and collects the remaining reagent water as a blank. "Dirty hands" stops the pump.

8.3.5 "Clean hands" removes the lid of the sample bottle and places the intake end of the tubing in the bottle.

8.3.6 "Dirty hands" starts the pump and passes approximately 50 mL through the tubing and filter into the remaining clean sample bottle and then stops the pump. "Clean hands" uses the filtrate to rinse the bottle, discards the waste sample, and returns the outlet tube to the sample bottle.

8.3.7 "Dirty hands" starts the pump and the remaining sample is processed through the filter and collected in the sample bottle. If preservation is required, the sample is acidified at this point (Section 8.4).

8.3.8 "Clean hands" replaces the lid on the bottle, returns the bottle to the inside bag, and zips the bag. "Clean hands" then places the zipped bag into the outer bag held by "dirty hands."

8.3.9 "Dirty hands" zips the outer bag, and places the double-bagged sample bottle into a clean, ice-filled cooler for immediate shipment to the laboratory.

NOTE: *It is not advisable to reclean and reuse filters. The difficulty and risk associated with failing to properly clean these devices far outweighs the cost of purchasing a new filter.*

8.4 Preservation

8.4.1 Field preservation is not necessary for dissolved metals, except for trivalent and hexavalent chromium, provided that the sample is preserved in the laboratory and allowed to stand for at least two days to allow the metals adsorbed to the container walls to redissolve. Field preservation is advised for hexavalent chromium in order to provide sample stability for up to 30 days. Mercury samples should be shipped by overnight courier and preserved when received at the laboratory.

8.4.2 If field preservation is required, preservation must be performed in the glove bag or in a designated clean area, with gloved hands, as rapidly as possible to preclude particulates from contaminating the sample. For preservation of trivalent chromium, the glove bag or designated clean area must be large enough to accommodate the vacuum filtration apparatus (Section 6.17.3), and an area should be available for setting up the wrist-action shaker (Section 6.17.5). It is also advisable to set up a work area that contains a "clean" cooler for storage of clean equipment, a "dirty" cooler for storage of "dirty" equipment, and a third cooler to store samples for shipment to the laboratory.

8.4.3 Preservation of aliquots for metals other than trivalent and hexavalent chromium—Using a disposable, precleaned, plastic pipet, add 5 mL of a 10% solution of ultrapure nitric acid in reagent water per liter of sample. This will be sufficient to preserve a neutral sample to pH <2.

8.4.4 Preservation of aliquots for trivalent chromium (References 8-9).

8.4.4.1 Decant 100 mL of the sample into a clean polyethylene bottle.

8.4.4.2 Clean an Eppendorf pipet by pipeting 1 mL of 10% HCl (Section (7.4.4) followed by 1 mL of reagent water into an acid waste container. Use the rinsed pipet to add 1 mL of chromium (III) extraction solution (Section 7.4.3) to each sample and blank.

8.4.4.3 Cap each bottle tightly, place in a clean polyethylene bag, and shake on a wrist action shaker (Section 6.17.5) for one hour.

8.4.4.4 Vacuum-filter the precipitate through a 0.4 µm pretreated filter membrane (Section 6.17.2), using fluoropolymer forceps (Section 6.17.1) to handle the membrane, and a 47 mm vacuum filtration apparatus with a precleaned filter holder (Section 6.17.3). After all sample has filtered, rinse the inside of the filter holder with approximately 15 mL of reagent water.

8.4.4.5 Using the fluoropolymer forceps, fold the membrane in half and then in quarters, taking care to avoid touching the side containing the filtrate to any surface. (Folding is done while the membrane is sitting on the filter holder and allows easy placement of the membrane into the sample vial). Transfer the filter to a 30 mL fluoropolymer vial. If the fluoropolymer vial was not pre-equipped with the ultrapure nitric acid (Section 7.4.1), rinse the pipet by drawing and discharging 1 mL of 10% HCl followed by 1 mL of reagent water into a waste container, and add 1 mL of ultrapure nitric acid to the sample vial.

8.4.4.6 Cap the vial and double-bag it for shipment to the laboratory.

8.4.4.7 Repeat Steps 8.4.4.4-8.4.4.6 for each sample, rinsing the fluoropolymer forceps and the pipet with 10% high-purity HCl followed by reagent water between samples.

8.4.5 Preservation of aliquots for hexavalent chromium (Reference 20).

8.4.5.1 Decant 125 mL of sample into a clean polyethylene bottle.

8.4.5.2 Prepare an Eppendorf pipet by pipeting 1 mL of 10% HCl (Section 7.4.4) followed by 1 mL of reagent water into an acid waste container. Use the rinsed pipet to add 1 mL NaOH to each 125 mL sample and blank aliquot.

8.4.5.3 Cap the vial(s) and double-bag for shipment to the laboratory.

9.0 Quality Assurance/Quality Control

9.1 The sampling team shall employ a strict quality assurance/ quality control (QA/QC) program. The minimum requirements of this program include the collection of equipment blanks, field blanks, and field replicates. It is also desirable to include blind QC samples as part of the program. If samples will be processed for trivalent chromium determinations, the sampling team shall also prepare method blank, OPR, and MS/MSD samples as described in Section 9.6.

9.2 The sampling team is permitted to modify the sampling techniques described in this method to improve performance or reduce sampling costs, provided that reliable analyses of samples are obtained and that samples and blanks are not contaminated. Each time a modification is made to the procedures, the sampling team is required to demonstrate that the modification does not result in contamination of field and equipment blanks. The requirements for modification are given in Sections 9.3 and 9.4. Because the acceptability of a modification is based on the results obtained with the modification, the sampling team must work with an analytical laboratory capable of making trace metals determinations to demonstrate equivalence.

9.3 Equipment Blanks

9.3.1 Before using any sampling equipment at a given site, the laboratory or equipment cleaning contractor is required to generate equipment blanks to demonstrate that the equipment is free from contamination. Two types of equipment blanks are required: bottle blanks and sampling equipment blanks.

9.3.2 Equipment blanks must be run on all equipment that will be used in the field. If, for example, samples are to be collected using both a grab sampling device and the jar sampling device, then an equipment blank must be run on both pieces of equipment.

9.3.3 Equipment blanks are generated in the laboratory or at the equipment cleaning contractor's facility by processing reagent water through the equipment using the same procedures that are used in the field (Section 8.0). Therefore, the "clean hands/dirty hands" technique used during field sampling should be followed when preparing equipment blanks at the laboratory or cleaning facility. In addition, training programs must require must require sampling personnel to collect a clean equipment blank before performing on-site field activities.

9.3.4 Detailed procedures for collecting equipment blanks are given in the analytical methods referenced in Table 1.

9.3.5 The equipment blank must be analyzed using the procedures detailed in the referenced analytical method (see Table 1). If any metal(s) of interest or any potentially interfering substance is detected in the equipment blank at the minimum level specified in the referenced method, the source of contamination/interference must be identified and removed. The equipment must be demonstrated to be free from the metal(s) of interest before the equipment may be used in the field.

9.4 Field Blank

9.4.1 To demonstrate that sample contamination has not occurred during field sampling and sample processing, at least one field blank must be generated for every 10 samples that are collected at a given site. Field blanks are collected before sample collection.

9.4.2 Field blanks are generated by filling a large carboy or other appropriate container with reagent water (Section 7.1) in the laboratory, transporting the filled container to the sampling site, processing the water through each of the sample processing steps and equipment (e.g., tubing, sampling devices, filters, etc.) that will be used in the field, collecting the field blank in one of the sample bottles, and shipping the bottle to the laboratory for analysis in accordance with the method(s) referenced in Table 1. For example, manual grab sampler field blanks are collected by directly submerging a sample bottle into the water, filling the bottle, and capping. Subsurface sampler field blanks are collected by immersing the tubing into the water and pumping water into a sample container.

9.4.3 Filter the field blanks using the procedures described in Section 8.3.

9.4.4 If it is necessary to acid clean the sampling equipment between samples (Section 10.0), a field blank should be collected after the cleaning procedures but before the next sample is collected.

9.4.5 If trivalent chromium aliquots are processed, a separate field blank must be collected and processed through the sample preparation steps given in Sections 8.4.4.1 through 8.4.4.6.

9.5 Field Duplicate

9.5.1 To assess the precision of the field sampling and analytical processes, at least one field duplicate sample must be collected for every 10 samples that are collected at a given site.

9.5.2 The field duplicate is collected either by splitting a larger volume into two aliquots in the glove box, by using a sampler with dual inlets that allows simultaneous collection of two samples, or by collecting two samples in rapid succession.

9.5.3 Field duplicates for dissolved metals determinations must be processed using the procedures in Section 8.3. Field duplicates for trivalent chromium must be processed through the sample preparation steps given in Sections 8.4.4.1 through 8.4.4.6.

9.6 Additional QC for Collection of Trivalent Chromium Aliquots

9.6.1 Method blank—The sampling team must prepare one method blank for every ten or fewer field samples. Each method blank is prepared using the steps in Sections 8.4.4.1 through 8.4.4.6 on a 100 mL aliquot of reagent water (Section 7.1). Do not use the procedures in Section 8.3 to process the method blank through the 0.45 µm filter (Section 6.14.1), even if samples are being collected for dissolved metals determinations.

9.6.2 Ongoing precision and recovery (OPR)—The sampling team must prepare one OPR for every ten or fewer field samples. The OPR is prepared using the steps in Sections 8.4.4.1 through 8.4.4.6 on the OPR standard (Section 7.4.7). Do not use the procedures in Section 8.3 to process the OPR through the 0.45 µm filter (Section 6.14.1), even if samples are being collected for dissolved metals determinations.

9.6.3 MS/MSD—The sampling team must prepare one MS and one MSD for every ten or fewer field samples.

9.6.3.1 If, through historical data, the background concentration of the sample can be estimated, the MS and MSD samples should be spiked at a level of one to five times the background concentration.

9.6.3.2 For samples in which the background concentration is unknown, the MS and MSD samples should be spiked at a concentration of 25 µg/L.

9.6.3.3 Prepare the matrix spike sample by spiking a 100-mL aliquot of sample with 2.5 mL of the standard chromium spike solution (Section 7.4.6), and processing the MS through the steps in Sections 8.4.4.1 through 8.4.4.6.

9.6.3.4 Prepare the matrix spike duplicate sample by spiking a second 100-mL aliquot of the same sample with 2.5 mL of the standard chromium spike solution, and processing the MSD through the steps in Sections 8.4.4.1 through 8.4.4.6.

9.6.3.5 If field samples are collected for dissolved metals determinations, it is necessary to process an MS and an MSD through the 0.45 µm filter as described in Section 8.3.

10.0 Recleaning the Apparatus Between Samples

10.1 Sampling activity should be planned so that samples known or suspected to contain the lowest concentrations of trace metals are collected first with the samples known or suspected to contain the highest concentrations of trace metals collected last. In this manner, cleaning of the sampling equipment between samples in unnecessary. If it is not possible to plan sampling activity in this manner, dedicated sampling equipment should be provided for each sampling event.

10.2 If samples are collected from adjacent sites (e.g., immediately upstream or downstream), rinsing of the sampling Apparatus with water that is to be sampled should be sufficient.

10.3 If it is necessary to cross a gradient (i.e., going from a high-concentration sample to a low-concentration sample), such as might occur when collecting at a second site, the following procedure may be used to clean the sampling equipment between samples:

10.3.1 In the glove bag, and using the "clean hands/dirty hands" procedure in Section 8.2.5, process the dilute nitric acid solution (Section 7.2) through the Apparatus.

10.3.2 Dump the spent dilute acid in the waste carboy or in the waterbody away from the sampling point.

10.3.3 Process 1 L of reagent water through the Apparatus to rinse the equipment and discard the spent water.

10.3.4 Collect a field blank as described in Section 9.4.

10.3.5 Rinse the Apparatus with copious amounts of the ambient water sample and proceed with sample collection.

10.4 Procedures for recleaning trivalent chromium preservation equipment between samples are described in Section 8.4.4.

11.0 Method Performance

Samples were collected in the Great Lakes during September–October 1994 using the procedures in this sampling method.

12.0 Pollution Prevention

12.1 The only materials used in this method that could be considered pollutants are the acids used in the cleaning of the Apparatus, the boat, and related materials. These acids are used in dilute solutions in small amounts and pose little threat to the environment when managed properly.

12.2 Cleaning solutions containing acids should be prepared in volumes consistent with use to minimize the disposal of excessive volumes of acid.

12.3 To the extent possible, the Apparatus used to collect samples should be cleaned and reused to minimize the generation of solid waste.

13.0 Waste Management

13.1 It is the sampling team's responsibility to comply with all federal, state, and local regulations governing waste management, particularly the discharge regulations, hazardous waste identification rules, and land disposal restrictions; and to protect the air, water, and land by minimizing and controlling all releases from field operations.

13.2 For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel* and *Less is Better—Laboratory Chemical Management for Waste Reduction*, available from the American Chemical Society's Department of Government Relations and Science Policy, 1155 16th Street NW, Washington, DC 20036.

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2. Berman, S.S. and Yeats, P.A. "Sampling of Seawater for Trace Metals," *CRC Reviews in Analytical Chemistry* **1985**, *16*.

3. Bloom, N.S. "Ultra-Clean Sampling, Storage, and Analytical Strategies for the Accurate Determination of Trace Metals in Natural Waters." Presented at the 16th Annual EPA Conference on the Analysis of Pollutants in the Environment, Norfolk, VA, May 5, 1993.

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14. Phillips, H., Shafer, M., Dean, P., Walker, M., and Armstrong, D. "Recommendations for Trace Metals Analysis of Natural Waters"; Wisconsin Department of Natural Resources: Madison, WI, May 1992.

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15.0 Glossary of Definitions and Purposes

These definitions and purposes are specific to this sampling method but have been conformed to common usage as much as possible.

15.1 Ambient Water—Waters in the natural environment (e.g., rivers, lakes, streams, and other receiving waters), as opposed to effluent discharges.

15.2 Apparatus—The sample container and other containers, filters, filter holders, labware, tubing, pipets, and other materials and devices used for sample collection or sample preparation, and that will contact samples, blanks, or analytical standards.

15.3 Equipment Blank—An aliquot of reagent water that is subjected in the laboratory to all aspects of sample collection and analysis, including contact with all sampling devices and apparatus. The purpose of the equipment blank is to determine if the sampling devices and apparatus for sample collection have been adequately cleaned before they are shipped to the field site. An acceptable equipment blank must be achieved before the sampling devices and Apparatus are used for sample collection.

15.4 Field Blank—An aliquot of reagent water that is placed in a sample container in the laboratory, shipped to the field, and treated as a sample in all respects, including contact with the sampling devices and exposure to sampling site conditions, filtration, storage, preservation, and all analytical procedures. The purpose of the field blank is to determine whether the field or sample transporting procedures and environments have contaminated the sample.

15.5 Field Duplicates (FD1 and FD2)—Two identical aliquots of a sample collected in separate sample bottles at the same time and place under identical circumstances using a duel inlet sampler or by splitting a larger aliquot and treated exactly the same throughout field and laboratory procedures. Analyses of FD1 and FD2 give a measure of the precision associated with sample collection, preservation, and storage, as well as with laboratory procedures.

15.6 Matrix Spike (MS) and Matrix Spike Duplicate (MSD)—Aliquots of an environmental sample to which known quantities of the analytes are added in the laboratory. The MS and MSD are analyzed exactly like a sample. Their purpose is to quantify the bias and precision caused by the sample matrix. The background concentrations of the analytes in the sample matrix must be determined in a separate aliquot and the measured values in the MS and MSD corrected for background concentrations.

15.7 May—This action, activity, or procedural step is optional.

15.8 May Not—This action, activity, or procedural step is prohibited.

15.9 Minimum Level (ML)—The lowest level at which the entire analytical system gives a recognizable signal and acceptable calibration point (Reference 21).

15.10 Must—This action, activity, or procedural step is required.

15.11 Reagent Water—Water demonstrated to be free from the metal(s) of interest and potentially interfering substances at the MDL for that metal in the referenced method or additional method.

15.12 Should—This action, activity, or procedural step is suggested but not required.

15.13 Trace-Metal Grade—Reagents that have been demonstrated to be free from the metal(s) of interest at the method detection limit (MDL) of the analytical method to be used for determination of this metal(s).

The term "trace-metal grade" has been used in place of "reagent grade" or "reagent" because acids and other materials labeled "reagent grade" have been shown to contain concentrations of metals that will interfere in the determination of trace metals at levels listed in Table 1.

TABLE 1. ANALYTICAL METHODS, METALS, AND CONCENTRATION LEVELS APPLICABLE TO METHOD 1669

Method	Technique	Metal	MDL (µg/L) [1]	ML (µg/L) [2]
1631	Oxidation/Purge & Trap/CVAFS	Mercury	0.0002	0.0005
1632	Hydride AA	Arsenic	0.003	0.01
1636	Ion Chromatography	Hexavalent Chromium	0.23	0.5
1637	CC/STGFAA	Cadmium	0.0075	0.02
		Lead	0.036	0.1
1638	ICP/MS	Antimony	0.0097	0.02
		Cadmium	0.013	0.1
		Copper	0.087	0.2
		Lead	0.015	0.05
		Nickel	0.33	1
		Selenium	0.45	1
		Silver	0.029	0.1
		Thallium	0.0079	0.02
		Zinc	0.14	0.5
1639	STGFAA	Antimony	1.9	5
		Cadmium	0.023	0.05
		Trivalent Chromium	0.10	0.2
		Nickel	0.65	2
		Selenium	0.83	2
		Zinc	0.14	0.5
1640	CC/ICP/MS	Cadmium	0.0024	0.01
		Copper	0.024	0.1
		Lead	0.0081	0.02
		Nickel	0.029	0.1

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[1] Method Detection Limit as determined by 40 *CFR* Part 136, Appendix B.

[2] Minimum Level (ML) calculated by multiplying laboratory-determined MDL by 3.18 and rounding result to nearest multiple of 1, 2, 5, 10, 20, 50, etc., in accordance with procedures used by EAD and described in the EPA *Draft National Guidance for the Permitting, Monitoring, and Enforcement of Water Quality-Based Effluent Limitations Set Below Analytical Detection/Quantitation Levels*, March 22, 1994.

TABLE 2. ANALYTES, PRESERVATION REQUIREMENTS, AND CONTAINERS

Metal	Preservation Requirements	Acceptable Containers
Antimony Arsenic Cadmium Copper Lead Nickel Selenium Silver Thallium Zinc	Add 5 mL of 10% $HN0_3$ to 1-L sample; preserve on-site or immediately upon laboratory receipt.	500 mL or 1 L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid
Chromium (III)	Add 1 mL chromium (III) extraction solution to 100 mL aliquot, vacuum filter through 0.4 µm membrane, add 1 mL 10% $HN0_3$; preserve on-site immediately after collection.	500 mL or 1 L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid
Chromium (IV)	Add 50% NaOH; preserve immediately after sample collection.	500 mL or 1 L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid
Mercury	Total: Add 0.5% high-purity HCl or 0.5% BrCl to pH < 2; Total & Methyl: Add 0.5% high-purity HCL; preserve on-site or immediately upon laboratory receipt	Fluoropolymer or borosilicate glass bottles with fluoropolymer or fluoropolymer-lined caps

Figure 1 - Grab Sampling Device

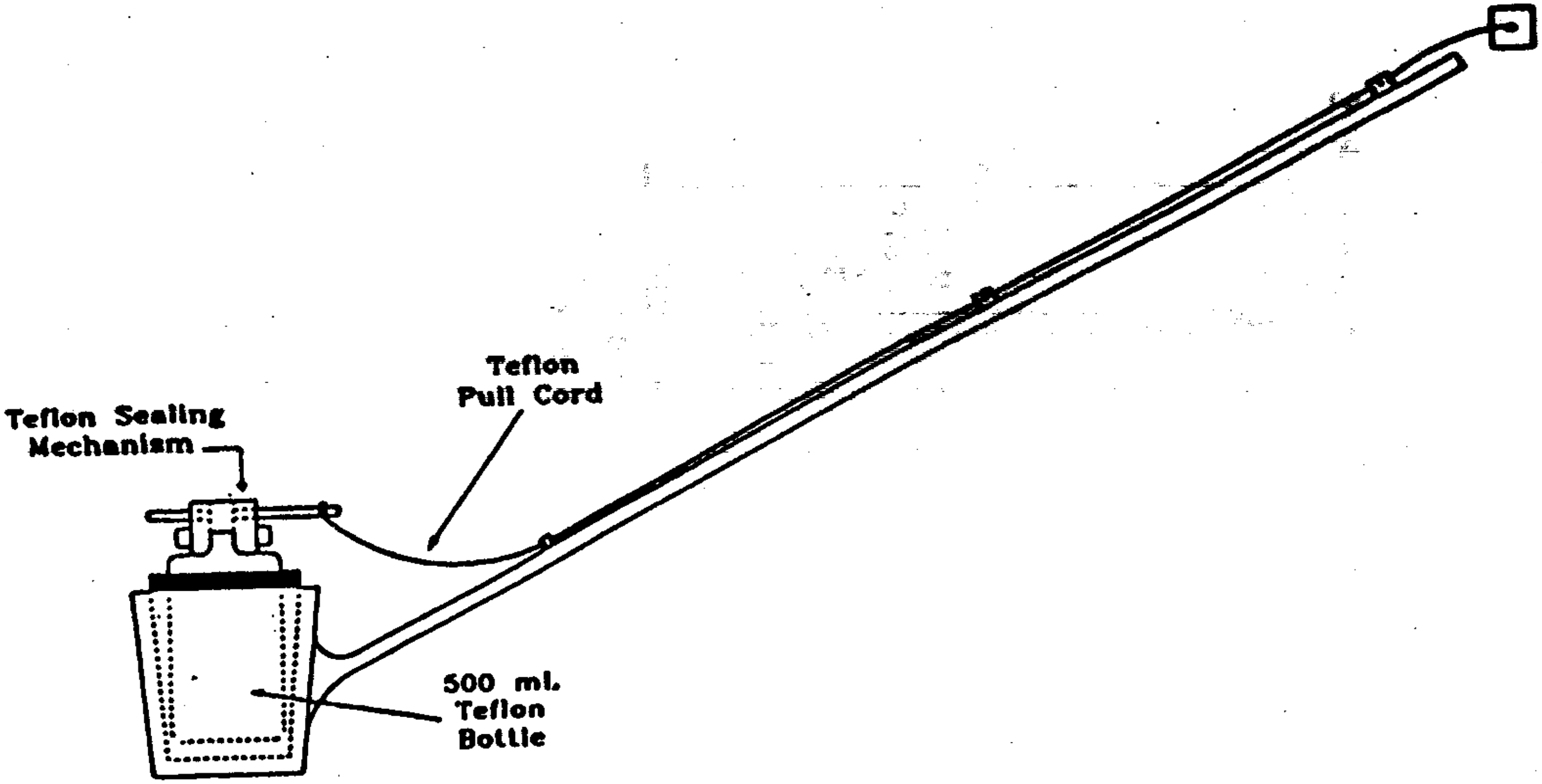


Figure 2 - Grab Sampling Device

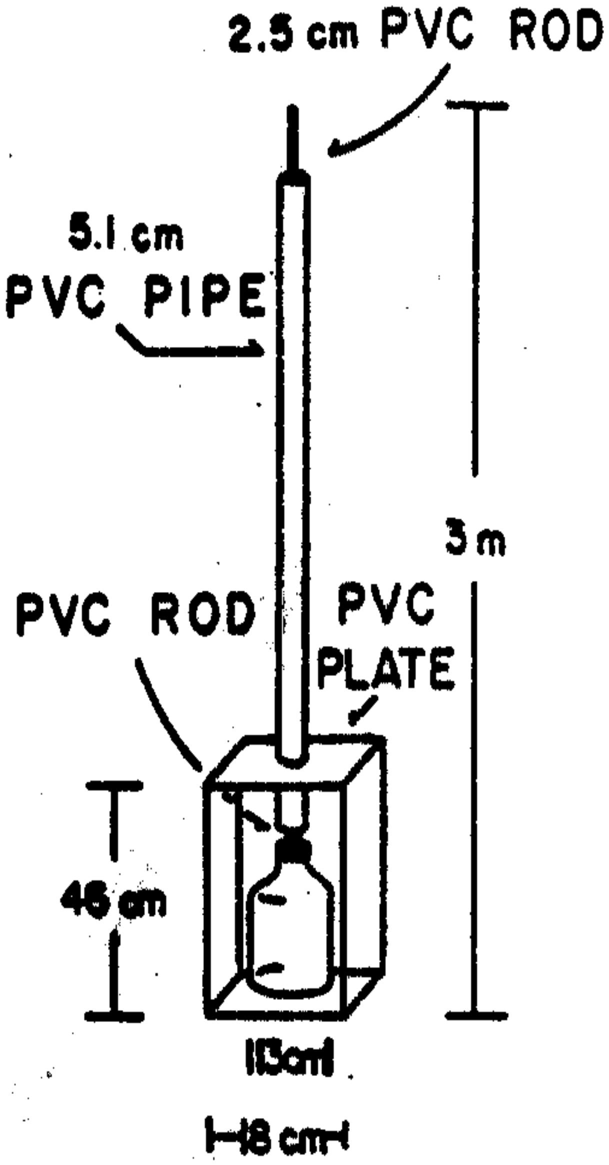


Figure 3 - Jar Sampling Device

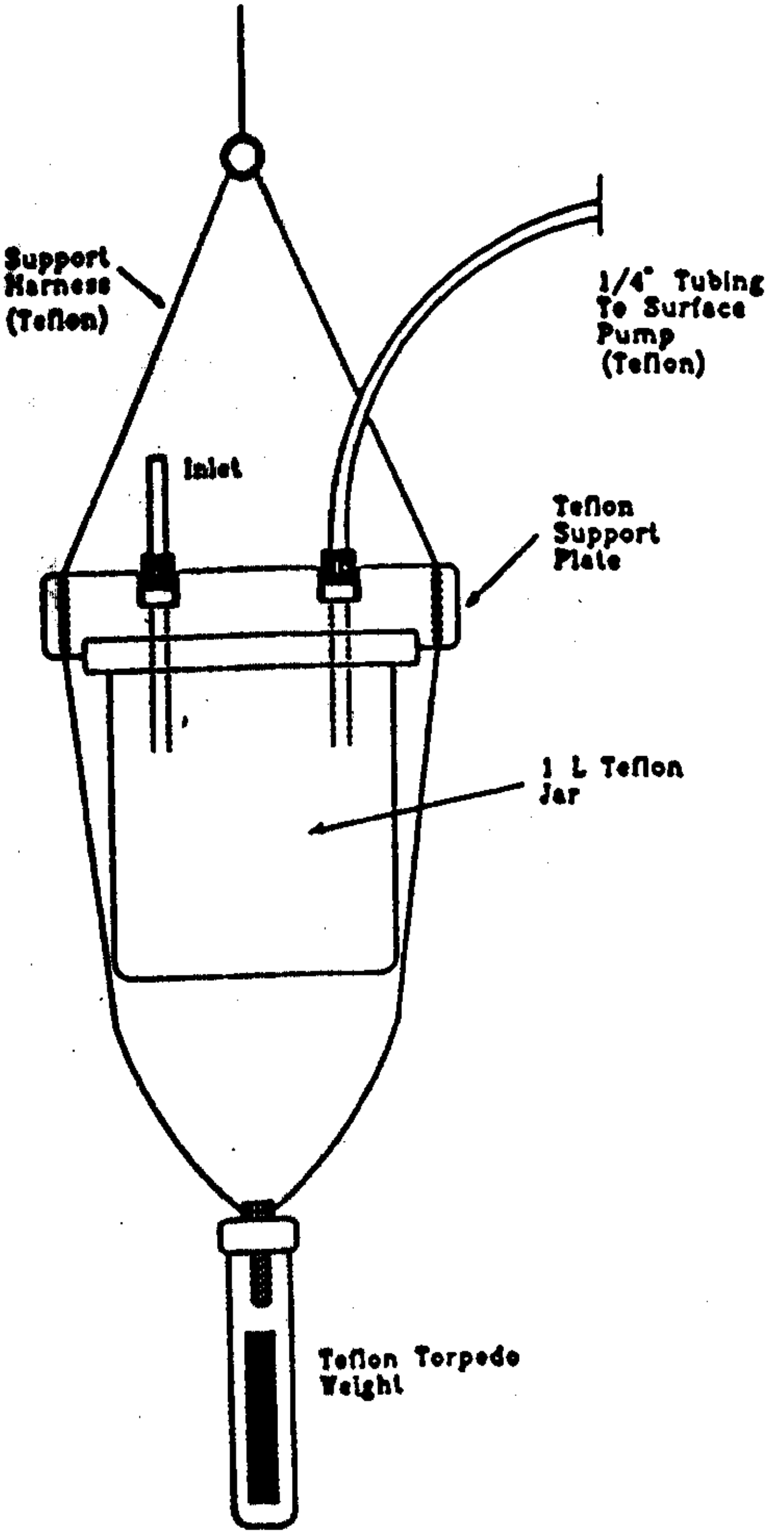
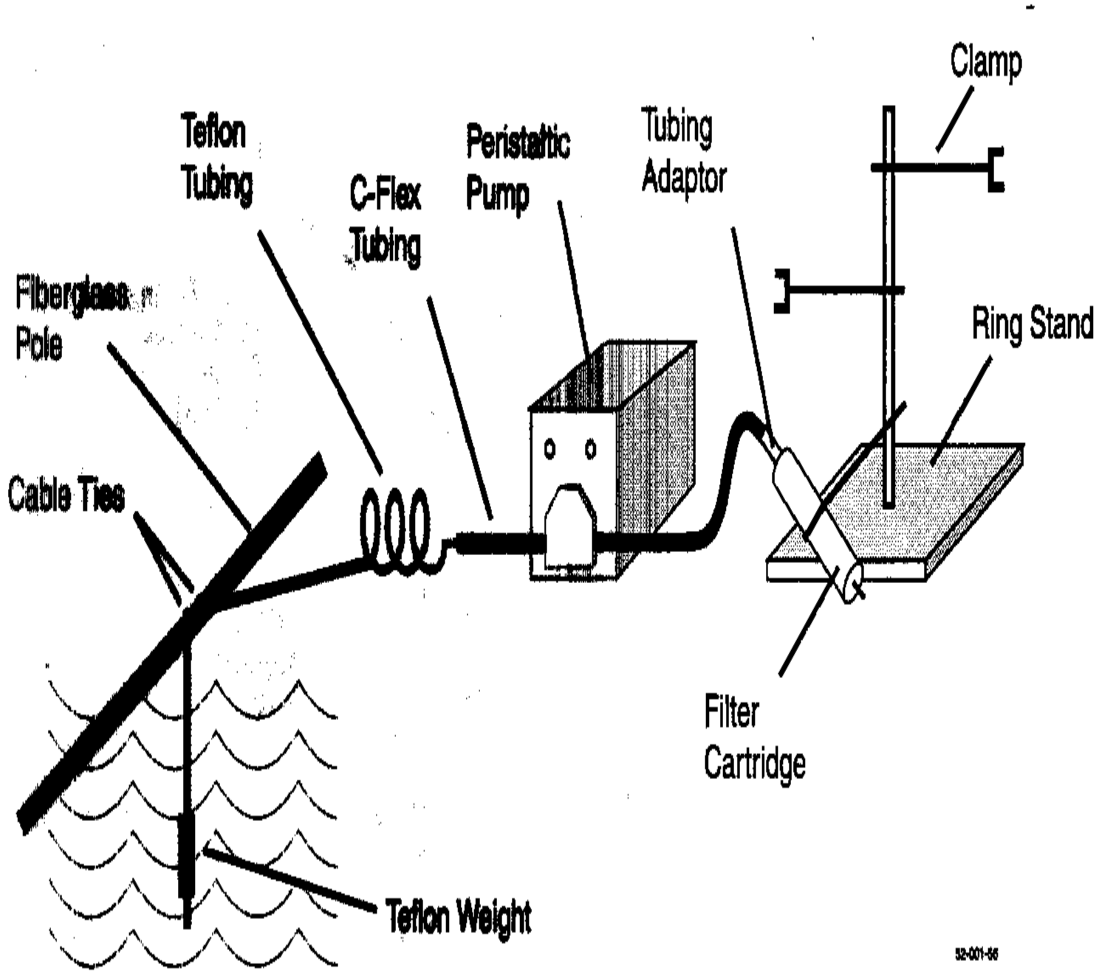


Figure 4 - Sample Pumping System



QUALITY ASSURANCE PROJECT PLAN

APPENDIX B

DATA REVIEW AND VERIFICATION CHECKLIST

DATA REVIEW AND VERIFICATION CHECKLIST

This checklist should be used to document data review verification of data generated through implementation of the FERC-approved study plan.

GENERAL

☐ For each sample event, samples have been collected and analyzed at all locations and for all analyses specified in the study plan.
☐ For each sample and analyses, the project file contains records field notes, chain-of-custody, and analytical results, including quality assurance documenation (hardcopy and electronic)

FIELD DATA

☐ Field notes and/or data sheets include date, time of sample collection, field sampling staff, time arrived at site, time left site, site identification, description of site conditions (weather), field parameters, reservoir level or flow information (measured or estimated), sample collection procedures, and call-out quality assurance samples collected. If mistakes are found on the field data sheet, changes can be made by crossing out the mistake and marking the change with a date of change, initials, and reason for change.
☐ Documentation of field equipment calibration is in the fieldnotes and/or project records.
☐ Field data entered into Excel, have been checked by a second-party.

LABORATORY REPORT

☐ Field duplicates, blanks, and rinsates were submitted to the laboratory at the frequency specified in the study plan.
☐ Any constituents found in blanks or rinsates are discussed in the final report.
☐ Any duplicate concentrations that differ by more than 10% are discussed in the final report.
☐ Samples were received by the laboratory intact and analyzed within method and/or study specified holding times.
☐ On laboratory reports, sample IDs, analyses, reporting/detection limits, units, column labels, footnotes, and titles are accurate. Have lab re-issue report with corrections if there are inconsistencies.
☐ Check that non-detects are always reported in the same manner using consistent notation. For example, either “ND” or “<.” Have lab re-issue report with corrections if there are inconsistencies.
☐ If observed, “J” qualified data and/or elevated detection limits are discussed in the final report.

STUDY REPORT W&AR-01
WATER QUALITY ASSESSMENT

ATTACHMENT B

FIELD QUALITY ASSURANCE DOCUMENTATION

3.0 Series 5, and 5X Sonde Functional Test Data Sheet

Section A:

Service Request # 312222835	Customer Rental		Date Started 07-25-12
Housing Serial # R49422	Embedded Serial# R49422		Additional Driver Firmware:
Technician HL	Model: [✓ Datasonde 5] [✓ Minisonde 5X] Pipesonde		

Customer Display Information

I/D	DOM	Baud Rate	Security	SDI	TTY
Parameter	Time	Temp	pH	Spcond	Sal
Units		°C	units	mS/cm	ppt
Parameter	Turb	LDO%	LDO	Depth Ld	Ibatt
Units	SC	Sat	mg/l	meters	Volts

For Sonde with Depth – Coefficients

A:	B:	C:	D:
E:	F:	G:	H:
I:	J:	SER:	

FLUOROMETER OFFSETS

1ST	X10:	X1:
2ND	X10:	X1:

For Sonde with TDG or PAR – Coefficients

A:	B:	C:	D:
Local:	Ref:		

Performance, Test and Evaluation

Current MPL Rev-- 543 Upgrade to MPL Rev-- N/A	pH Electrolyte & Teflon Junction Replaced- Yes [✓ No] NA	DO membrane Replaced Yes [✓ No] NA
Lenses cleaned - [✓ Yes] No NA	RTC Battery Replaced [✓ Yes] No	No Desiccant Replaced – [✓ Yes]

Section B:

	Submission Day	Submission Day	Submission Day
Customer Observations Verified	✓ / Y / N / PT&E / Upgrade	/ Y / N / PT&E / Upgrade	/ Y / N / PT&E / Upgrade
Set Time and Date	✓		
Verified all hardware updates as current	✓		
Total current draw. (Circle all that apply) MPL PCB 40mA SC Turbidity 20mA LDO 70mA 4Beam Turbidity 10mA Flourometers: 1st 30mA 2nd 30mA 3rd 30mA PAR 10mA (Optimal Values not to exceed +20mA overall.)	120 mA		
Current draw of circulator. (20 mA max. beyond previous values.)	N/A		
Operation of self cleaning motor verified—	P F [✓ NA]	P F NA	P F NA
Audio functions correctly	[✓ P] F	P F	P F
RTC sleep/wake-up test.	[✓ P] F	P F	P F
Temp probe test at room temperature. 24.35 °C	24.34		
DO 100% sat integrity window verified at +50 mmHg over current bp. (Clark Cell only)	P F [✓ NA]	P F NA	P F NA

DATE 10-24-08	DOCUMENT#: 19002-00-Series5Sonde
PAGE	REVISION 3

DO 100% saturation calibration verified- local – (+/- 0.2 mg/l Clark Cell) (+/- 0.1 mg/l LDO)	N/A		
Scale Factor. (1.5 to 0.5) (LDO only)			
Conductivity zero (air) calibration verified - (+/- .005mS)	0.0		
Conductivity calibration verified – (+/-.2 mS) 12.856 mS/cm / 47.6 mS/cm	12.86		
Conductivity 1.412mS linearity verified –(+/-.15 mS)	1.396		
Conductivity .100mS verified – (+/-.005 mS)	.102		
pH 7 buffer calibration verified– (+/- .2 pH)	N		
pH slope calibration verified at _____ units.			
ORP calibration verified at _____ ° C (+/- 20 mV)			
Turbidity - Calibration accepted & verified with DI Water (0.0 +/-0.7 NTU)			
Turbidity - Calibration accepted & verified at (100.0 +/- 1 NTU) with Hach StablCal	A		
Turbidity - Linearity verified with 40 NTU Hach StablCal – (+/- 4 NTU)			
Depth zero calibration verified – (.02 meters)	0.0		
Depth Check verified – (+/- 0.03 meters)- Tank depth	pass		
Specific Ion Low C mV High C mV	Specific Ion Low C mV High C mV	Specific Ion Low C mV High C mV	
N03- calibration verified	P F [✓ NA]	P F NA	P F
NH4+ calibration verified	P F [✓ NA]	P F NA	P F
Cl- calibration verified	P F [✓ NA]	P F NA	P F
Chlorophyll 'a' calibration verified	P F [✓ NA]	P F NA	P F
Rhodamine 'wt' calibration verified	P F [✓ NA]	P F NA	P F
Blue-green Algae calibration verified	P F [✓ NA]	P F NA	P F
PAR calibration verified	P F [✓ NA]	P F NA	P F
TDG calibration verified (+/- 2 mmHg)	P F [✓ NA]	P F NA	P F
Logging/Sensor Stability Test	[✓ P] F	P F	P F
pH linearity verified at ____ units. (+/- 0.20 units)	✓		
Battery pack setup and checked	[✓ P] F NA	P F NA	P F
Hydras3 LT Communications verified, unused slots deactivated.	✓		
Display, Baud Rate, Communications mode settings returned as received.	[✓ Yes] No	Yes No	Yes No

Calibrated Test Equipment Used –

Description	**X-number**
Power Supply	X- 7208
DVM Digital Multimeter	X- 7200

Section C. Final Check-off Prior to Submitting for Estimate --

Exterior is clean ✓	Hach Business System updated ✓
Storage cup filled with pH 4. buffer ✓	Date Completed 07-26-12

3.0

Quanta and Quanta G Functional Test Sheet

Section A:

Service Request # 312222835	Customer Rental	Serial # QT5747
Technician HL	Model Type [✓ Quanta] Quanta G	Date Started 07-25-12

Performance, Test and Evaluation

Current MPL Rev. 3.1 Upgrade to MPL Rev N/A	DO membrane installed [✓ Yes] No NA	PH Electrolyte and Teflon Junction installed - [✓ Yes] No NA
Lenses cleaned [✓ Yes] No NA	Desiccant installed [✓ Yes] No NA	Turbidity Firmware Rev.

Section B:

	Submission ✓ Day ____	Submission __ Day ____	Submission __ Day ____
Verified customer's observations	Y / N PT&E / Upgrade	Y / N PT&E / Upgrade	Y / N PT&E / Upgrade
Verified proper operation of circulator	[✓ Y] / N / NA	Y / N / NA	Y / N / NA
Temp probe test at room temperature 21.35 °C	21.34		
pH 7 Buffer calibration verified (+/- .2 pH)	7.0		
pH slope calibration verified at ____ units.	10.02		
Conductivity calibration verified (+/-.2mS/cm) 12.856 mS/cm / 47.6 mS/cm	12.86		
ORP calibration verified at ______ degrees C (+/-20 mV)	N/A		
Conductivity .100 mS linearity verified-- (+/- .005 mS)	.102		
Conductivity 1.412 mS linearity verified -- (+/- .15 mS)	1.413		
DO 100% sat integrity window verified at +50 mmHg above current bp.	[✓ P] / F / NA	P / F / NA	P / F / NA
DO 100% saturation calibration verified -- local (+/- .5%)	634		
Turbidity calibration verified in DI water 0.0-(+/-.5NTU)	0.0		
4 Beam Turbidity calibrated at 100 NTU (+/- 1 NTU) Dilute Formazin verified against "in-house" 2100P	99.8		
4 Beam Turbidity linearity verified at 40 NTU with Dilute Formazin verified against "in-house" 2100P (+/- 10% of reading.)	40.2		
Depth calibration verified -- (+/- .02 meters)	N/A		
Depth check -- (+/- .1 meters)			
Logging/Sensor Stability Test	P / F / NA	P / F / NA	P / F / NA
pH linearity verified at ______ units. (+/- 0.20 units)			

Calibrated Test Equipment Used --

Description	**X-number** N/A
DVM Multimeter	X-

Section C. Final Check-off Prior to Submitting for Estimate -

Exterior is clean ✓	Hach Business System updated oLP
Storage cup filled with pH 4 buffer ✓	**Date Completed** 07-26-12

Don Pedro
2012 Sampling and
Analysis

DATA REVIEW AND VERIFICATION CHECKLIST

This checklist should be used to document data review verification of data generated through implementation of the FERC-approved study plan.

GENERAL

☒ For each sample event, samples have been collected and analyzed at all locations and for all analyses specified in the study plan. Two dry sites

☒ For each sample and analyses, the project file contains records field notes, chain-of-custody, and analytical results, including quality assurance documenation (hardcopy and electronic)

FIELD DATA

☒ Field notes and/or data sheets include date, time of sample collection, field sampling staff, time arrived at site, time left site, site identification, description of site conditions (weather), field parameters, ~~reservoir level or flow information (measured or estimated)~~, sample collection procedures, and call-out quality assurance samples collected. If mistakes are found on the field data sheet, changes can be made by crossing out the mistake and marking the change with a date of change, initials, and reason for change. N/A not in study plan

☒ Documentation of field equipment calibration is in the fieldnotes and/or project records.

☒ Field data entered into Excel, have been checked by a second-party. S. Bunger

LABORATORY REPORT

☒ Field duplicates, blanks, and rinsates were submitted to the laboratory at the frequency specified in the study plan.

☒ Any constituents found in blanks or rinsates are discussed in the final report.

☒ Any duplicate concentrations that differ by more than 10% are discussed in the final report.

☒ Samples were received by the laboratory intact and analyzed within method and/or study specified holding times.

☒ On laboratory reports, sample IDs, analyses, reporting/detection limits, units, column labels, footnotes, and titles are accurate. Have lab re-issue report with corrections if there are inconsistencies.

☒ Check that non-detects are always reported in the same manner using consistent notation. For example, either "ND" or "<." Have lab re-issue report with corrections if there are inconsistencies.

☒ If observed, "J" qualified data and/or elevated detection limits are discussed in the final report.

Table B-1. Rinstate and Trip Blank Water Quality Data--Summer 2012

Analyte	*Sample ID*	Method Detection Limit	Reporting Limit	FIELD BLANK-1		METHOD BLANK-1		FIELD BLANK-3		METHOD BLANK-3		RINSATE-1		FIELD BLANK-2		METHOD BLANK-2		177261-8		177261-8	
	Date			8/21/2012		--		8/22/2012		--		8/22/2012		8/23/2012		--		8/23/2012		8/23/2012	
	Sample Type			Field Blank		Method Blank		Field Blank		Method Blank		Rinsate		Field Blank		Method Blank		Original		Duplicate	
	latitude/longitude			Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes
	Units	--	--	737842	4195595	--		--		732763	4183297	732763	4183297	727608	4176308	727608	4176308	727341	4174879	727341	4174879
Basic Water Quality, Inorganic Ions, and Nutrients																					
Alkalinity, Total (as $CaCO_3$)	mg/L	0.85	1.0	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	12.5		12.5	
Ammonia (as N)	mg/L	0.094	0.10	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.10	ND	0.10	ND
Calcium	mg/L	0.0118	0.10	0.0286	J	0.1	ND	0.038	J	0.1	ND	0.0466	J	0.0819	J	0.1	ND	2.83		2.74	
Carbon, Dissolved Organic	mg/L	0.021	0.50	0.78	B	0.18	J	0.45	B,J	0.19	J	0.47	B,J	0.29	J	0.5	ND	3.6		3.6	
Carbon, Total Organic	mg/L	0.026	0.50	0.34	B,J	0.12	J	0.42	B,J	0.17	J	0.39	B,J	0.28	J	0.5	ND	3.4		3.4	
Chloride	mg/L	0.24	1.0	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	0.74	J	0.71	J
Hardness, Total	mg/L	0.99	2.0	2	ND	2	ND	2	ND	2	ND	2	ND	2	ND	2	ND	11		11	
Magnesium	mg/L	0.00336	0.10	0.00543	J	0.1	ND	0.00483	J	0.1	ND	0.00361	J	0.0123	J	0.1	ND	1.25		1.25	
Nitrate (as N)	mg/L	0.037	0.10	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.047	J	0.063	J
Nitrite (as N)	mg/L	0.016	0.10	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.10	ND	0.10	ND
o-Phosphate (as P)	mg/L	0.031	0.10	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.10	ND	0.10	ND
Phosphorus, Total	mg/L	0.022	0.10	0.037	J	0.1	ND	0.027	J	0.1	ND	0.052	J	0.1	ND	0.1	ND	0.1	ND	0.1	ND
Potassium	mg/L	0.103	0.50	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.535		0.534	
Sodium	mg/L	0.103	0.50	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.398	J	0.5	ND	1.93		1.81	
Solids, Total Dissolved	mg/L	0.82	1.0	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	30		27	
Solids, Total Suspended	mg/L	0.95	1.0	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	1	ND	1.0	ND	1.0	ND
Total Kjeldahl Nitrogen	mg/L	0.46	0.50	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.50	ND	0.50	ND
Pesticides																					
Aldrin	µg/L	0.0016	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Alpha-BHC	µg/L	0.0017	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Beta-BHC	µg/L	0.0039	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Chlordane	µg/L	0.0052	0.025	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND
Chlorpyrifos	µg/L	0.0024	0.005	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND
Delta-BHC	µg/L	0.0016	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Diazinon	µg/L	0.0029	0.0050	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND
Dieldrin	µg/L	0.0016	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Endosulfan I	µg/L	0.0015	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Endosulfan II	µg/L	0.0016	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Endrin	µg/L	0.0016	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Gamma-BHC	µg/L	0.0023	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Heptachlor	µg/L	0.0018	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Heptachlor Epoxide	µg/L	0.0017	0.010	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Toxaphene	µg/L	0.023	0.12	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND
Total Metals Concentrations																					
Arsenic	µg/L	0.04	0.15	0.15	ND	--		0.05	J	--		0.06	J	0.05	J	--		0.26		0.27	
Cadmium	µg/L	0.003	0.02	0.02	ND	--		0.02	ND	--		0.003	J	0.02	ND	--		0.004	J	0.003	J
Copper	µg/L	0.01	0.1	0.02	J	--		0.02	J	--		0.87		0.02	J	--		0.49		0.48	
Iron	µg/L	0.6	10	0.8	J	--		10	ND	--		2	J	10	ND	--		19		18	
Lead	µg/L	0.003	0.04	0.04	ND	--		0.04	ND	--		0.010	J	0.04	ND	--		0.005	J	0.006	J
Mercury	ng/L	0.08	0.5	0.5	ND	--		0.16	J	--		27.4		0.08	ND	--		0.34	J	0.28	J
Methyl Mercury	ng/L	0.026	0.05	0.05	ND	--		0.05	ND	--		0.436		0.05	ND	--		0.05	ND	0.05	ND
Selenium	µg/L	0.31	0.6	0.6	ND	--		0.6	ND	--		0.6	ND	0.6	ND	--		0.6	ND	0.6	ND
Silver	µg/L	0.002	0.02	0.02	ND	--		0.02	ND	--		0.02	ND	0.02	ND	--		0.002	J	0.02	ND
Zinc	µg/L	0.03	0.2	0.13	J	--		0.19	J	--		1.07		0.08	J	--		0.19	J	0.18	J
Dissolved Metals Concentrations																					
Arsenic	µg/L	0.04	0.15	0.4	J	--		0.06	J	--		0.04	J	0.05	J	--		0.27		0.24	
Cadmium	µg/L	0.003	0.02	0.02	ND	--		0.02	ND	--		0.02	ND	0.02	ND	--		0.02	ND	0.02	ND
Copper	µg/L	0.01	0.1	0.04	J	--		0.06	J	--		0.45		0.05	J	--		0.47		0.46	
Iron	µg/L	0.6	10	10	ND	--		10	ND	--		0.6	J	10	ND	--		4	J	3	J
Lead	µg/L	0.003	0.04	0.04	ND	--		0.04	ND	--		0.04	ND	0.04	ND	--		0.04	ND	0.04	ND
Methyl Mercury	ng/L	0.026	0.05	0.05	ND	--		0.05	ND	--		0.26		0.5	ND	--		0.05	ND	0.05	ND
Silver	µg/L	0.002	0.02	0.02	ND	--		0.02	ND	--		0.02	ND	0.05	ND	--		0.02	ND	0.02	ND
Zinc	µg/L	0.03	0.2	0.11	J	--		0.20		--		0.91		0.09	J	--		0.29		0.27	

--	Laboratory methods do not include method blanks specific to water quality study metals analyses.
B	Analyte was present in the associated method blank.
FB	Field Blank
J	Analyte was detected at a concentration below the reporting limit and above the laboratory method detection limit. Reported value is estimated.
ND	Analyte included in the analysis, but not detected at the reporting limit.

STUDY REPORT W&AR-01
WATER QUALITY ASSESSMENT

ATTACHMENT C

WATER QUALITY ELEMENT DATA

Table C-1. Water Quality Data--Summer 2012

Analyte	Benchmark	*River Name*	Method Detection Limit	Reporting Limit	Tuolumne River		Woods Creek		Sullivan Creek		Don Pedro Reservoir		Don Pedro Reservoir		Don Pedro Reservoir		Don Pedro Reservoir		Tuolumne River		Tuolumne River		Tuolumne River	
		Sample Location			Above Don Pedro Reservoir		Above Don Pedro Reservoir		Above Don Pedro Reservoir		Between Upper and Middle Bays		Between Upper and Middle Bays		Near Don Pedro Dam		Near Don Pedro Dam		Below Don Pedro Dam		Below Don Pedro Dam		Below La Grange Dam	
		Sample ID			177261-3		177261-1		177261-2		177261-4		177261-5		177261-6		177261-7		177261-8		177261-8		177261-9	
		Sample Depth			Surface		Surface		Surface		Surface		Bottom		Surface		Bottom		Surface		Surface		Surface	
		Date			8/21/2012						8/22/2012		8/22/2012		8/23/2012		8/23/2012		8/23/2012		8/23/2012		8/22/2012	
		Sample Type			Original		Original		Original		Original		Original		Original		Original		Original		Duplicate		Original	
		latitude/longitude			Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes	Result	Notes
		Units	--	--	737842	4195595	--		--		732763	4183297	732763	4183297	727608	4176308	727608	4176308	727341	4174879	727341	4174879	725619	4171913
In Situ Measurments																								
Temperature	--	°C	--	± 1	21.35		--		--		27.13		9.91		26.12		9.67		11.1		--		13.75	
Specific Conductance	150	µmhos	--	0.001	20		--		--		34		40		32		44		33		--		33	
pH	6.5-8.5	stnd units	--	0.1	**6.4**		--		--		7.95		**6.47**		7.81		**6.42**		6.7		--		6.84	
Dissolved Oxygen	< 7	mg/L	--	0.1	9.0		--		--		8.0		**3.2**		8.1		**4.8**		9.3		--		12.6	
Turbidity	--	NTU	--	0.1	8.6		--		--		283		0		0		0		0.0		--		--	
Basic Water Quality, Inorganic Ions, and Nutrients																								
Alkalinity, Total (as $CaCO_3$)	< 20 or > 500	mg/L	0.85	1.0	**3.5**		--		--		**13.8**		**15.5**		**12.6**		**15**		**12.5**		**12.5**		**12.2**	
Ammonia (as N)	Temp & pH Dep't	mg/L	0.094	0.10	0.10	ND	--		--		0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND
Calcium	--	mg/L	0.0118	0.10	2.12		--		--		2.9		3.95		2.73		3.77		2.83		2.74		2.79	
Carbon, Dissolved Organic	--	mg/L	0.021	0.50	3.1	B	--		--		3.3	B	4.7		3.7		4.6		3.6		3.6		3.4	
Carbon, Total Organic	--	mg/L	0.026	0.50	2.6	B	--		--		3.3	B	4.6		3.4		4		3.4		3.4		3.2	
Chloride	230	mg/L	0.24	1.0	0.58	J	--		--		0.64	J	0.72	J	0.75	J	0.83	J	0.74	J	0.71	J	0.6	J
Hardness, Total	--	mg/L	0.99	2.0	6		--		--		11		15		12		15		11		11		11	
Magnesium	--	mg/L	0.00336	0.10	0.443		--		--		1.52		1.46		1.38		1.55		1.25		1.25		1.25	
Nitrate (as N)	45	mg/L	0.037	0.10	0.10	ND	--		--		0.10	ND	0.10		0.10	ND	0.11		0.047	J	0.063	J	0.037	J
Nitrite (as N)	1	mg/L	0.016	0.10	0.10	ND	--		--		0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND
o-Phosphate (as P)	--	mg/L	0.031	0.10	0.10	ND	--		--		0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.10	ND	0.051	J
Phosphorus, Total	--	mg/L	0.022	0.10	0.055	J	--		--		0.057	J	0.076	J	0.025	J	0.034	J	0.1	ND	0.1	ND	0.046	J
Potassium	--	mg/L	0.103	0.50	0.647		--		--		0.547		0.662		0.61		0.693		0.535		0.534		0.546	
Sodium	> 20	mg/L	0.103	0.50	1.2		--		--		1.96		1.86		2.3		2.31		1.93		1.81		1.49	
Solids, Total Dissolved	500	mg/L	0.82	1.0	20		--		--		27		30		27		47		30		27		23	
Solids, Total Suspended	--	mg/L	0.95	1.0	16		--		--		1.1		1.0	ND	1.0		1.0	ND	1.0	ND	1.0	ND	1.7	
Total Kjeldahl Nitrogen	--	mg/L	0.46	0.50	0.50	ND	--		--		0.50	ND	0.50	ND	0.50	ND	0.50	ND	0.50	ND	0.50	ND	0.50	ND
Pesticides																								
Aldrin	3.0	µg/L	0.0016	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Alpha-BHC	0.08	µg/L	0.0017	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Beta-BHC	0.08	µg/L	0.0039	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Chlordane	0.0043	µg/L	0.0052	0.025	0.025	ND	--		--		0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND	0.025	ND
Chlorpyrifos	0.014	µg/L	0.0024	0.005	0.0050	ND	--		--		0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND
Delta-BHC	0.08	µg/L	0.0016	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Diazinon	0.05	µg/L	0.0029	0.0050	0.0050	ND	--		--		0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND	0.0050	ND
Dieldrin	0.056	µg/L	0.0016	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Endosulfan I	0.056	µg/L	0.0015	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Endosulfan II	0.056	µg/L	0.0016	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Endrin	0.036	µg/L	0.0016	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Gamma-BHC	0.08	µg/L	0.0023	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Heptachlor	0.0038	µg/L	0.0018	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Heptachlor Epoxide	0.0038	µg/L	0.0017	0.010	0.010	ND	--		--		0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND	0.010	ND
Toxaphene	0.0002	µg/L	0.023	0.12	0.12	ND	--		--		0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND	0.12	ND
Total Metals Concentrations																								
Arsenic	10	µg/L	0.04	0.15	0.28		--		--		0.25		0.32		0.28		0.33		0.26		0.27		0.3	
Cadmium	5	µg/L	0.003	0.02	0.006	J	--		--		0.004	J	0.003		0.004	J	0.004	J	0.004	J	0.003	J	0.003	J
Copper	1000	µg/L	0.01	0.1	0.69		--		--		0.98		0.65		0.62		1.18		0.49		0.48		0.58	
Iron	300	µg/L	0.6	10	**314**		--		--		105		38		32		33		19		18		21	
Lead	15	µg/L	0.003	0.04	0.142		--		--		0.008	J	0.007	J	0.008	J	0.008	J	0.005	J	0.006	J	0.008	J
Mercury	50	ng/L	0.08	0.5	1.08		--		--		0.62		4.07		0.08	J	4.57		0.34	J	0.28	J	0.43	J
Methyl Mercury	--	ng/L	0.026	0.05	0.029	J	--		--		0.05	ND	0.042	J	0.05	ND	0.053		0.05	ND	0.05	ND	0.05	ND
Selenium	50	µg/L	0.31	0.6	0.6	ND	--		--		0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND
Silver	100	µg/L	0.002	0.02	0.002	J	--		--		0.002	J	0.003	J	0.02	ND	0.02	ND	0.002	J	0.02	ND	0.02	ND
Zinc	5000	µg/L	0.03	0.2	1.03		--		--		0.2		6.35		0.14	J	0.3		0.19	J	0.18	J	0.18	J
Dissolved Metals Concentrations																								
Arsenic	--	µg/L	0.04	0.15	0.23		--		--		0.28		0.29		0.29		0.34		0.27		0.24		0.27	
Cadmium	Hardness Dep't	µg/L	0.003	0.02	0.003	J	--		--		0.02	ND	0.004	J	0.003	J	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Copper	Hardness Dep't	µg/L	0.01	0.1	0.4		--		--		0.96		**6.25**		0.7		**8.16**		0.47		0.46		0.63	
Iron	Hardness Dep't	µg/L	0.6	10	18		--		--		96		8	J	1	J	7	J	4	J	3	J	5	J
Lead	Hardness Dep't	µg/L	0.003	0.04	0.01	J	--		--		0.008	J	0.01	J	0.04	ND	0.008	J	0.04	ND	0.04	ND	0.009	J
Methyl Mercury	--	ng/L	0.026	0.05	0.05	ND	--		--		0.05	ND	0.293		0.05	ND	0.349		0.05	ND	0.05	ND	0.05	ND
Silver	Hardness Dep't	µg/L	0.002	0.02	0.02	ND	--		--		0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Zinc	Hardness Dep't	µg/L	0.03	0.2	0.36		--		--		0.18	J	0.90		0.20		0.88		0.29		0.27		0.61	

Table C-1. Water Quality Data--Summer 2012: Notes and Footnotes

NOTES

B	Analyte was present in the associated method blank.
FB	Field Blank
J	Analyte was detected at a concentration below the reporting limit and above the laboratory method detection limit. Reported value is estimated.
ND	Analyte included in the analysis, but not detected at the reporting limit.

FOOTNOTES

[a] At Rice Crossing, Downstream of Dobbins Creek, upstream of Englebright

[b] From CDEC. Stream flow at gages near monitoring sites at time of sampling.

Table C-2. Ammonia Criteria

pH	USEPA National Recommended Water Quality Criteria to Protect Freshwater Aquatic Life Total Ammonia Nitrogen Continuous Concentration, 30-day Average (mg N/L) Fish Early Life Stages Present Temperature, degrees C									Maximum Concentration 1-hour Average (mg N/L) Salmonids	
	6.5 -14	**15.8**	**16.6 - 16.8**	**17.1**	**17.6**	**17.9**	**20.0**	**20.7**	**20.9**	**21.3**	**Present**	**Absent**
6.6	6.6	6.0	5.7	5.6	5.4	5.3	4.6	4.4	4.3	4.2	31.3	46.8
6.7	6.4	5.9	5.6	5.5	5.3	5.2	4.5	4.3	4.3	4.2	29.8	44.6
6.8	6.3	5.8	5.5	5.3	5.1	5.1	4.4	4.2	4.2	4.1	28.0	42.0
6.9	6.1	5.6	5.3	5.2	5.0	4.9	4.3	4.1	4.0	4.0	26.2	39.2
7.0	5.9	5.4	5.2	5.0	4.8	4.8	4.1	4.0	3.9	3.8	24.1	36.1
7.1	5.7	5.2	5.0	4.8	4.6	4.6	4.0	3.8	3.7	3.7	21.9	32.9
7.2	5.4	5.0	4.7	4.6	4.4	4.3	3.8	3.6	3.6	3.5	19.7	29.5
7.3	5.1	4.7	4.4	4.3	4.2	4.1	3.6	3.4	3.4	3.3	17.5	26.2
7.4	4.7	4.4	4.1	4.0	3.9	3.8	3.3	3.2	3.1	3.1	15.3	23.0
7.5	4.4	4.0	3.8	3.7	3.6	3.5	3.1	2.9	2.9	2.8	13.3	19.9
7.6	4.0	3.7	3.5	3.4	3.3	3.2	2.8	2.7	2.6	2.6	11.4	17.0
7.7	3.6	3.3	3.1	3.0	2.9	2.9	2.5	2.4	2.4	2.3	9.6	14.4
7.8	3.2	2.9	2.8	2.7	2.6	2.6	2.2	2.1	2.1	2.1	8.1	12.1
7.9	2.8	2.6	2.4	2.4	2.3	2.3	2.0	1.9	1.8	1.8	6.8	10.1
8.0	2.4	2.2	2.1	2.1	2.0	2.0	1.7	1.6	1.6	1.6	5.6	8.4
8.1	2.1	1.9	1.8	1.8	1.7	1.7	1.5	1.4	1.4	1.4	4.6	6.9
8.2	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.2	3.8	5.7
8.3	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	1.0	3.1	4.7

Source: Marshack 2008

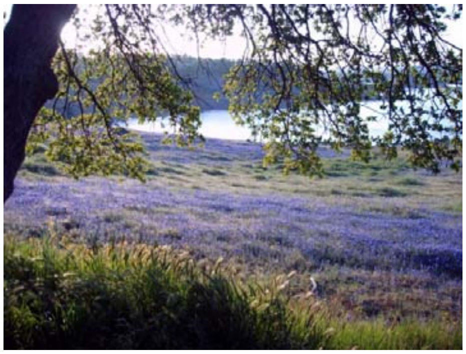
Notes:

mg N/L = milligrams Nitrogen per Liter

Table C-3. Hardness-dependent Metals (dissolved) Criteria

	California Toxics Rule				
	Continuous Concentration, 4 day average (dissolved)				
Hardness	Cadmium	Copper	Lead	Silver	Zinc
mg/L as CaCO	µg/L	µg/L	µg/L	µg/L	µg/L
5	0.24	0.7	0.09	0.020	9
6	0.28	0.8	0.11	0.027	11
7	0.31	0.9	0.13	0.036	12
8	0.34	1.0	0.15	0.045	14
9	0.38	1.1	0.17	0.055	15
10	0.41	1.3	0.19	0.066	17
11	0.44	1.4	0.21	0.077	18
12	0.46	1.5	0.24	0.090	20
13	0.49	1.6	0.26	0.103	21
14	0.52	1.7	0.28	0.117	22
15	0.55	1.8	0.30	0.132	24

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



Prepared for:
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Modesto Irrigation District – Modesto, California

Prepared by:
Stillwater Sciences

January 2013

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

Glossary of Terms and Definitions

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.

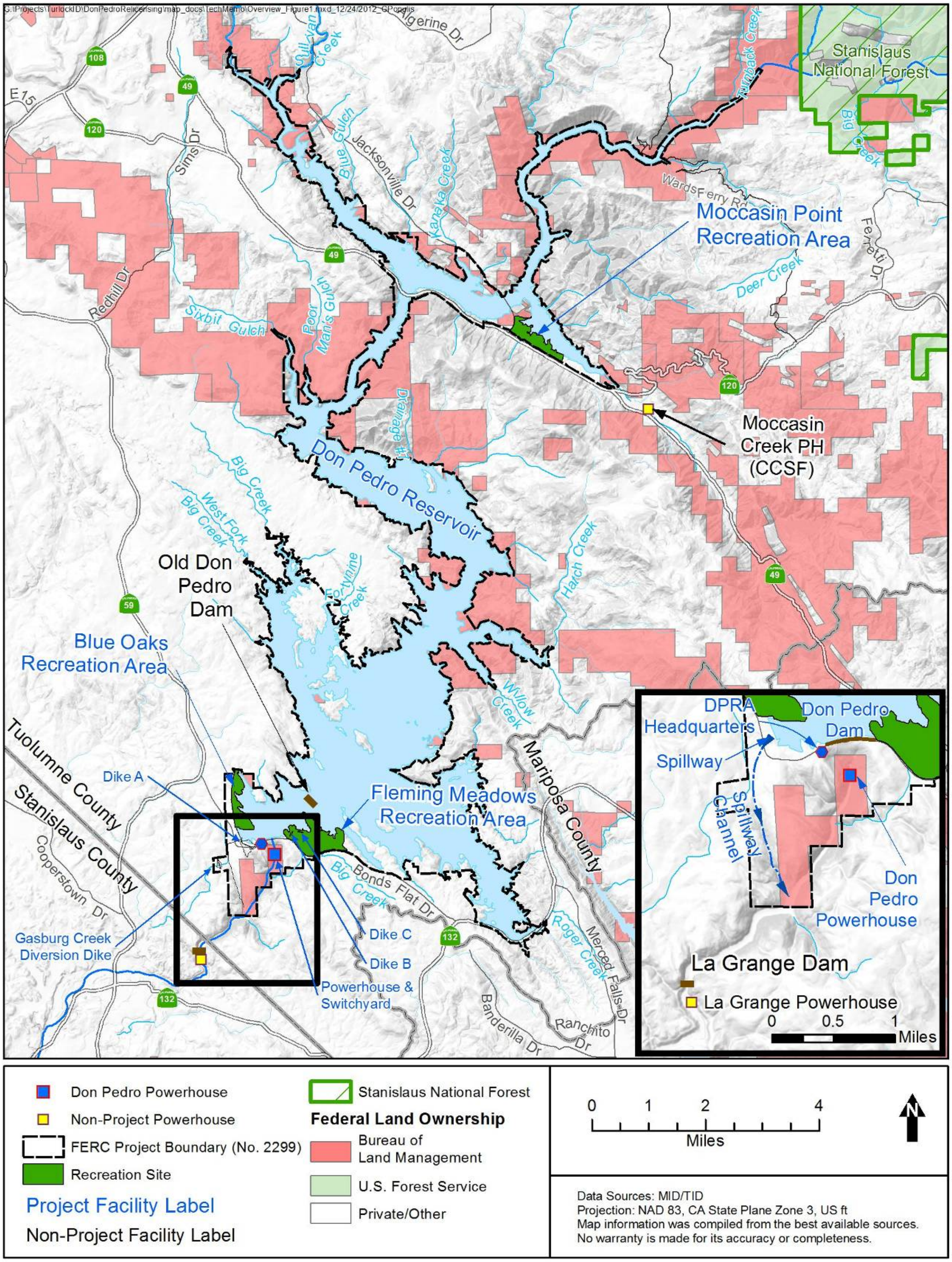

Figure 1.1-1. Don Pedro Project location.

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.

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[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

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[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

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[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	░	█	█	░								░
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.

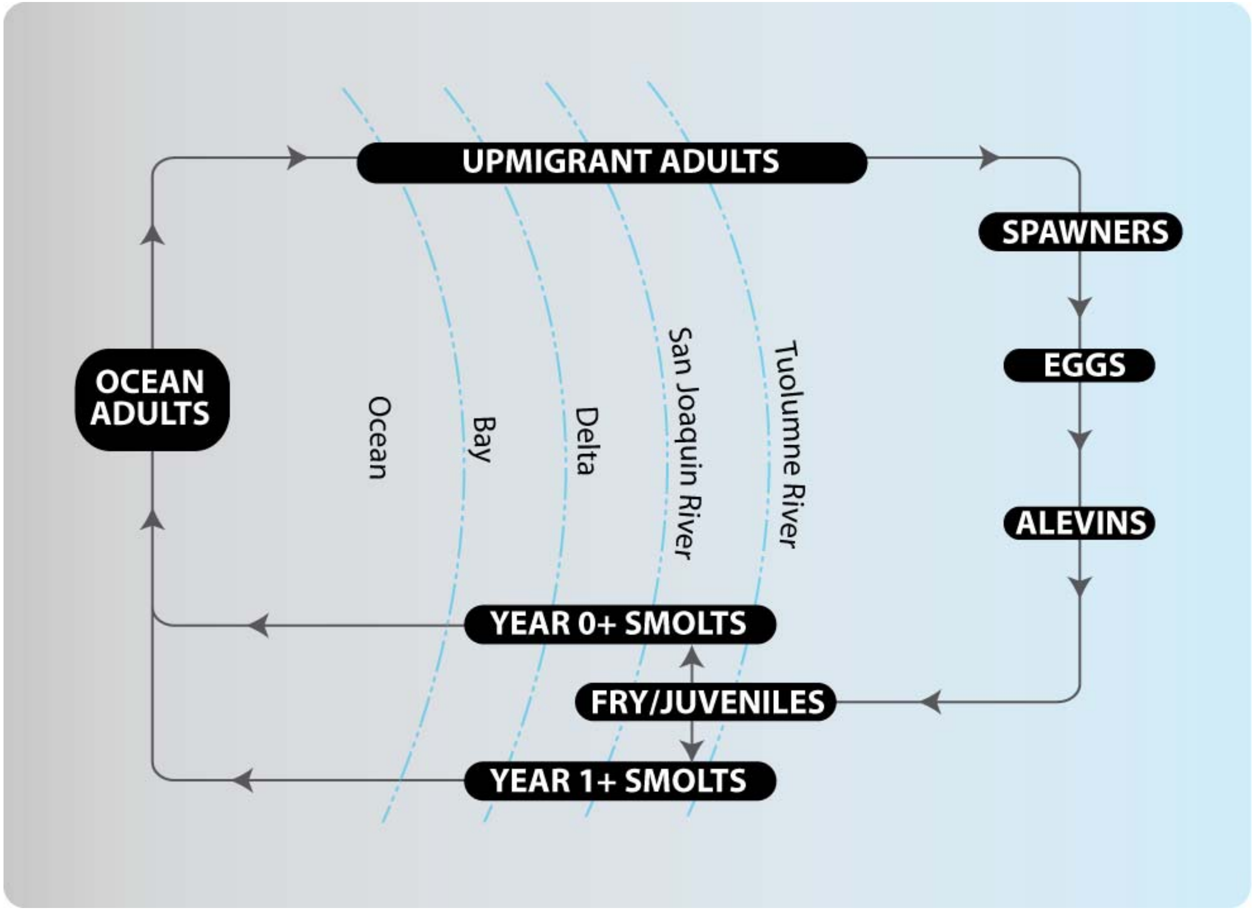

Figure 5.2-1. Fall-run Chinook salmon life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

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).

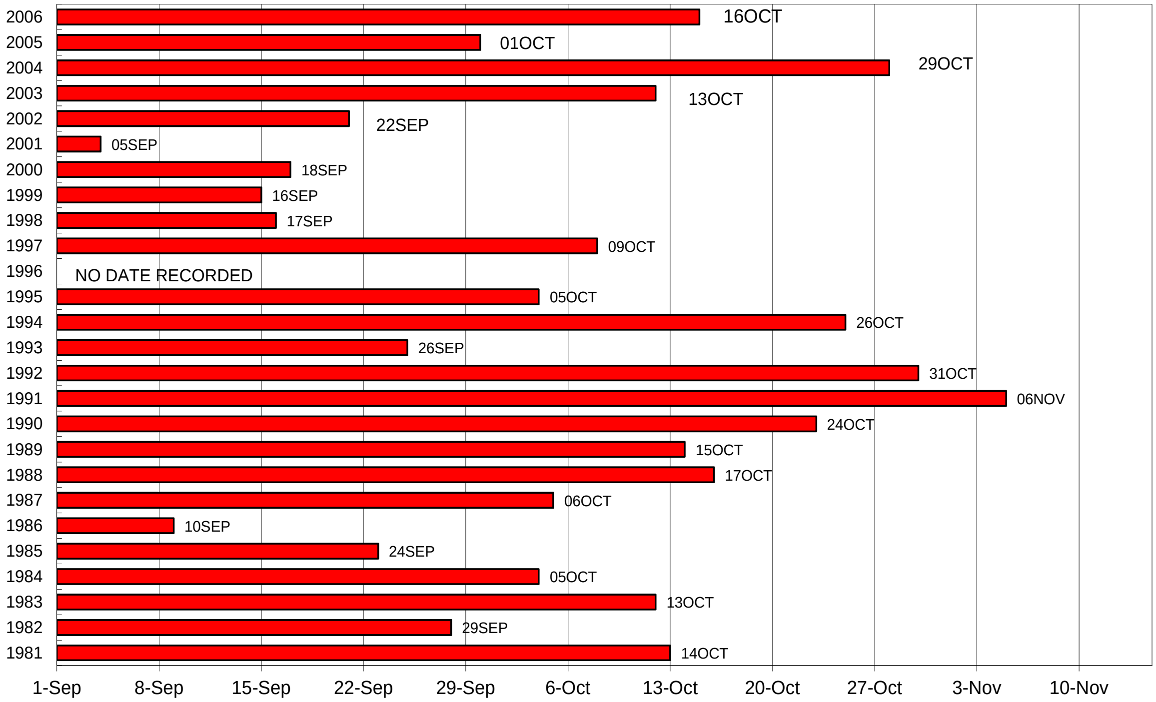

Figure 5.2-2. Dates of first observation of adult salmon near La Grange (1981–2006).

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).

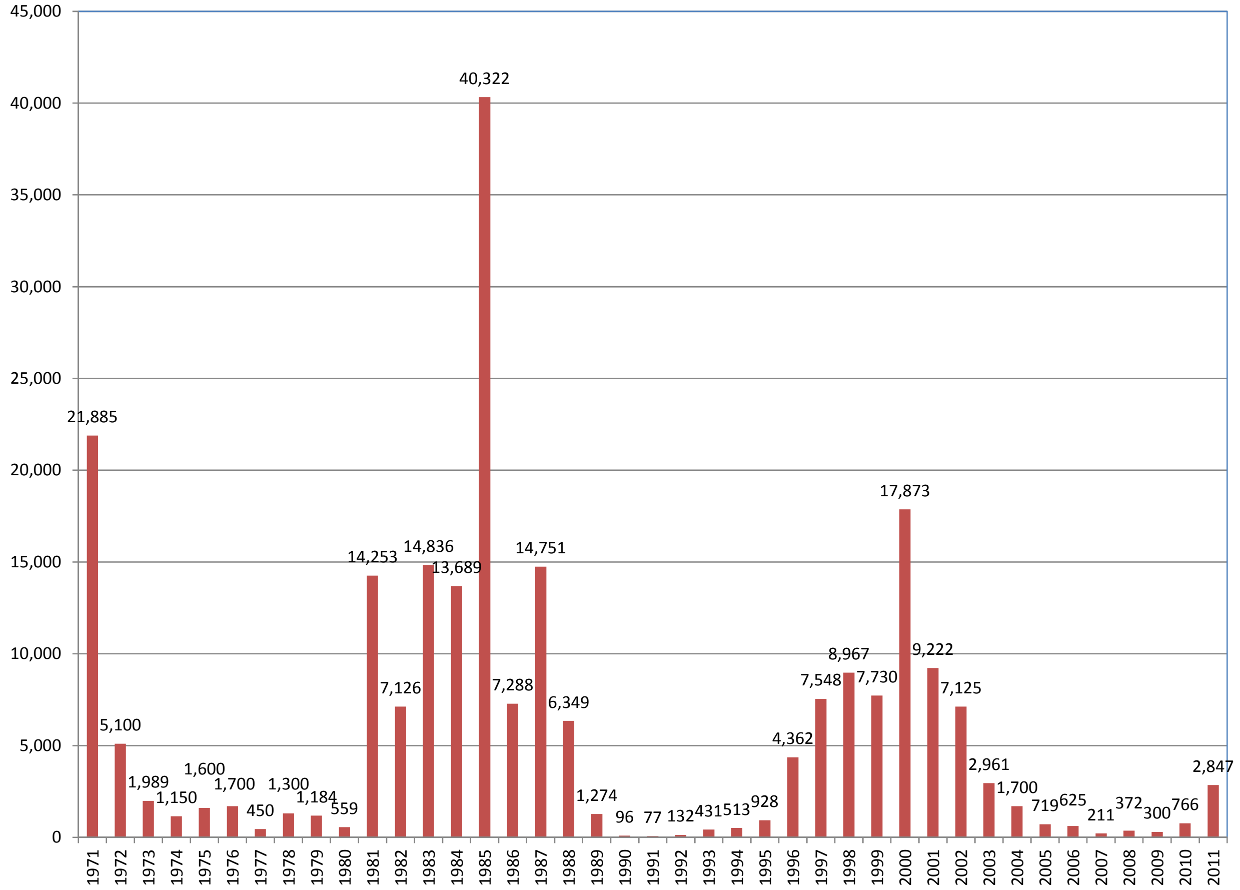

Figure 5.2-3. Tuolumne River Chinook salmon run estimates, 1971-2011 (Years 2009-2011 based on weir counts).

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.

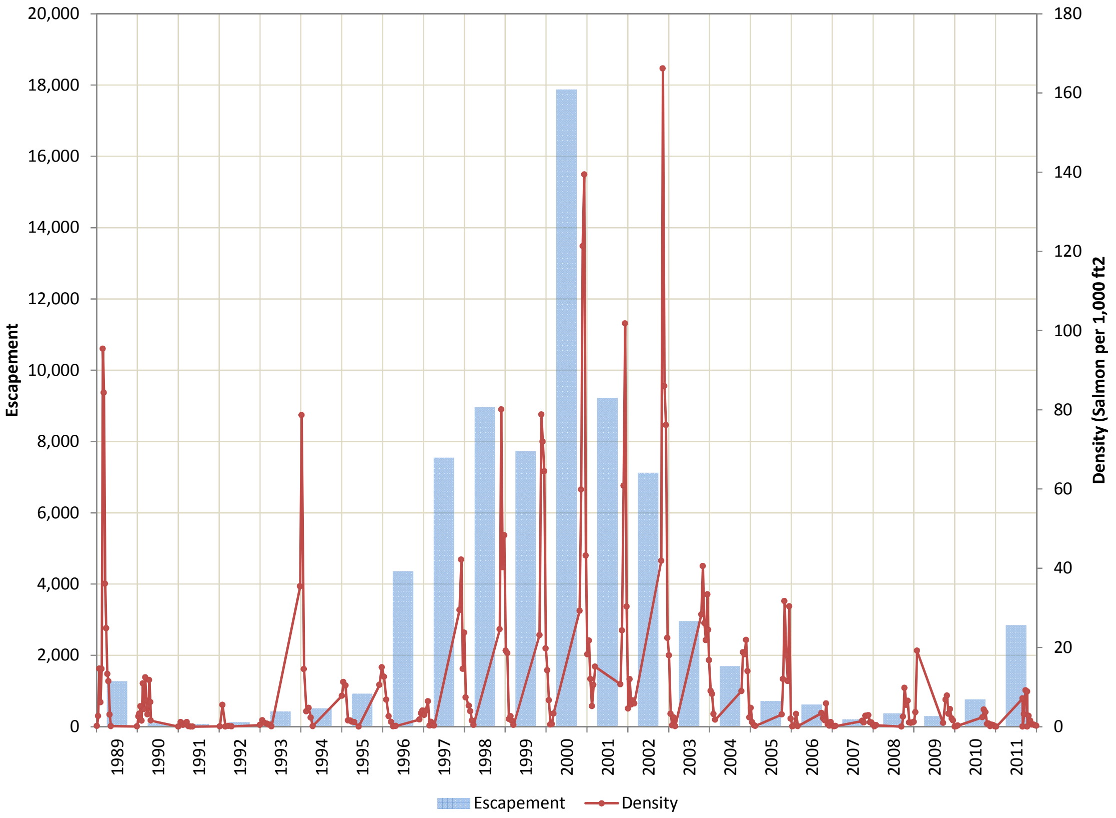

Figure 5.2-4. **Average juvenile salmon density in all seine hauls by survey with estimated escapement (1989–2011).**

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

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[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).

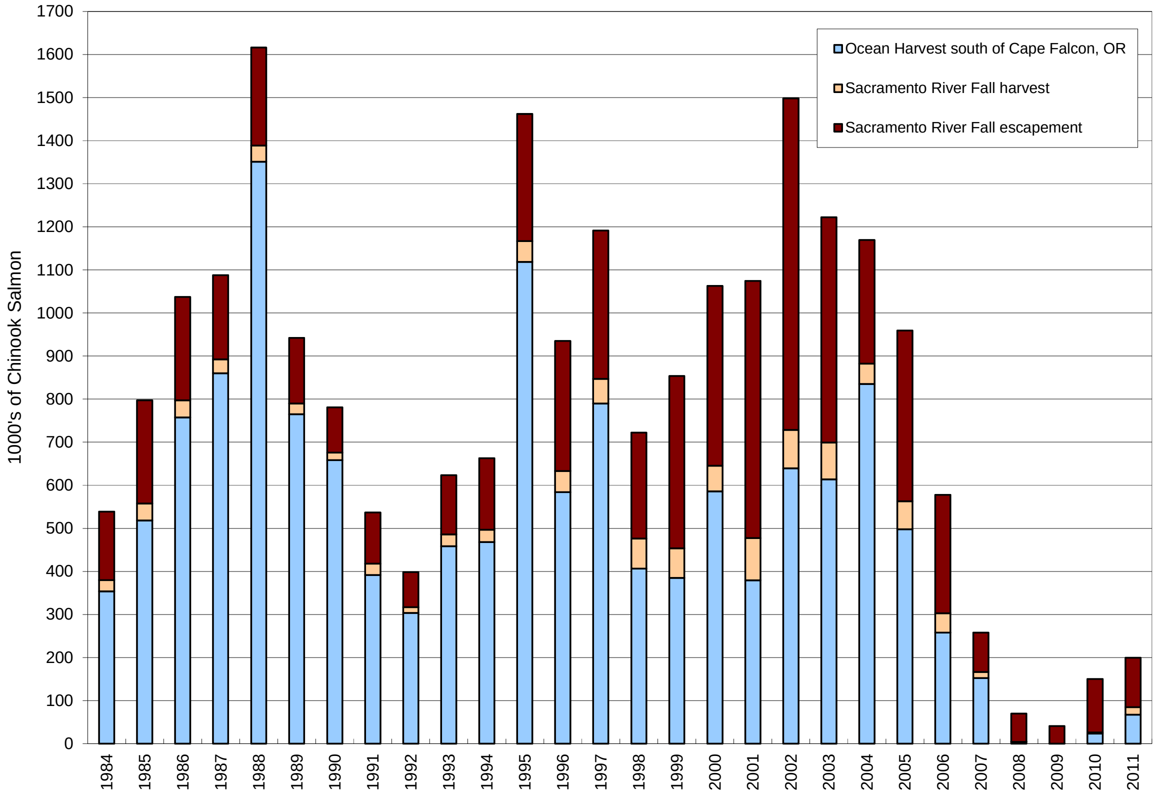

Figure 5.2-5. Sacramento River Chinook salmon abundance from ocean and Sacramento River harvest plus escapement (1984–2011).

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.

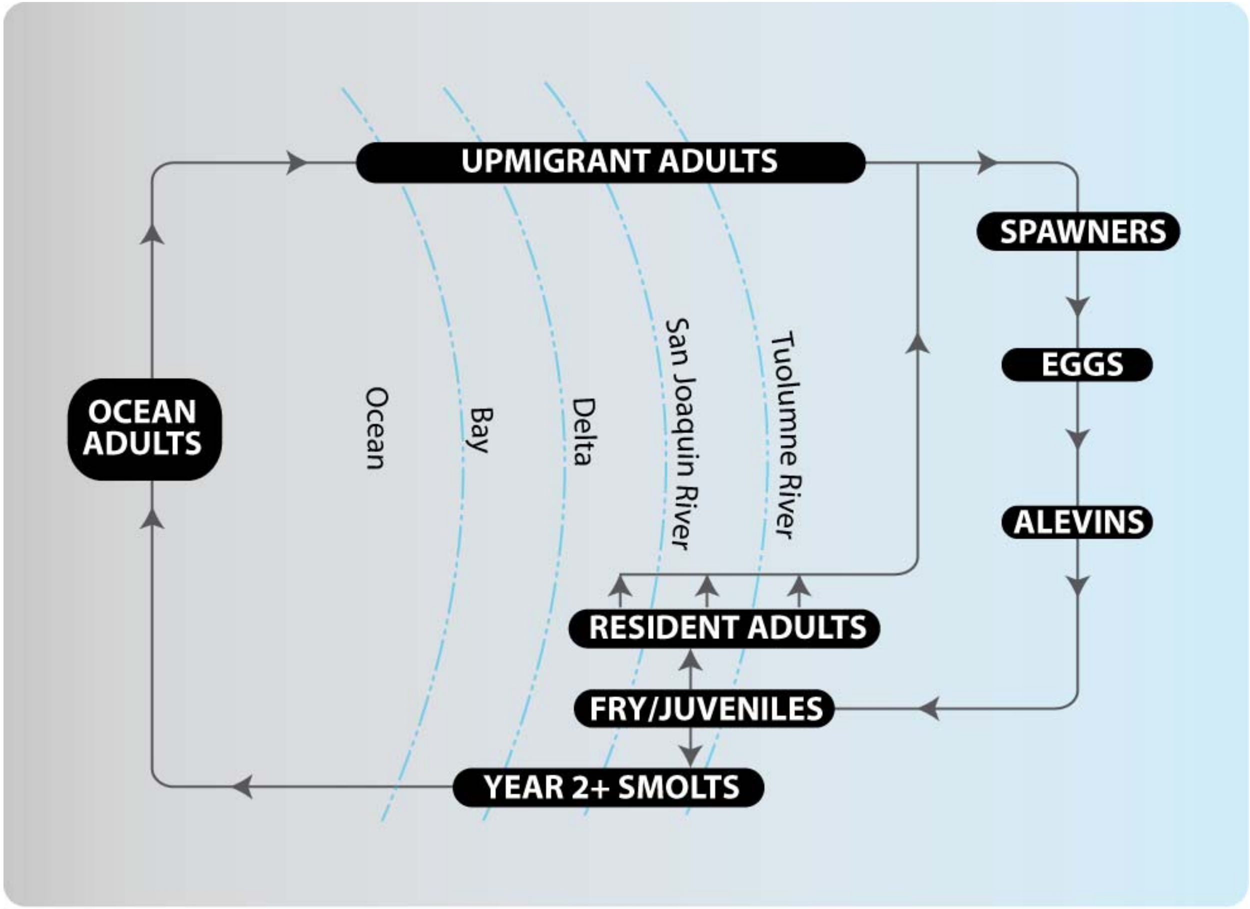

Figure 5.3-1. Central Valley steelhead and rainbow trout life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne rivers.

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).

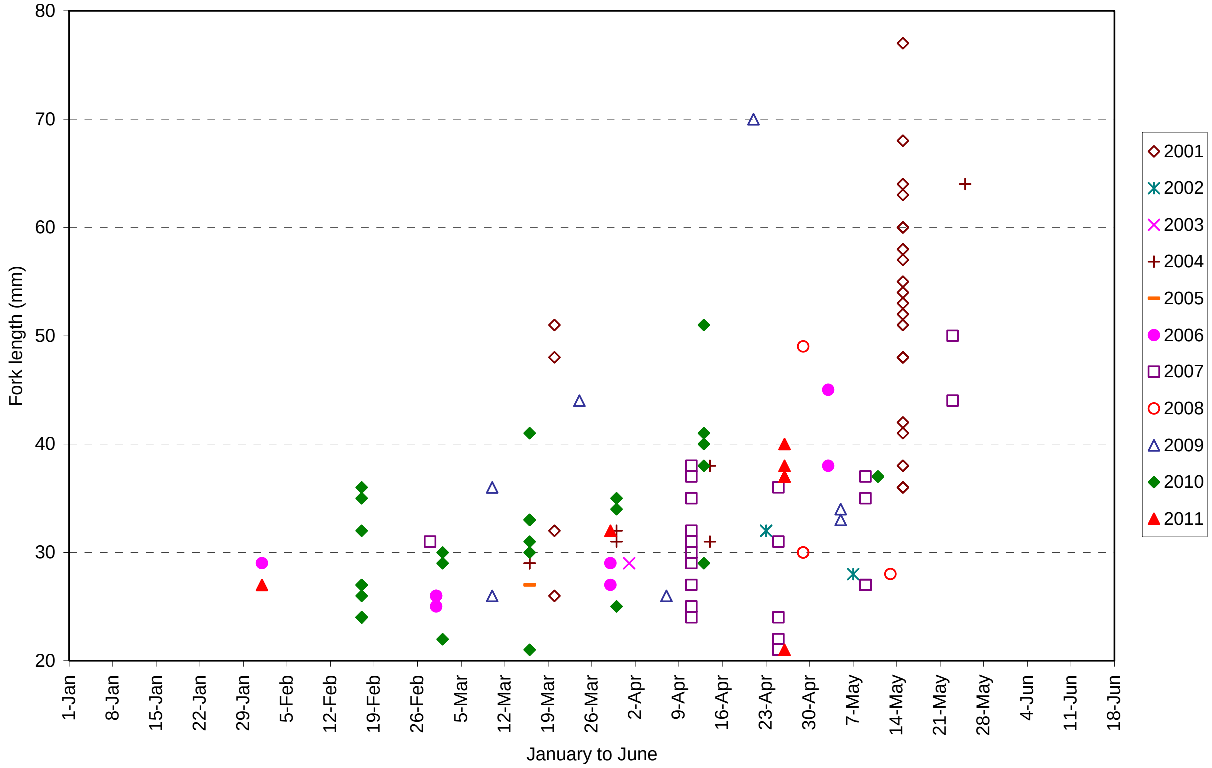

Figure 5.3-2. Seasonal sizes of juvenile *O. mykiss* captured during Tuolumne River seining surveys, 2001–2011.

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**

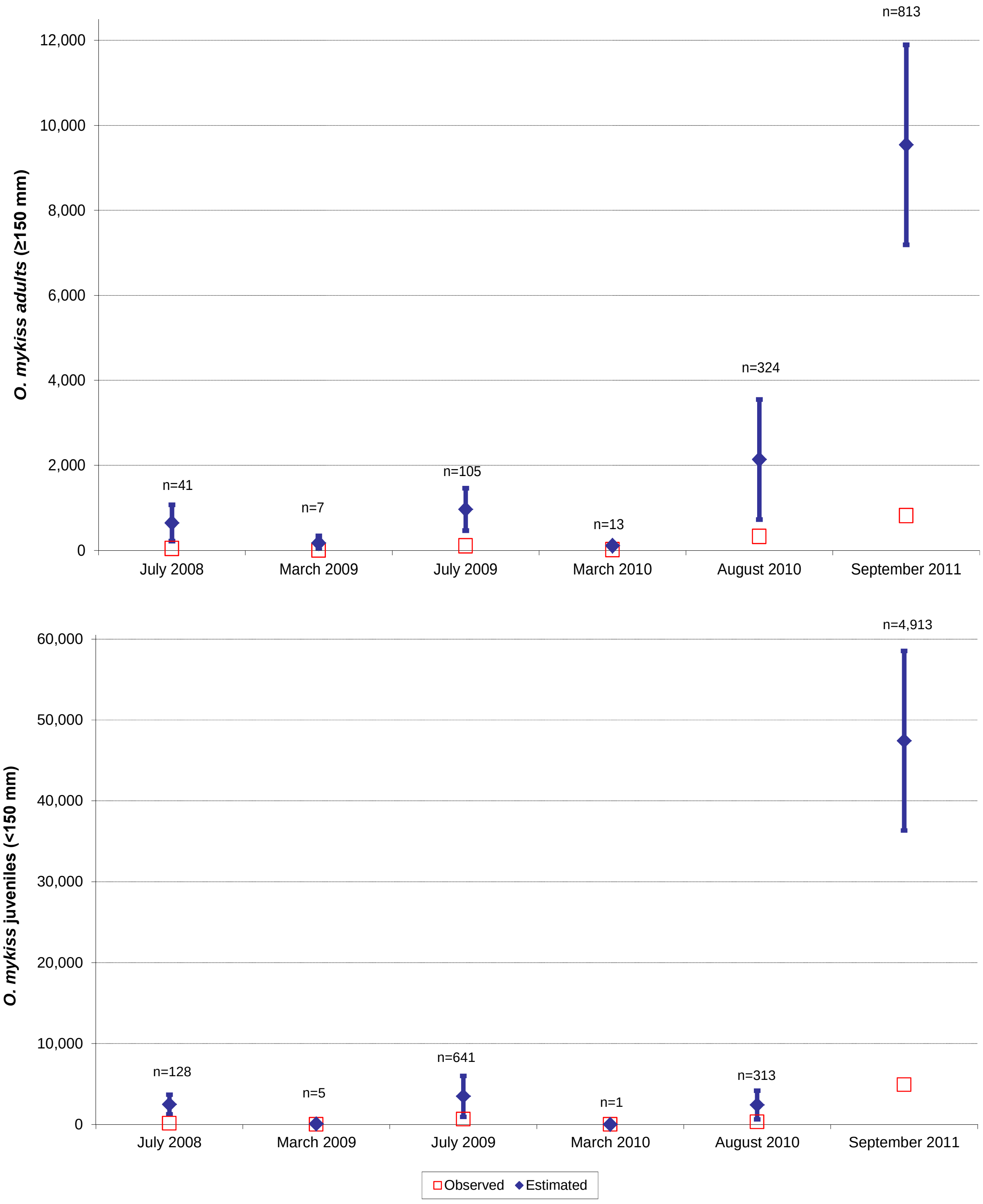

Figure 5.3-3. **Population size estimates (95% CI) of juvenile (<150 mm) and adult (≥150 mm) *O. mykiss* in the Tuolumne River, July 2008 through September 2011.**

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.

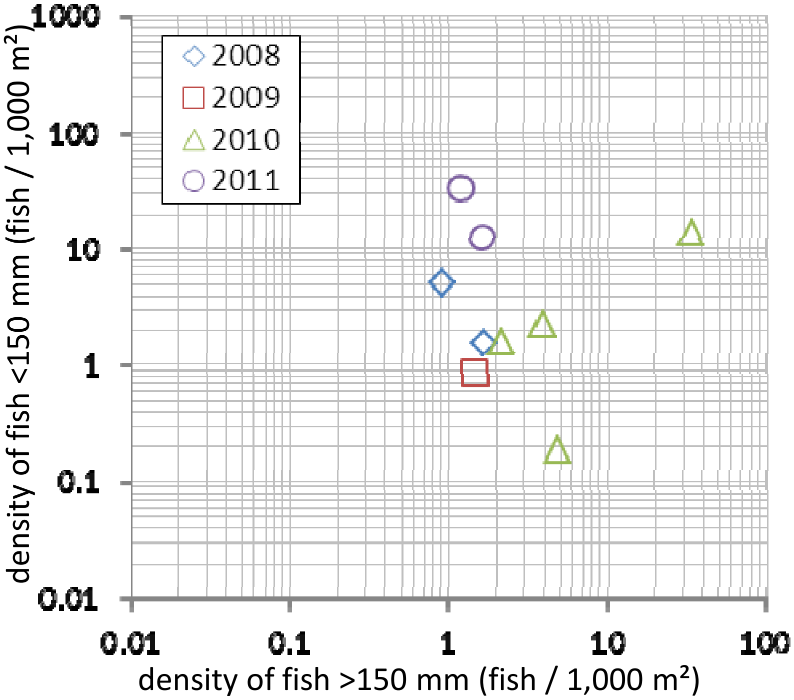

Figure 5.3-4. Comparison of Age 0+ vs. Age 1+ *O. mykiss* density in pool head habitats sampled in the Tuolumne River (2008-2011).

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

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[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.

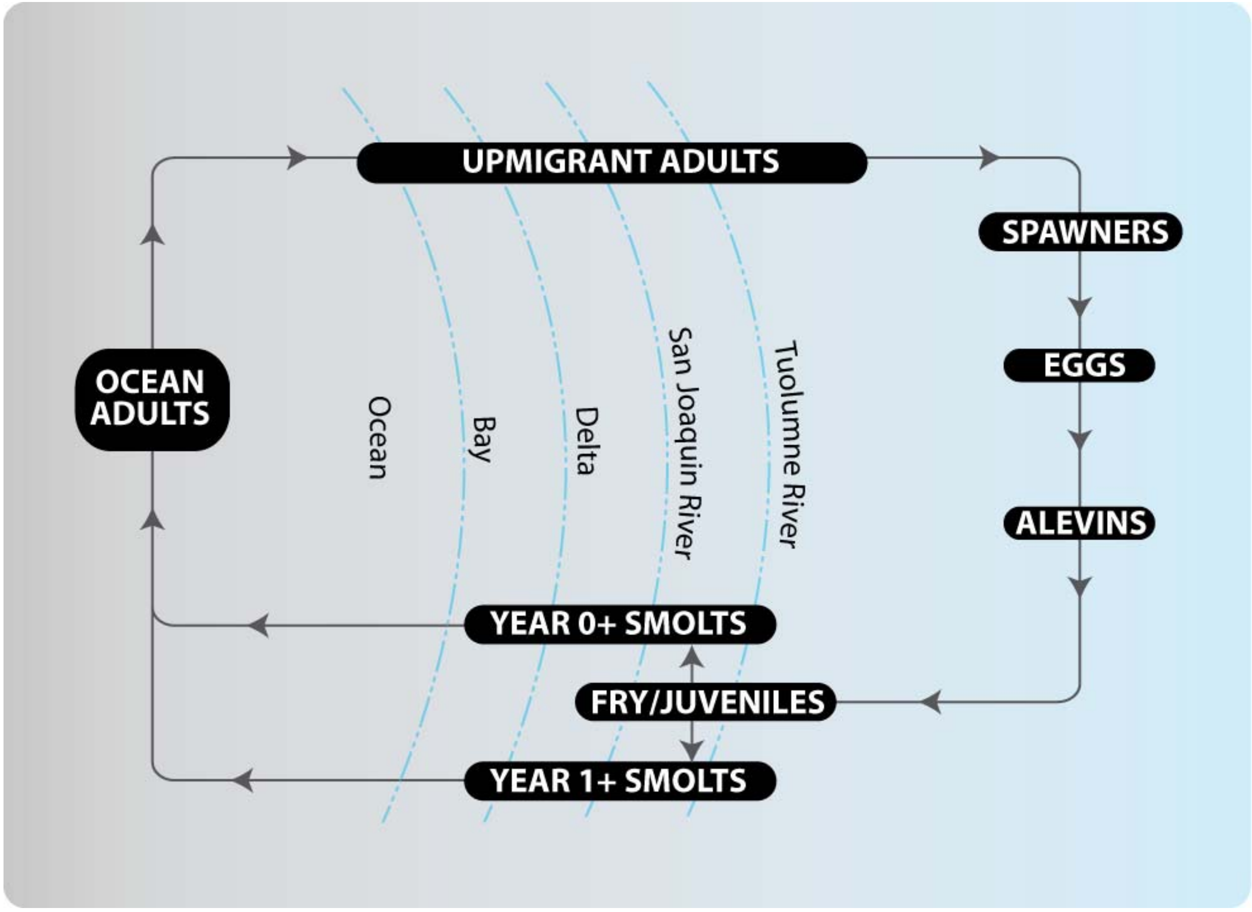

Figure B-1. Fall-run Chinook salmon life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.

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.

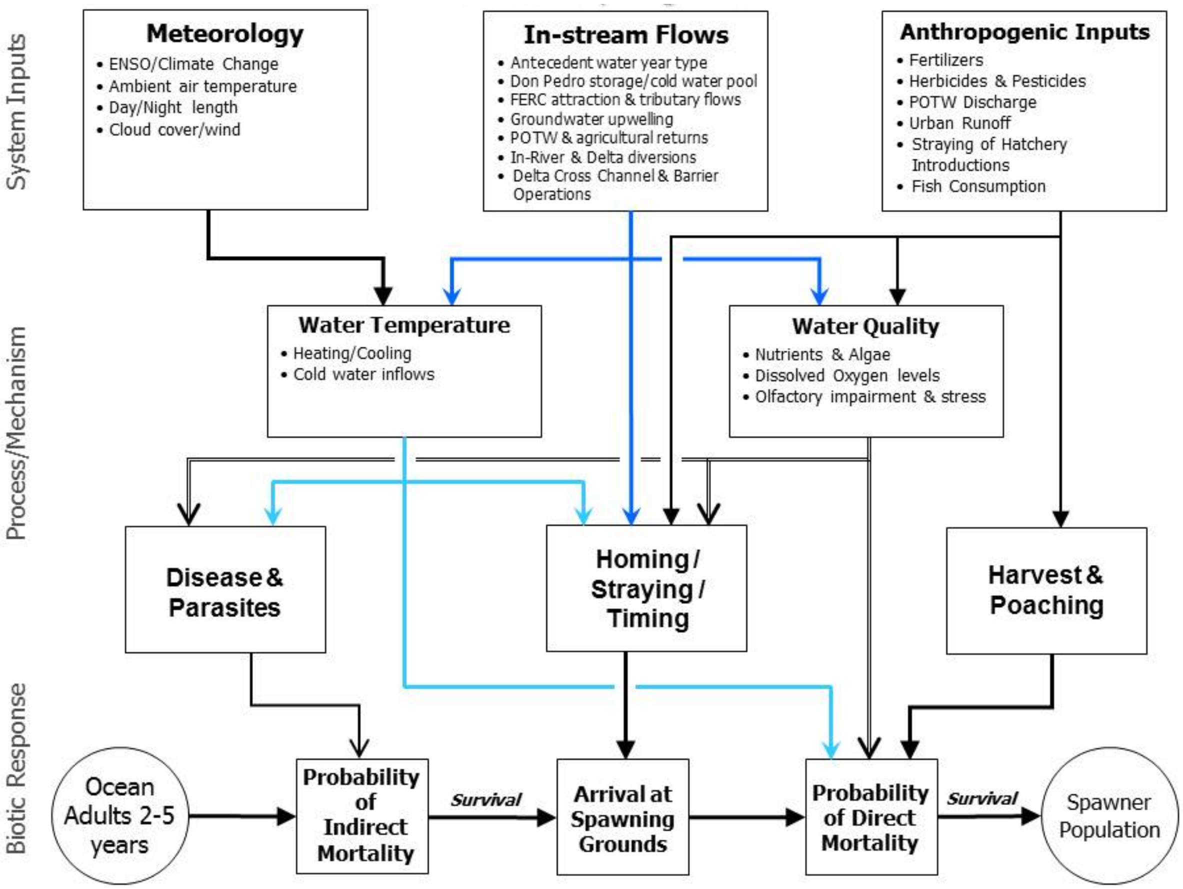

Figure B-2. **Potential issues affecting fall-run Chinook salmon upmigration through the San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.**

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.

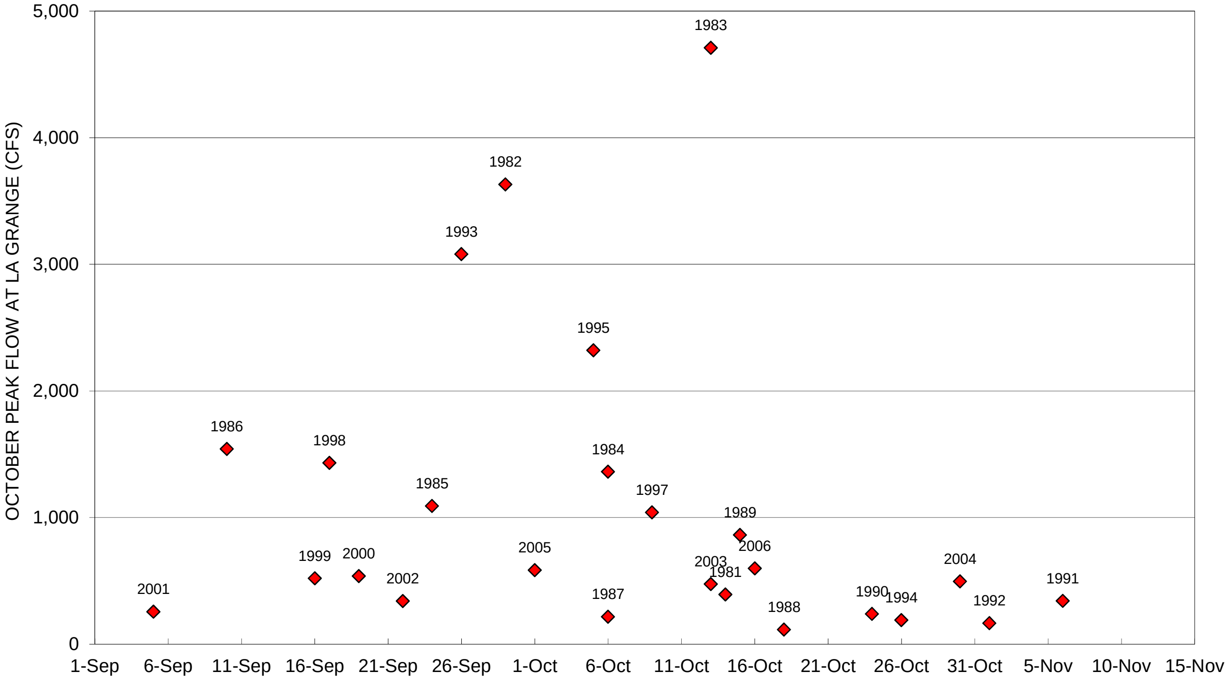

Figure B-3. **Relationship between Chinook salmon arrival timing as observed near La Grange and peak flows at La Grange during October from 1981–2006.**

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.

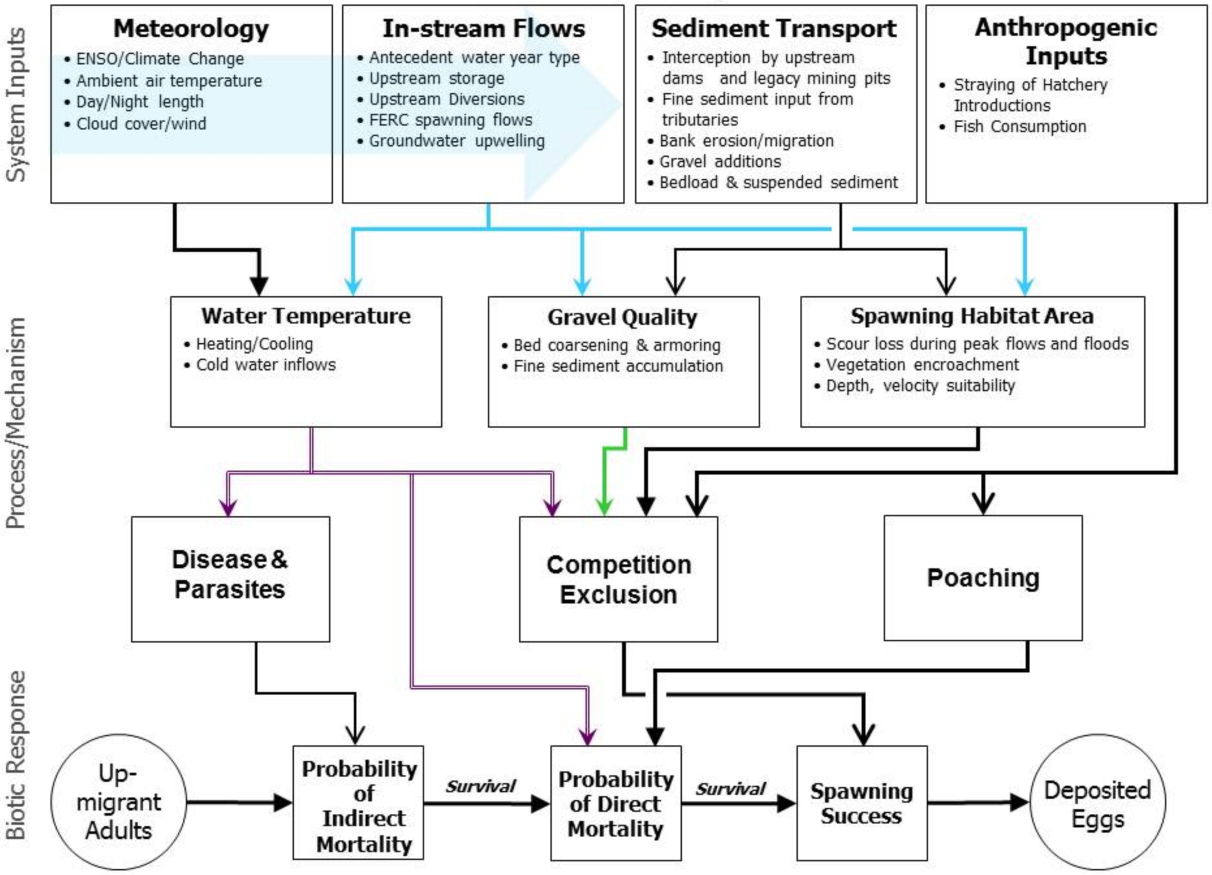

Figure B-4. **Potential issues affecting fall-run Chinook salmon spawning in the lower Tuolumne River.**

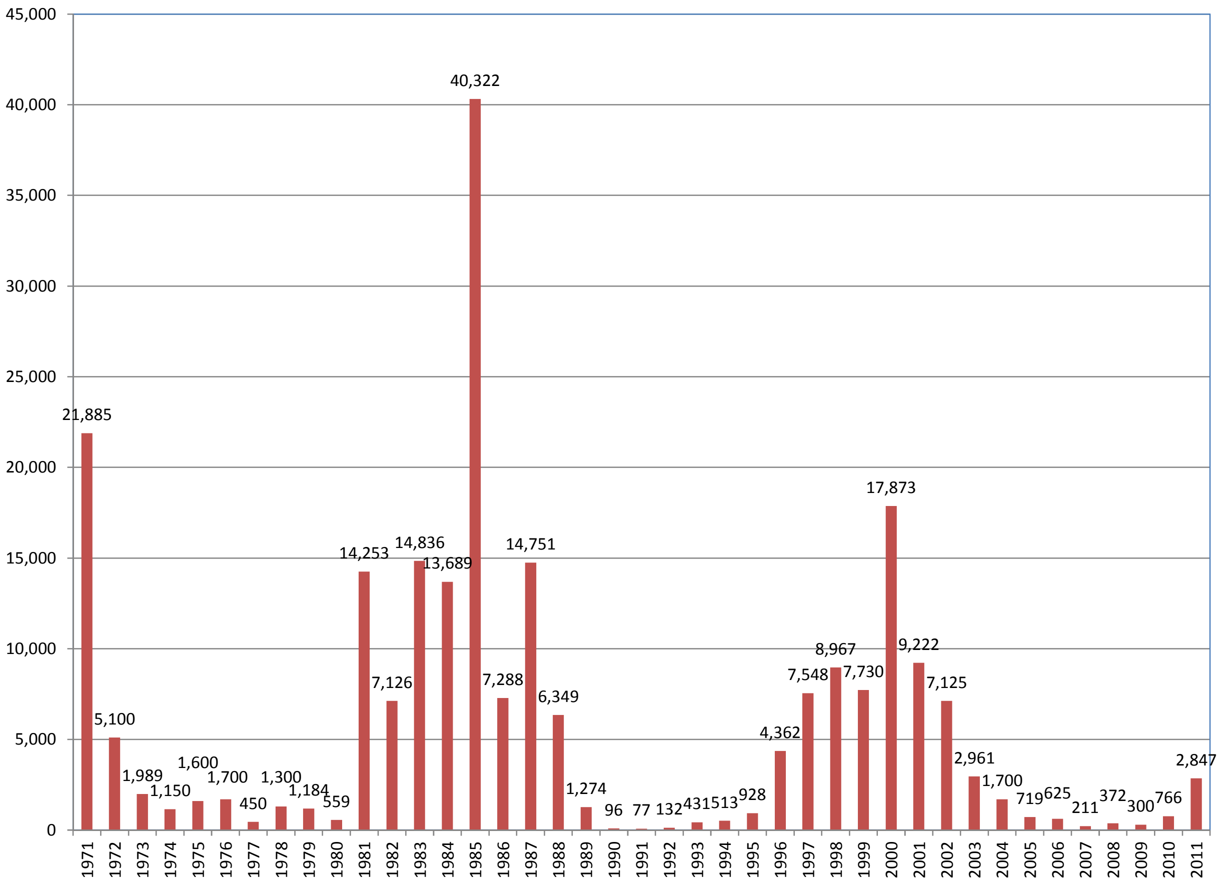

Figure B-5. **Tuolumne River Chinook salmon run estimates, 1971-2011 (Years 2009-2011 based on weir counts).**

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.

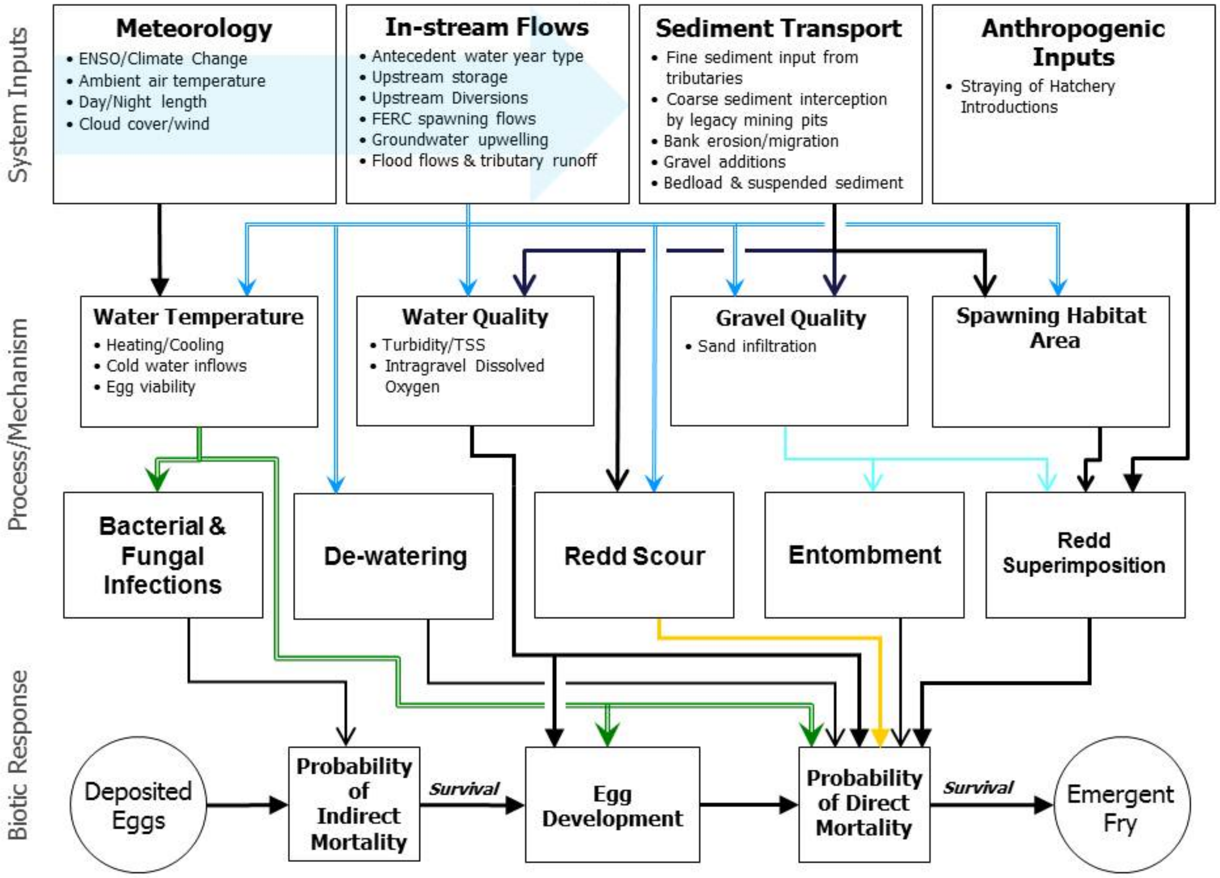

Figure B-6. **Potential issues affecting fall-run Chinook salmon egg incubation, alevin development, and fry emergence in the lower Tuolumne River.**

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,

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[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.

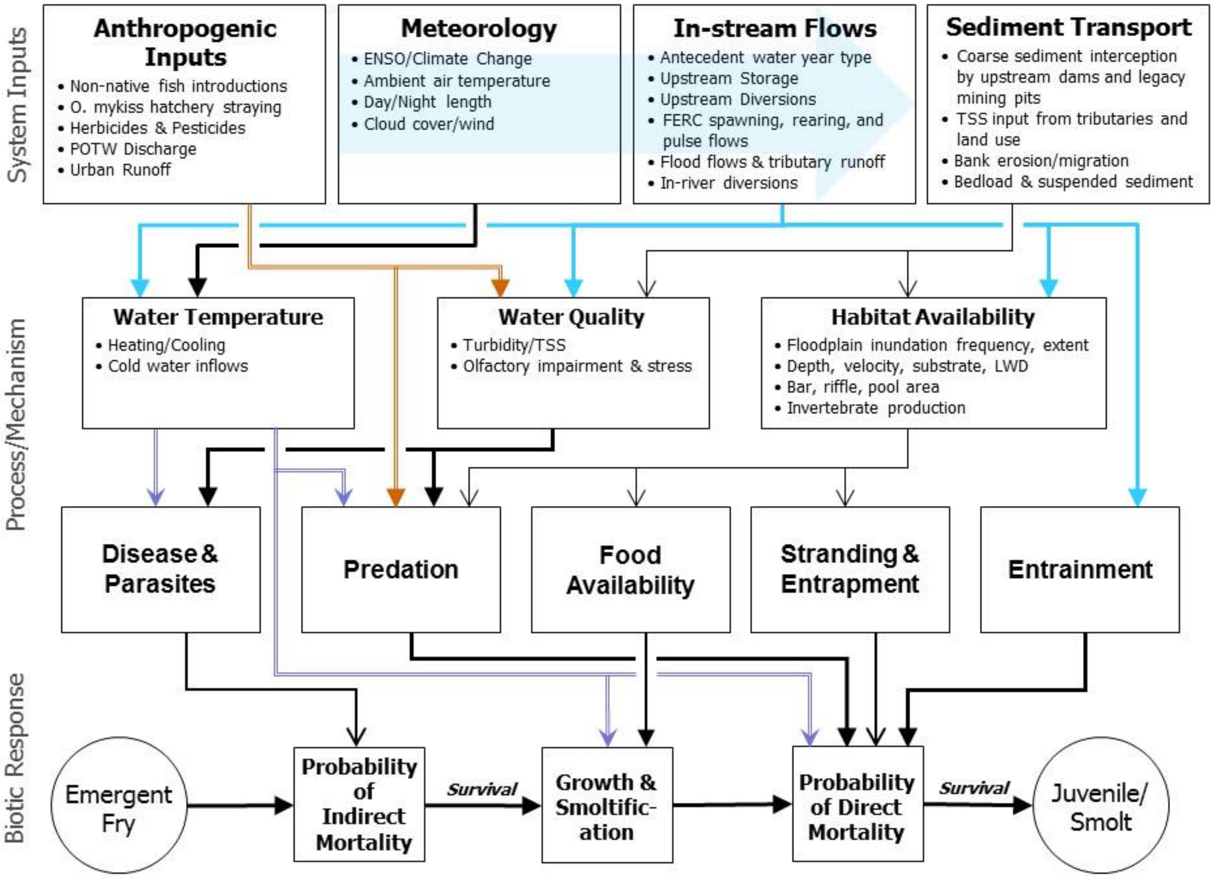

Figure B-7. **Potential issues affecting in-river rearing and smolt emigration of fall-run Chinook salmon from the lower Tuolumne River.**

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).

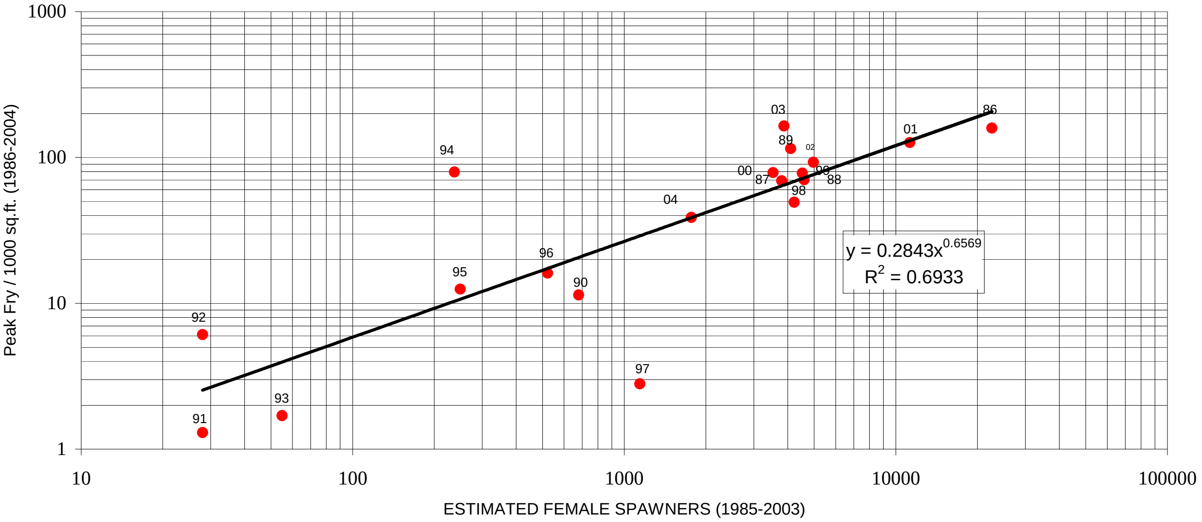

Figure B-8. **Relationship between peak salmon fry density in annual biweekly seine surveys and estimates of female spawners (1985–2003).**

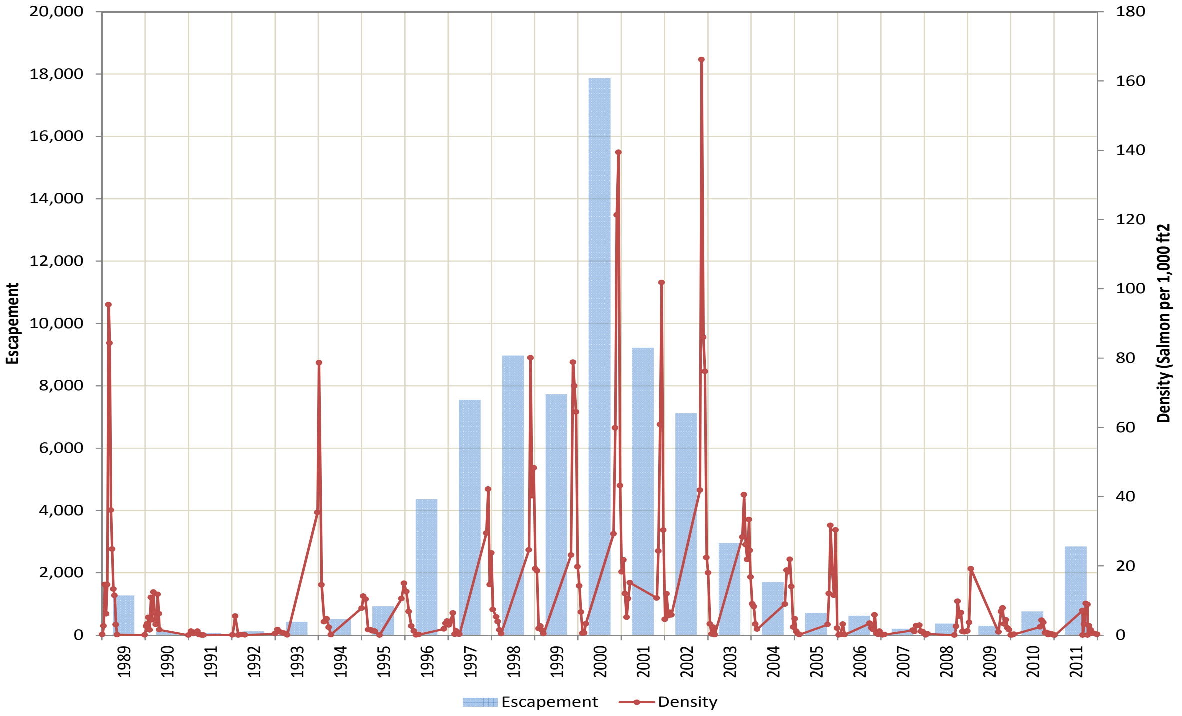

Figure B-9. **Average juvenile salmon density in all seine hauls by survey with estimated escapement (1989–2011).**

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.

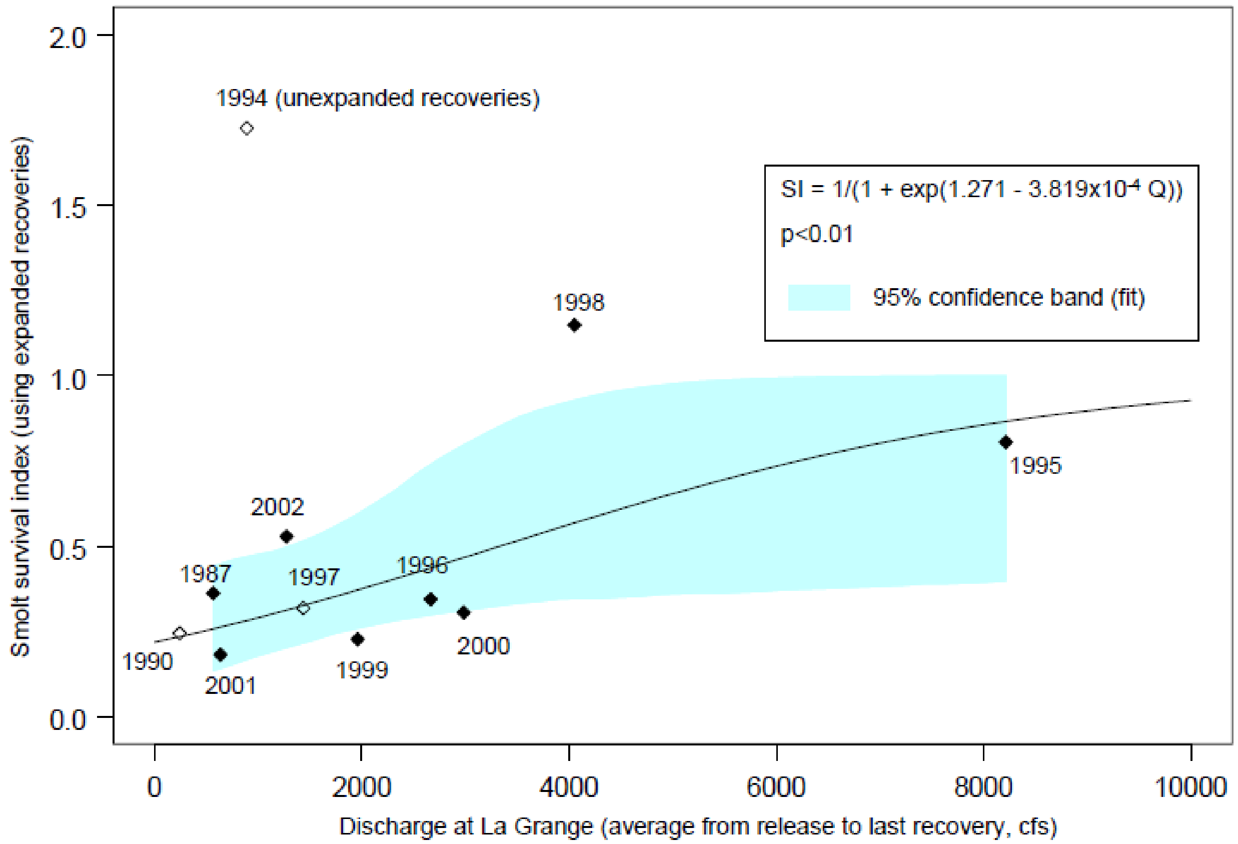

Figure B-10. Logistic regression of validated smolt survival indices by the recovery-weighted flow (cfs) at La Grange from release to last recapture at Mossdale Trawl.

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.

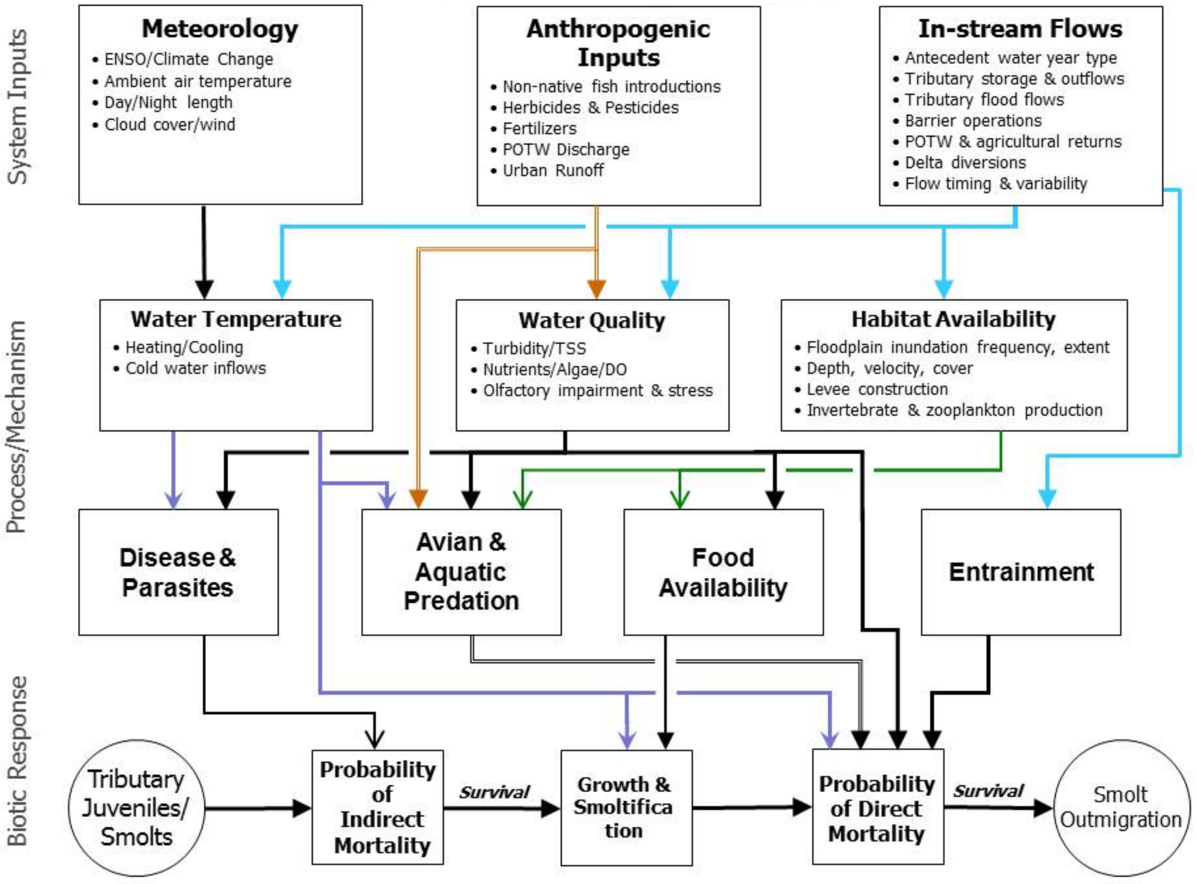

Figure B-11. Potential issues affecting Tuolumne River fall-run Chinook salmon juvenile rearing and smolt emigration from the Delta.

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.

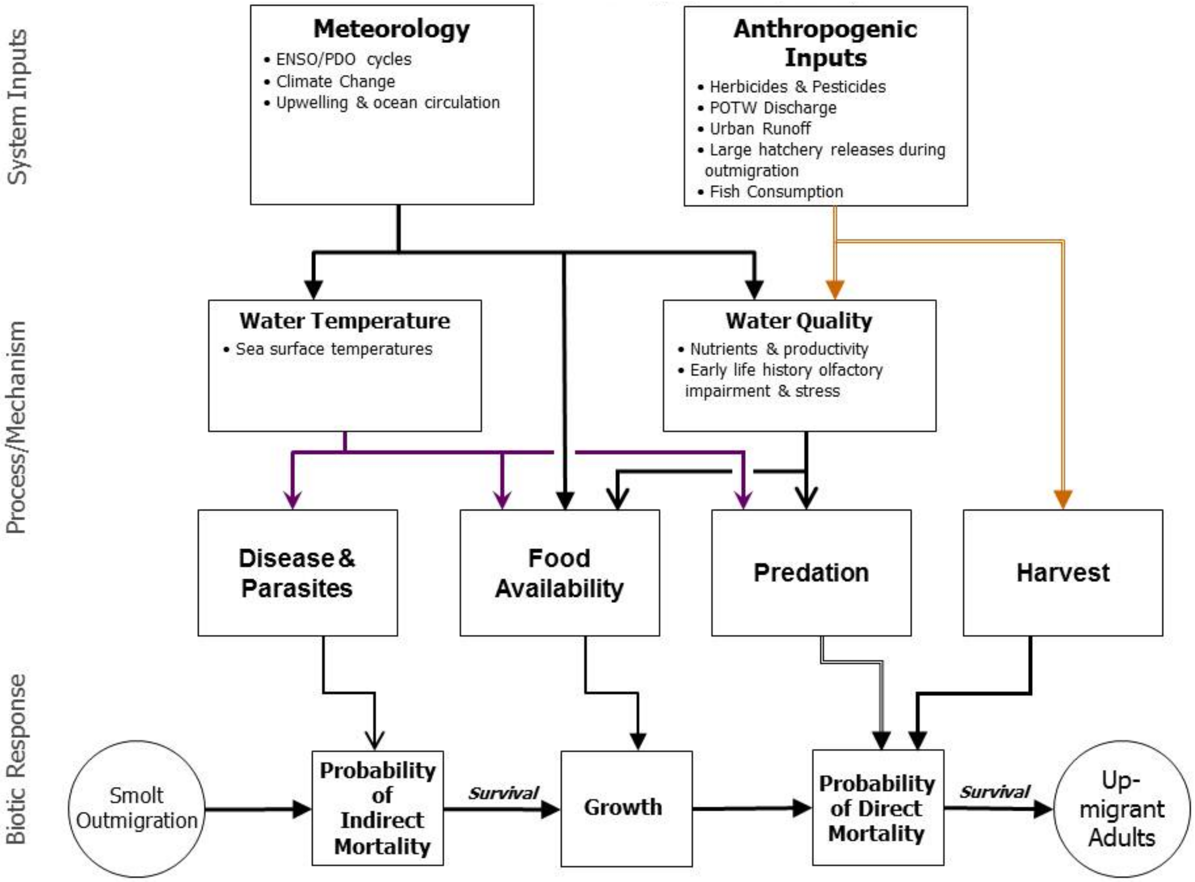

Figure B-12. Potential issues affecting Tuolumne River fall-run Chinook salmon during adult rearing in the Pacific Ocean.

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

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

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

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

information presented in the *Salmonid Populations Information Integration and Synthesis Study* report ("synthesis") regarding primary ecosystem inputs as well as historical habitat modifications and other factors affecting *O. mykiss*. These factors include, but are not limited to: 1) historical modifications to water supplies and instream flows (e.g., water development in the Tuolumne River and broader Central Valley, FERC (1996) instream flow requirements for the benefit of salmonids and other aquatic resources); 2) effects of historical water supply development (e.g., dam construction, hydrograph modification, Delta water exports, etc.) as well as in-channel and floodplain mining upon sediment supplies and transport; 3) anthropogenic influences on land uses along the lower Tuolumne River and Delta (e.g., agriculture, mining, urbanization, levees, etc.) as well as introductions of both chemicals (e.g., fertilizers, pesticides, herbicides, etc.) and non-native fish species (e.g., bass and other sport-fish, salmon hatcheries); 4) seasonal and longer-term variations (e.g., ENSO, PDO) in climate and meteorology upon local and regional water temperatures and runoff as well as broader effects upon ocean circulation and productivity. The following sections discuss issues affecting individual life stages (e.g., spawning gravel availability, predation, food availability, etc.), separated into mechanisms affecting reproduction, growth, as well as sources of direct and indirect mortality.

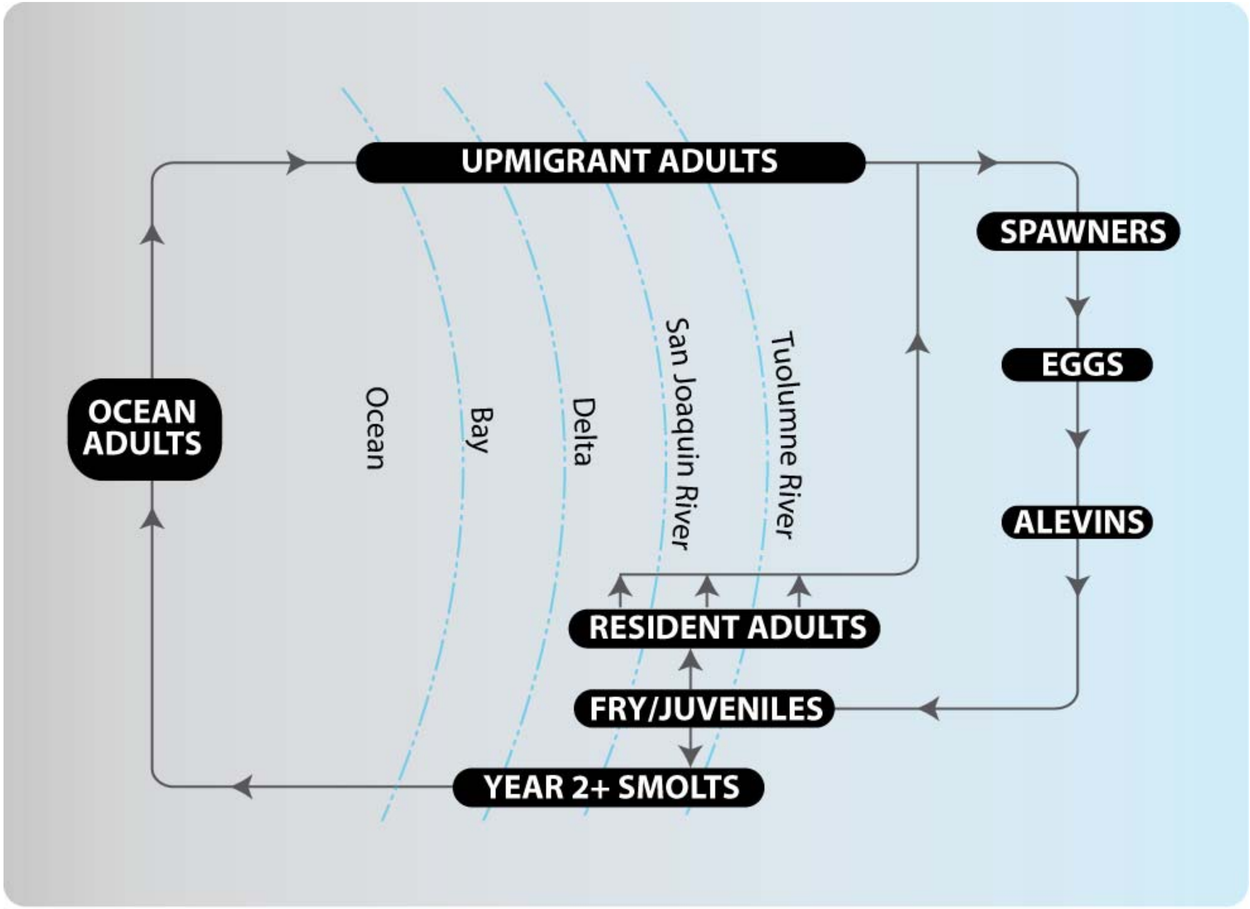

Figure C-1. **Central Valley steelhead and rainbow trout life cycle through the Pacific Ocean, San Francisco estuary, Delta, lower San Joaquin, and Tuolumne Rivers.**

2.0 STEELHEAD UPMIGRATION

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

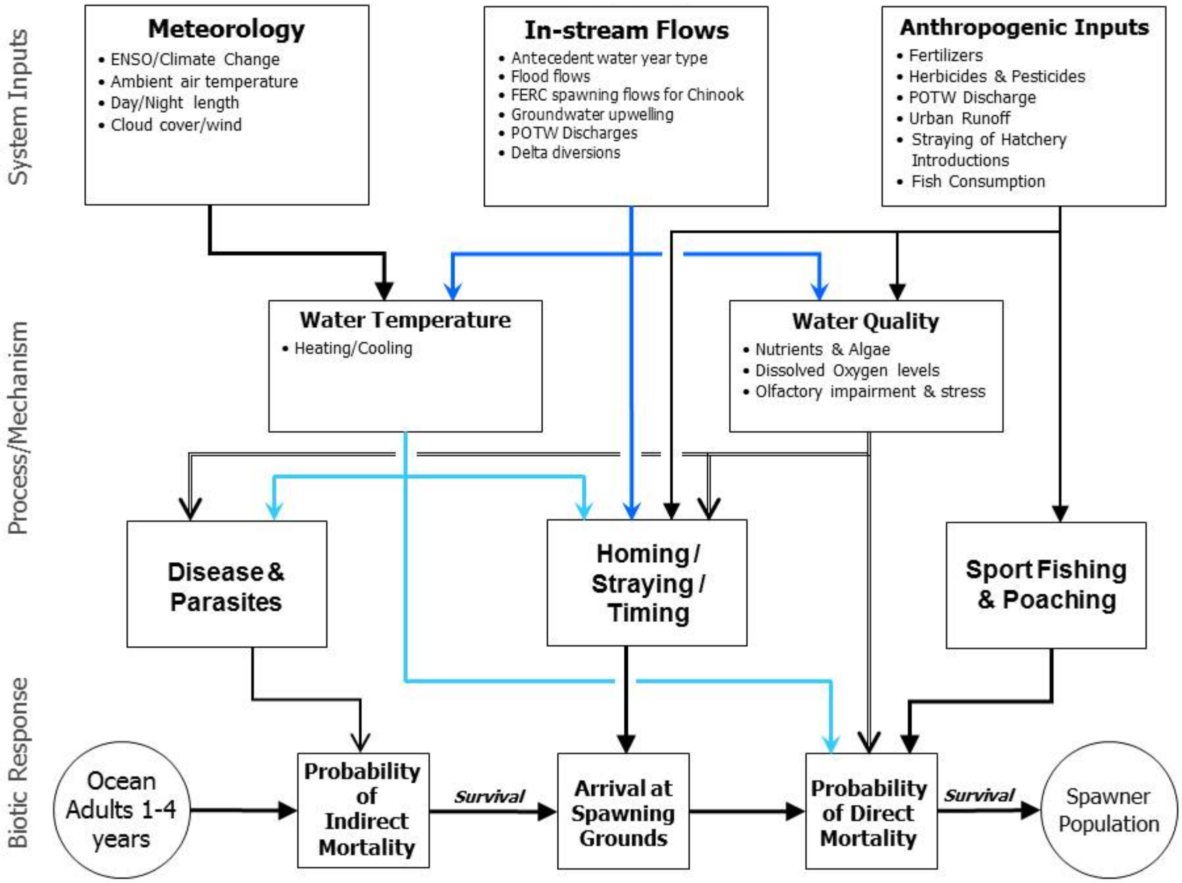

Figure C-2. Potential issues that may affect any Central Valley steelhead upmigration through the San Francisco estuary, Delta, lower San Joaquin River, and arrival in the Tuolumne River.

2.1 Processes/Mechanisms Affecting Arrival at Spawning Grounds

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

2.1.1 Flow Effects on Arrival Timing, Homing, and Straying

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

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

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

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

2.1.3 Influence of Hatchery Straying on Spawning Ground Arrival

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

2.2 Processes/Mechanisms Affecting Direct Mortality

2.2.1 Water Quality

In addition to factors affecting instream flows in the San Joaquin River and Delta, anthropogenic inputs of nutrients, as well as accidental discharges of other contaminants may result in unsuitable water quality conditions for migrating adult steelhead. However, mortality of adult steelhead is unlikely to result from water quality impairments such as DO depletion from algal and bacterial respiration or from episodic toxicity events. For this reason, water quality effects on direct mortality during steelhead upmigration are not considered further in this Synthesis Study.

2.2.2 Water Temperature

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

2.2.3 Sportfishing and Poaching

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

2.3 Processes/Mechanisms Affecting Indirect Mortality

2.3.1 Disease and Parasites

As examined in the current *Water Temperature Modeling Study* (Study W&AR-15), local meteorology and instream flows in the lower Tuolumne River are well related to instream water temperatures. During Upmigration through the Delta and lower San Joaquin River, elevated water temperatures and adverse water quality conditions which in turn, may contribute to stress and disease (Holt et al. 1975, Wood 1979). Wild steelhead may also contract diseases which are spread through the water column (Buchanan et al. 1983), and in some cases disease may lead to mortality of adults prior to spawning, though this has not been documented in the Tuolumne River. Many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for *Renibacterium salmoninarum* (Foott 1992). However, there are no known data indicating that disease or parasites are likely to contribute to indirect mortality (e.g., via physiological stress or pre-spawn mortality) for adult steelhead during upstream migration to the Tuolumne River. Given the general up-migration timing of adult steelhead (i.e., winter-run) and because of the short exposure time to potentially adverse water quality conditions during upmigration, disease and parasite effects upon steelhead during upmigration are not considered further in this synthesis.

3.0 *O. MYKISS* SPAWNING

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

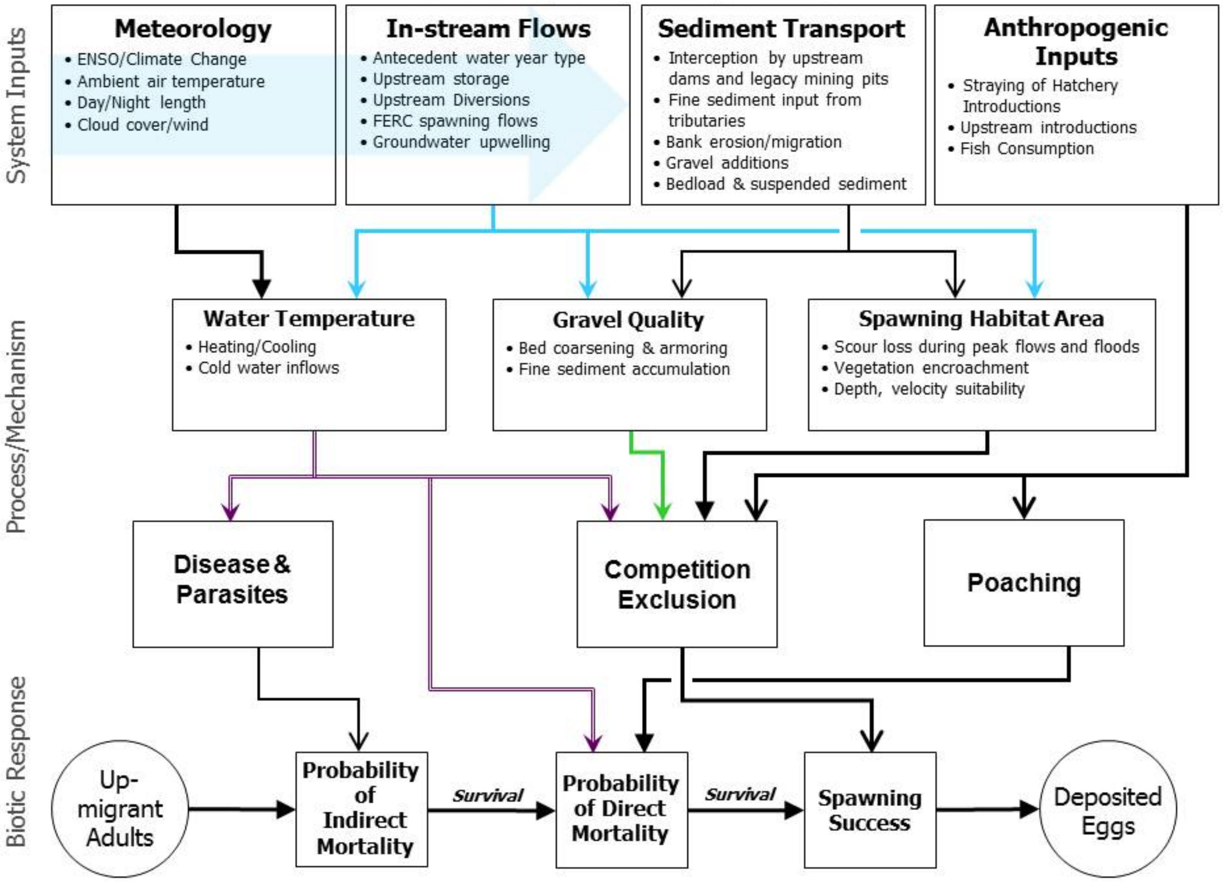

Figure C-3. Potential issues affecting *O. mykiss* spawning in the lower Tuolumne River.

3.1 Processes/Mechanisms affecting Spawning Success

3.1.1 Effects of Spawning Habitat Availability

As with the corresponding discussion for Chinook salmon above, Figure C-3 shows spawning habitat area availability in the lower Tuolumne River (RM 52–24) is affected by meteorological effects upon precipitation and flood flows, flows provided by the Project for spawning under the current FERC (1996) license, as well as long-term effects of upstream dams upon sediment supply and transport (McBain and Trush 2000, 2004). Other than isolated observations of *O. mykiss* carcasses in annual spawning reports (e.g., TID/MID 2001, Report 2001), spawning locations used by *O. mykiss* has not been well documented in spawning surveys extending from mid-October to mid-January in most years (e.g., TID/MID 2012, Report 2011-2). Roelofs (1983) suggested that steelhead may use smaller tributary streams for spawning to reduce mortality risks due to redd scour as well as lower predator densities. The current *Redd Mapping Study* (Study W&AR-8) will document locations of any *O. mykiss* spawning occurring in 2013 and the current *Spawning Gravel Study* (W&AR-4) provides an estimate of gravel availability and the river-wide distribution of suitable spawning habitat.

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

3.1.2 Effects of Spawning Gravel Quality

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

3.1.3 Effects of Water Temperature

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

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

3.1.4 Effects of Hatchery Straying

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

3.2 Processes/Mechanisms Affecting Direct Mortality

3.2.1 Sportfishing and Poaching

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

3.2.2 Water Temperature

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

3.3 Processes/Mechanisms Affecting Indirect Mortality

3.3.1 Disease and Parasites

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

4.0 EGG INCUBATION

As shown in Figure C-4, several processes and mechanisms may potentially affect egg incubation and fry emergence of *O. mykiss* in the lower Tuolumne River, including meteorological and instream flow effects upon sediment transport, gravel quality, water quality, water temperature, as well as the influence of stray hatchery fish from other systems. Although *O. mykiss* spawning has not been well documented in the Tuolumne River to date, the following section provides inferences regarding habitat conditions for any *O. mykiss* spawning that may occur in the Tuolumne River based upon assessments of local habitat conditions, data from juvenile monitoring, as well as inferences from reviews of other information sources from the San Joaquin River, the Central Valley, and the Pacific Northwest.

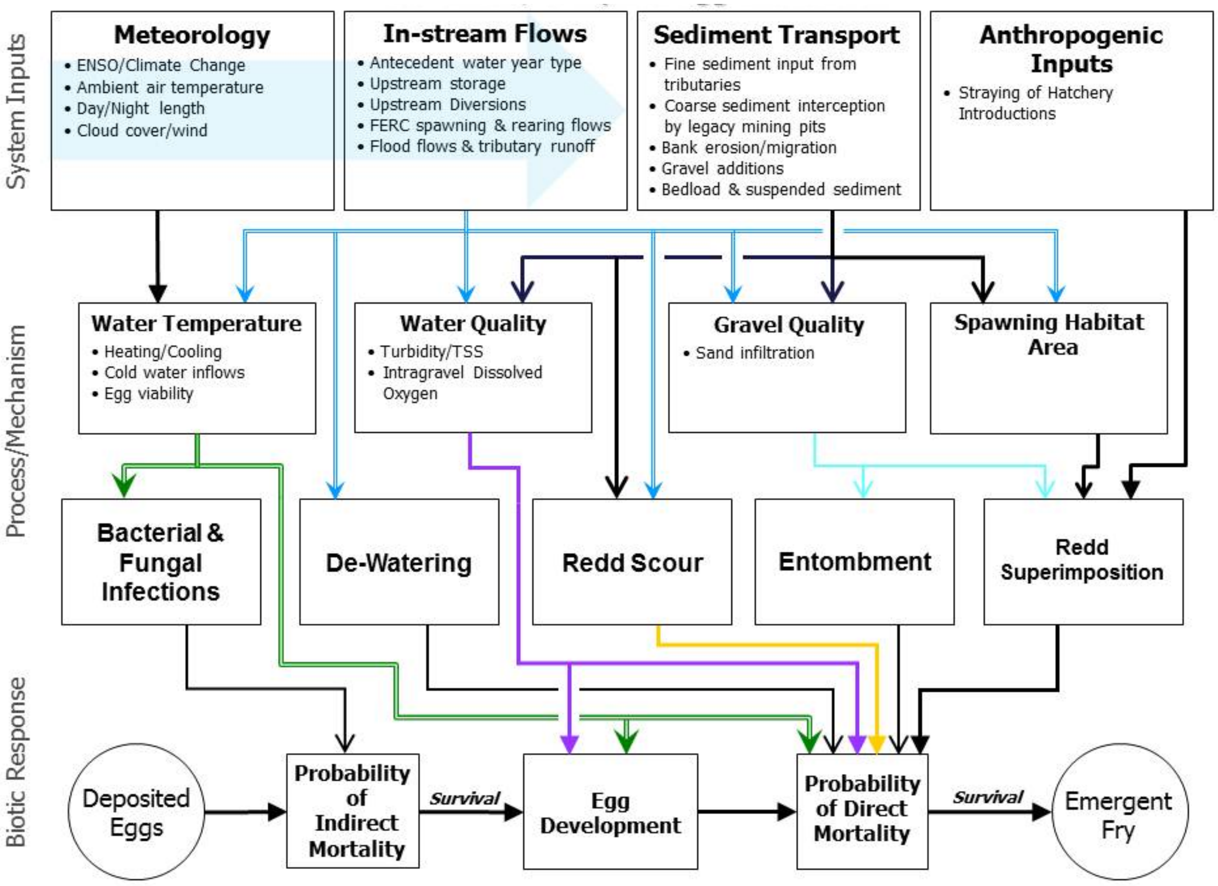

Figure C-4. **Potential issues affecting *O. mykiss* egg incubation, alevin development, and fry emergence in the lower Tuolumne River.**

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

4.1.1 Water Temperature

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

4.1.2 Water Quality

As with water temperature discussed above, successful *O. mykiss* embryo and alevin development and emergence is dependent upon suitable water quality conditions, such as intragravel dissolved oxygen concentrations. Water column dissolved oxygen levels are generally at or near saturation in the Tuolumne River, as measured downstream of Don Pedro and La Grange Dams as part of the current *Water Quality Assessment Study* (W&AR-1) and in prior assessments during spring 2004 (TID/MID 2005b, Report 2004-10). Intragravel dissolved oxygen conditions measured in artificial redds during February 2001 were in the range of 7–12 mg/L (TID/MID 2007, Report 2006-7) and it is unlikely that dissolved oxygen levels are adversely affecting egg incubation or alevin development.

4.2 Processes/Mechanisms Affecting Direct Mortality

4.2.1 Water Temperature

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

4.2.2 Water Quality

Variations in instream flows, water temperatures, as well as sediment transport may affect hyporheic water quality conditions such as intragravel dissolved oxygen and turbidity (e.g., Healey 1991, Williams 2006). Intragravel dissolved oxygen measurements were found in the range of 7–12 mg/L on the Tuolumne River (TID/MID 2007, Report 2006-7) and intragravel dissolved oxygen conditions measured in Chinook salmon incubation studies on the nearby Stanislaus River also generally ranged near 8–11 mg/L (Mesick 2002). Based upon these studies, although no *O. mykiss* spawning has been documented to date, it is unlikely that intragravel water quality conditions contribute to high rates of egg mortality on the Tuolumne River.

4.2.3 Redd Superimposition

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

4.2.4 Redd Scour

McBain and Trush (2000) suggested that habitat simplification and flow regulation by upstream dams on the lower Tuolumne River may result in increased vulnerability of redds to scour during flood events. The depth of egg pockets for *O. mykiss* redds is generally lower than for Chinook salmon (Devries 1997). Lapointe et al. (2000) reviewed several gravel transport studies to show that the thickness of the mobilized layer during flood-scour events is often less than the depth of normal egg pockets. For this reason, although redd scour may occur at some locations during flood conditions, and the current *Redd Mapping Study* (W&AR-8) may identify redd locations particularly vulnerable to scour, redd scour is not considered to contribute to high rates of direct egg mortality of *O. mykiss* and is not considered further in this synthesis.

4.2.5 Redd Dewatering

Redd dewatering can impair development and also cause direct mortality of salmonid eggs and alevins as a result of desiccation, insufficient oxygen, and thermal stress (Becker and Neitzel 1985). Although the current FERC spawning flow requirements are designed to protect against redd-dewatering, because *O. mykiss* spawning may occur later during the winter spring there is an increased likelihood of *O. mykiss* spawning at locations more vulnerable to dewatering during extended flood control releases. Williams (2006) discusses the implications of varying reservoir releases necessary to maintain flood storage space during periods of salmonid spawning on other Central Valley Rivers, but no incidences of *O. mykiss* stranding or dewatering were identified during literature reviews for this Synthesis. For this reason, only isolated redd dewatering incidents may potentially occur during flow reductions following flood control releases as well as during unplanned operational outages. Although the current *Redd Mapping Study* (W&AR-8) may identify redd locations particularly vulnerable to dewatering, redd dewatering is not considered to contribute to high rates of egg mortality and is not considered further in this Synthesis.

4.2.6 Entombment

Fine sediment intrusion was suggested to contribute to Chinook salmon egg and alevin mortality in prior survival-to-emergence modeling (TID/MID 1992, Appendix 8; TID/MID 2001, Report 2000-7), and fine sediment may potentially result in entombment of completed redds by effectively sealing the upper layers of redds and obstruct the emergence of alevins, causing subsequent mortality (Phillips et al. 1975, Barnhart 1986). The current *Redd Mapping Study* (W&AR-8) may identify redd locations vulnerable to entombment from fine sediment intrusion, such as at the mouths of Gasburg, Peaslee, and Dominici Creeks that have been shown to provide a continuing source of fine sediments to the lower Tuolumne River (McBain and Trush 2004, Appendix E). However, based upon suitable intra-gravel dissolved oxygen and the absence of entombment in Chinook salmon survival-to-emergence studies (TID/MID 2001, Report 2000-7), *O. mykiss* egg/alevin entombment mortality is unlikely.

4.3 Processes/Mechanisms Affecting Indirect Mortality

4.3.1 Bacterial and Fungal Infections

No information has been identified on disease incidence for incubating *O. mykiss* eggs in the Central Valley or in broader studies. Egg infection and subsequent diseases incidence in juvenile and adult salmonids is generally only been raised as an issue of concern in intensive fish culture practices at hatcheries (e.g., Scholz 1999). Further, because diseases incidence on incubating eggs in the wild has not been observed in the Tuolumne River or other Central Valley Rivers, bacterial and fungal infections of eggs and alevins is not expected to contribute to indirect mortality of steelhead/*O mykiss* and is not considered further in this Synthesis.

5.0 IN-RIVER REARING/OUTMIGRATION

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

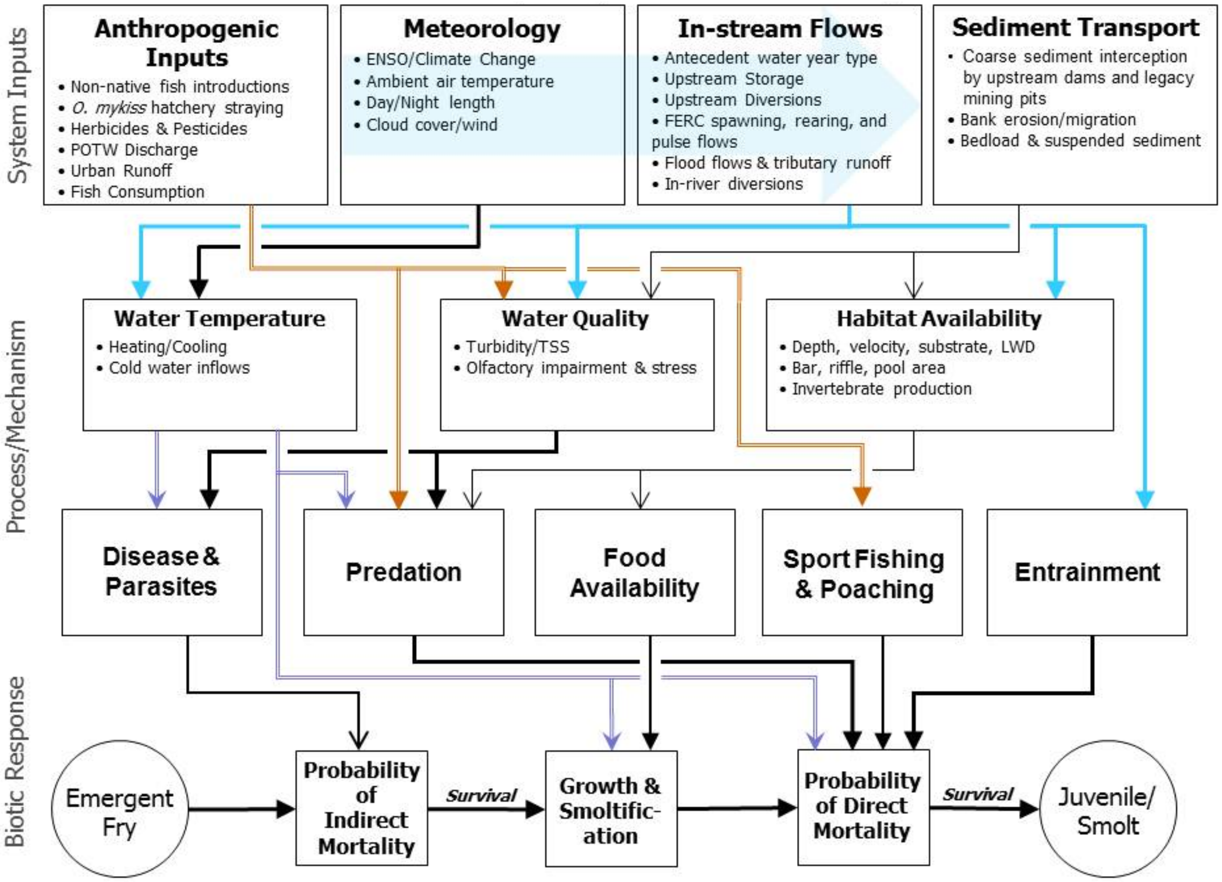

Figure C-5. **Potential issues affecting in-river rearing of juvenile *O. mykiss* and smolt emigration of any Central Valley steelhead from the lower Tuolumne River.**

5.1 Processes/Mechanisms affecting Juvenile Growth and Smoltification

5.1.1 In-channel and Floodplain Habitat Availability

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

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

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

At river flows near bankfull discharge and above, two-dimensional (2D) hydraulic modeling was conducted by in 2011 conducted for a range of flows (1,000–5,000 cfs) at three sites in the lower Tuolumne River (RM 48.5, RM 48.0, and RM 44.5) to provide estimates of suitable salmonid rearing habitat area at the study sites (Stillwater Sciences 2012b). Although juvenile *O. mykiss* are generally not found using floodplain habitats in the Tuolumne River or in floodplain studies in the Cosumnes River (Moyle et al. 2007), the results of the study show increased flows are associated with increased areas of suitable juvenile rearing habitat on floodplains at the study sites as flows increase above bankfull discharge, with habitat area rapidly increasing between discharges of 1,000 cfs to 3,000 cfs. It should be noted that the majority of floodplain habitat available at the flows studied (1,000–5,000 cfs) is limited to several disturbed areas between RM 51.5 and RM 42 formerly overlain by dredger tailings (Stillwater Sciences 2012).

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

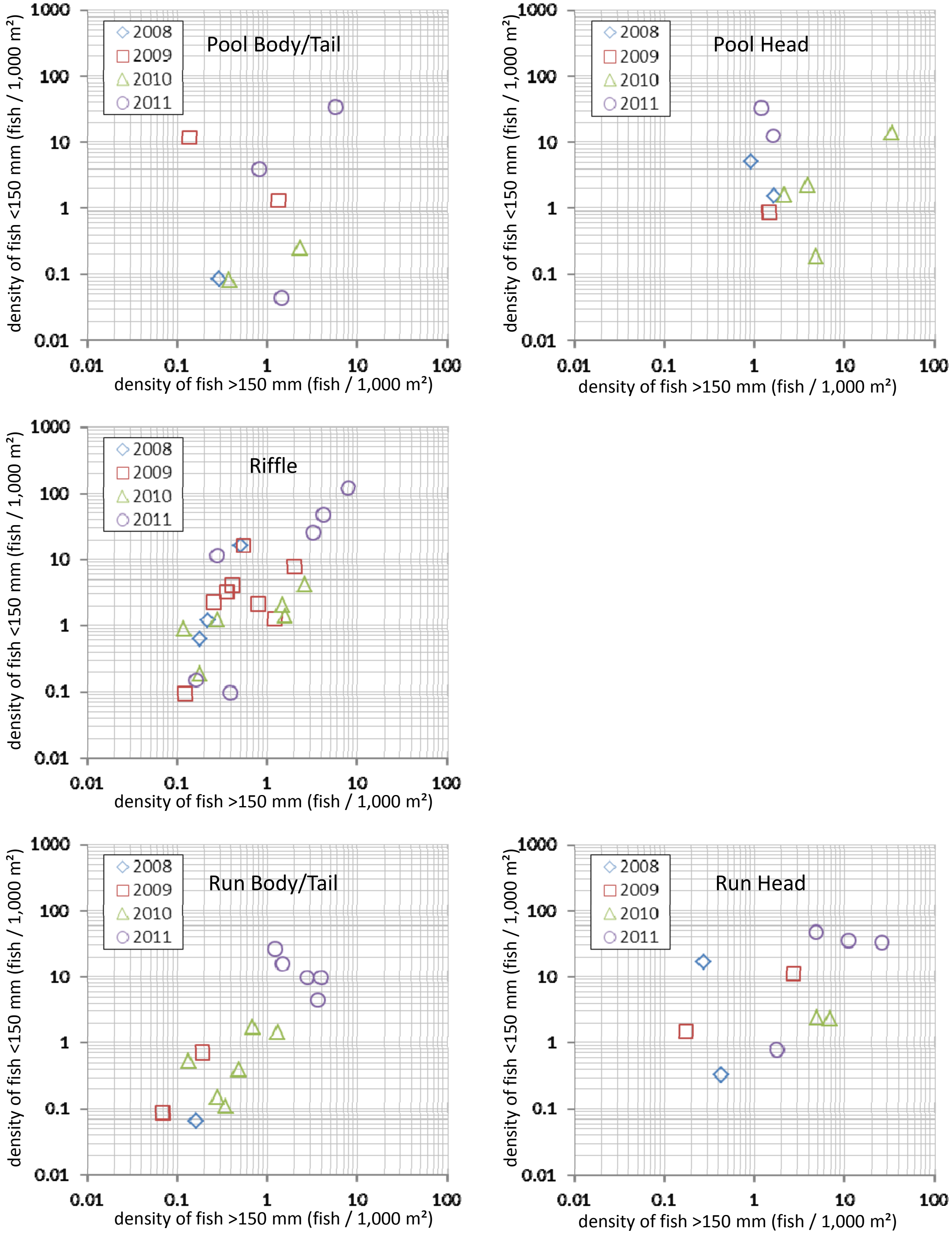

Figure C-6. **Comparison of Age 0+ vs. Age 1+ *O. mykiss* density in various habitat types sampled by snorkeling in the Tuolumne River (2008-2011).**

5.1.2 Water Temperature Effects on Growth and Smoltification

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

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

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

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

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

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

5.1.3 Food Availability Effects on Growth and Smoltification

As with Chinook salmon juveniles, food availability and growth rates of juvenile *O. mykiss* are affected by BMI, terrestrial and aquatic insect drift. No direct studies of *O. mykiss* feeding or diet have been conducted on the Tuolumne River. General steelhead diet information is well documented in the literature (Shapolov and Taft 1954, Bilby et al. 1998), and the diets of sub-yearling steelhead have been described for the American River (Merz and Vanicek 1996). As summarized by Merz (2002) for a Mokelumne River study, the diet of Age 0+ steelhead on the lower Mokelumne River was comprised of larval insects; similar to that reported by other studies. Long-term monitoring of BMI (TID/MID 1997, Report 1996-4; TID/MID 2003, Report 2002-8; TID/MID 2005, Report 2004-9; TID/MID 2009, Report 2008-7) has shown consistent densities of primary salmonid prey organisms and metrics suggestive of ecosystem "health" and adequate food supply for juvenile salmonids. For older age classes (Age 1+ and above), opportunistic feeding of upon other prey items as well as attached algae was observed on the Mokelumne River, and stomach content analysis also revealed the presence of Chinook salmon eggs and newly emerged fry in their diets during fall and winter 1998 (Merz 2002). Although no data are available to assess the condition of *O. mykiss* juveniles in the lower Tuolumne River, the high lipid content in Tuolumne River Chinook salmon smolts studied by Nichols and Foott (2002) suggest adequate food resources for rearing and potential smoltification of steelhead. However, because Tipping and Byrne (1996) found that artificial food limitation and lower condition factor in *O. mykiss* promoted a greater tendency for smoltification and outmigration than smolts that had higher food levels and higher condition factor, it is unknown whether the relatively high food availability in the Tuolumne River may currently select for a greater proportion resident *O. mykiss* rather than anadromous steelhead.

5.2 Processes/Mechanisms Affecting Direct Mortality

5.2.1 Water Temperature

Meteorology and to a minor degree instream flows combine to affect exposure of rearing juvenile *O. mykiss* trout to changes in water temperatures with varying probabilities of direct mortality. Since 1988, the Districts have conducted model predictions of water temperature with flow (TID/MID 1992, Appendices 18–19; Stillwater Sciences 2011) and the current *Lower Tuolumne River Temperature Model Study* (W&AR-16) provides current estimates of the relationships between flow and water temperature. In a water temperature review by Myrick and Cech (2001), juvenile Central Valley steelhead thermal tolerances are shown to be a function of acclimation temperature and exposure time and fish acclimated to high temperatures tend to show greater heat tolerance than those acclimated to cooler temperatures. Using a critical thermal maxima of 25°C (77°F) identified by Myrick and Cech (2001) associated with the increased probability of water temperature related mortality, water temperatures may exceed this threshold by July and August in some summers in the vicinity of Robert's Ferry Bridge (RM 39.5), with temperatures in excess of this level routinely found during summer at locations downstream of RM 23.6 (TID/MID 2005a). Although low rates of mortality due to water temperature are suggested by reduced numbers of over-summering juvenile *O. mykiss* (Table C-2), direct temperature mortality of juveniles is unlikely to occur during springtime rearing and emigration. Water temperature effects upon indirect mortality due to predation are discussed further below and comparisons of relevant water temperature criteria and water temperature conditions is provided in the current *Temperature Criteria Assessment (Chinook salmon and O. mykiss) Study* (W&AR-14). Based upon review of available information, low rates of water temperature related mortality are likely to occur for over-summering juvenile *O. mykiss* excluded from preferred cold water rearing habitats nearest La Grange Dam (RM 52).

5.2.2 Predation

Although avian predation has not been assessed on the lower Tuolumne River, predation by piscivorous fish species has long been identified as a factor potentially limiting the survival and production of juvenile Chinook salmon in the lower Tuolumne River (e.g., TID/MID 1992, Appendix 22). Many of the same mechanisms may potentially limit Age 0+ *O. mykiss* survival in habitats preferred by predatory fish species. Non-native largemouth and smallmouth bass have been found to prey on juvenile Chinook salmon in the lower Tuolumne River (TID/MID 1992, Appendix 22) and are believed to be a significant factor limiting Chinook salmon outmigrant survival, particularly during drier years. Sacramento pikeminnow and striped bass have also been documented in the lower Tuolumne River (TID/MID 2011, Report 2011-5) and may also be important salmon predators. Despite the lack of data, it can be reasonably assumed that juvenile *O. mykiss* are also subject to predation by these predator species. However, predation rates on *O. mykiss* are likely lower than for Chinook due to several factors related to juvenile life history and habitat preferences.

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

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

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

5.2.3 Stranding and Entrapment

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

5.2.4 Entrainment into unscreened riparian diversions

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

5.2.5 Sportfishing and Poaching

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

5.3 Processes/Mechanisms Affecting Indirect Mortality

5.3.1 Diseases and Parasites

Meteorology and instream flows combine to affect exposure of rearing juvenile *O. mykiss* to varying water temperatures, which in turn, may contribute to stress and disease incidence in some fish (Myrick and Cech 2001, Holt et al. 1975, Wood 1979) and contribute to subsequent mortality or good growth and survival. Wild steelhead may contract diseases which are spread through the water column (Buchanan et al. 1983) and many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), but no information regarding disease incidence was identified for *O. mykiss* in the Tuolumne River or other San Joaquin River tributaries. Although steelhead may potentially rear in the lower Tuolumne River for 1–3 years and because steelhead are presumed to be susceptible to the same diseases as Chinook salmon, the low disease incidence in Chinook salmon smolts (Nichols and Foott 2002) suggests a low risk of indirect mortality due to disease.

6.0 DELTA OUTMIGRATION

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

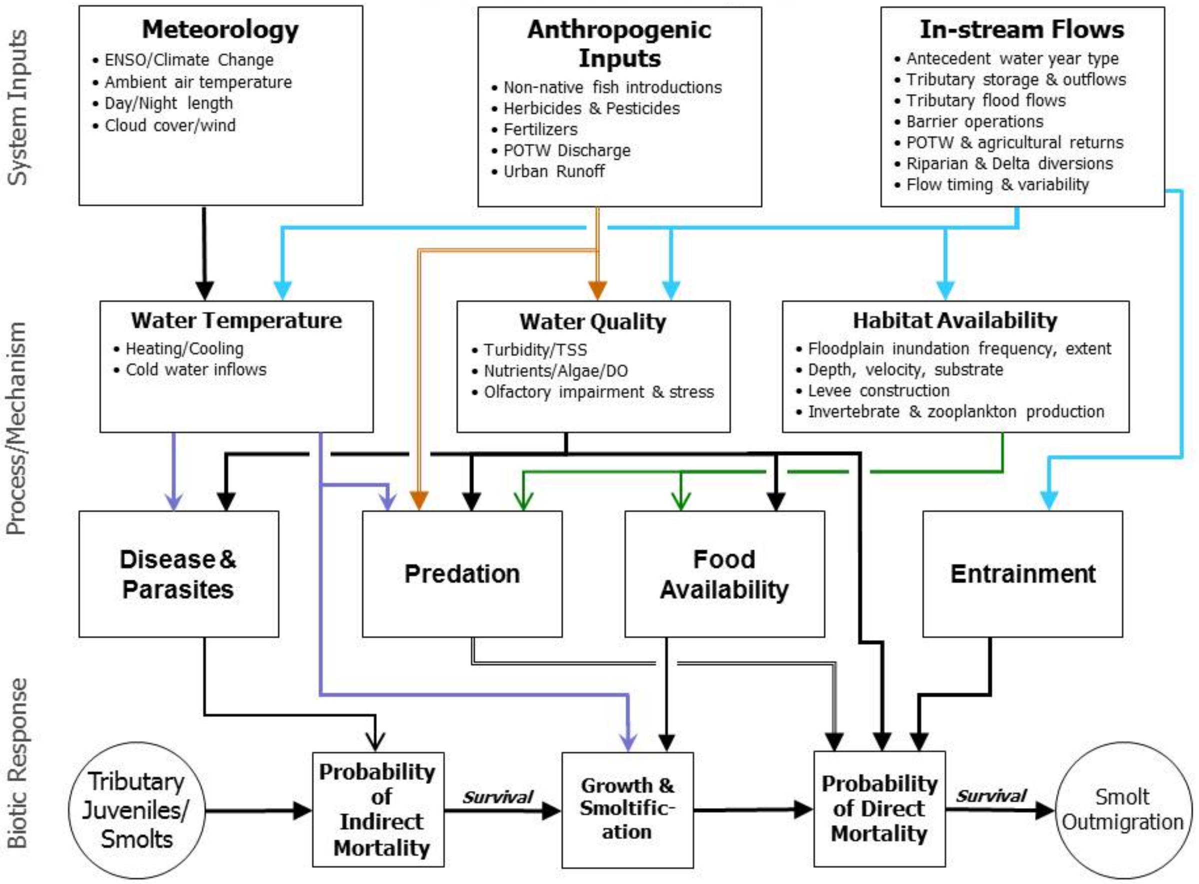


Figure C-7. **Potential issues affecting any Central Valley steelhead smolts emigrating from the Tuolumne River through the lower San Joaquin River, Delta, and San Francisco Estuary.**

6.1 Processes/Mechanisms Affecting Juvenile Growth and Smoltification

6.1.1 In-channel and Floodplain Habitat Availability

No studies have directly mapped the amounts of suitable rearing habitat for juvenile steelhead in the lower San Joaquin River and Delta. Smolt-sized steelhead are routinely captured in the Delta at the Mossdale trawl (RM 56.7) downstream of Vernalis (RM 69.3) (SJRGA 2011) as well as at the CVP fish salvage, with peak recoveries typically occurring in February and March (USBR 2008). Although data regarding habitat use of the Delta by rearing steelhead is limited, juvenile steelhead were documented to use the Yolo bypass during flood conditions in 1988 with some evidence of active feeding by stomach content analysis (USBR 2008). For these reasons, historical habitat losses of floodplain habitat (See Section 5.1 of the synthesis) may potentially affect the growth and survival of juvenile steelhead. Because extended periods of floodplain inundation in the lower San Joaquin River and Delta are not expected except those accompanying large flood control releases from the tributaries, it is likely that historical habitat changes in Delta habitats affect the numbers of smolts entering the ocean fishery as well as early ocean survival.

6.1.2 Water Temperature Effects on Growth and Smoltification

As shown in Figure C-7, suitable water temperatures are required for growth and survival for steelhead and may limit the times of year for successful smolt outmigration from upstream tributaries to winter and spring, typically February through May. Meteorology and to a minor degree instream flows combine to affect water temperature of both in-channel habitats in the San Joaquin River and Delta as well as water temperatures of off-channel habitats (e.g., sloughs, marshes, as well as seasonally inundated floodplains). As summarized above for in-river rearing (Section 5.1), steelhead smoltification is affected by water temperatures, growth rates, as well as genetic influences that may affect behavioral "decisions" regarding adoption of resident or anadromous life histories within riverine habitats. Although water temperature clearly has a strong influence upon steelhead life history timing, separate from direct and indirect mortality effects, both the degree to which water temperature affects smoltification (or desmoltification) in the Delta as well as long term population levels is unknown. Because fairly low temperatures are required for smoltification of Central Valley steelhead (Myrick and Cech 2001), it is unlikely that smoltification occurs within Delta habitats during late spring. For any Central Valley steelhead smolt emigrants from the Tuolumne River, Myrick and Cech (2004) would suggest that optimal growth conditions would be at temperatures below 19°C (66°F). Steelhead juveniles can survive temperatures as high as 27–29 °C (80–84°F) for short periods of time. Because water temperatures in the San Joaquin River near Vernalis (USGS 11303500) generally range from below 18–21°C (65–70°F) from mid-April to mid-May across a wide range of water years, it is likely that Delta conditions are suitable for smolt emigration as late as June in some years.

6.1.3 Food Availability

Although steelhead feeding in the Delta has not been well documented in the literature, active feeding of steelhead smolts has been documented in studies by DWR during 1998 (USBR 2008). In other estuaries, gammarid amphipod invertebrates (e.g., *Gammarus, Corophium,* *Eogammarus, Anisogammarus spp.*) have been found to make up a large proportion of the diet of steelhead (Needham 1939), but the larger mouth gape of Age 1+ and older steelhead smolts suggests they may potentially feed upon small fish up to 50% of their size as found in studies of Central Valley and other Pacific salmonids (Martin et al. 1993, Sholes and Hallock 1979, Damsgard 1995). Potential prey fishes available to steelhead smolts in the Delta include larval fishes as well as Chinook salmon juveniles and smolts. Although little is known regarding prey items eaten by steelhead in the Delta, because extensive predation of steelhead upon Chinook salmon fry has been documented in Sacramento River tributaries (e.g., Sholes and Hallock 1979; Menchen 1981), it is likely that steelhead feed upon these fishes in the Delta as well. Because of evidence of poor Chinook salmon growth conditions in the Delta by MacFarlane and Norton (2002) and apparent declines in pelagic prey species (Baxter et al. 2008), it is likely that food resources in the Delta may potentially limit the growth opportunity for steelhead smolts under non-flood conditions occurring in drier water year types, with affects upon early ocean survival and long-term population levels.

6.2 Processes/Mechanisms Affecting Direct Mortality

As shown in Figure C-7, water temperature related mortality, temperature effects upon predation as well as predation related mortality due to entrainment are primary factors that may result in direct mortality of emigrating steelhead smolts in the lower San Joaquin River, Delta, and the greater San Francisco Bay estuary. Although Age 1+ and older steelhead are typically large enough to reduce predation risk, aquatic predation during Delta rearing and outmigration is affected by the abundance and distribution of native and introduced species, changes in habitat that affect predator distribution, flow and water temperature effects on predator activity, as well as water temperature and water quality effects upon the ability of steelhead smolts to avoid potential predators.

6.2.1 Water Temperature

Seasonal and inter-annual changes in meteorology, air temperatures, and to a minor degree instream flows combine to affect exposure of emigrating steelhead smolts to periods of elevated water temperatures in the lower San Joaquin as well as increased rates of mortality. Water temperatures in the lower San Joaquin River at Vernalis (USGS 11303500) typically rise above 25°C (77°F) by mid-June in most years. Because water temperatures in excess of 25°C (77°F) are associated with increased mortality incidence (Myrick and Cech 2001), it is likely that water temperature related mortality occurs to some degree by mid-June in most years without extended flood conditions, with effects upon the numbers of adult recruits to the ocean fishery.

6.2.2 Predation by Native and Introduced Species

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

6.2.3 Flow and Water Temperature Effects on Predation

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

6.2.4 Entrainment Effects on Juvenile Salmon Mortality

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

6.2.5 Water Quality Effects on Direct Mortality and Predator Susceptibility

As with Chinook salmon juveniles rearing in the Delta, although no studies have assessed contaminant-related mortality of steelhead smolts in the Delta, direct mortality is likely uncommon. NMFS (2006) as well as Scott and Sloman (2004) provide reviews of potential effects of early life history exposure of salmonids to anthropogenic inputs of trace metals, herbicides and pesticides which may affect susceptibility of salmonids to piscine, avian, and mammalian predation over an extended period of time after exposure. For example, many chemicals that are applied to control aquatic weeds in the Delta contain ingredients that have been shown to cause behavioral and physical changes, including loss of equilibrium, erratic swimming patterns, prolonged resting, surfacing behaviors, and narcosis (NMFS 2006). Based upon review of available information, water quality effects upon predation of steelhead smolts in the Delta is considered unknown but unlikely due to the episodic nature of potential contaminant releases and short residency of steelhead smolts in the Delta.

6.3 Processes/Mechanisms Affecting Indirect Mortality

6.3.1 Diseases and Parasites

Variations in meteorology and instream flows as well as various anthropogenic sources of contamination may contribute to stress and disease incidence (Myrick and Cech 2001, Holt et al. 1975, Wood 1979) which may contribute to subsequent mortality of emigrating juvenile steelhead. Many of the natural and hatchery steelhead populations throughout California's coast and central valley have tested positive for *Renibacterium salmoninarum* (Foott 1992), but no information regarding disease incidence was identified for steelhead in the lower San Joaquin River and Delta. Wild steelhead may contract diseases which are spread through the water column (Buchanan et al. 1983). However, concerns regarding disease incidence in steelhead are generally related to hatchery management practices (Wood 1979). Although there is some evidence of impaired water quality and temperature conditions in the Delta, steelhead temperatures tolerances are generally higher than that of Chinook salmon (Myrick and Cech 2004). Assuming steelhead are susceptible to the same diseases as Chinook salmon, because no reports of clinical levels of infection were found in rearing Chinook salmon in the lower San Joaquin River and Delta in 2000 (Nichols et al. 2001) and only low rates were identified in the lower San Joaquin River in 2001 (Nichols and Foott 2002), it is unlikely that disease and parasites contribute to high rate of mortality of emigrating steelhead smolts in the Delta.

7.0 OCEAN REARING

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

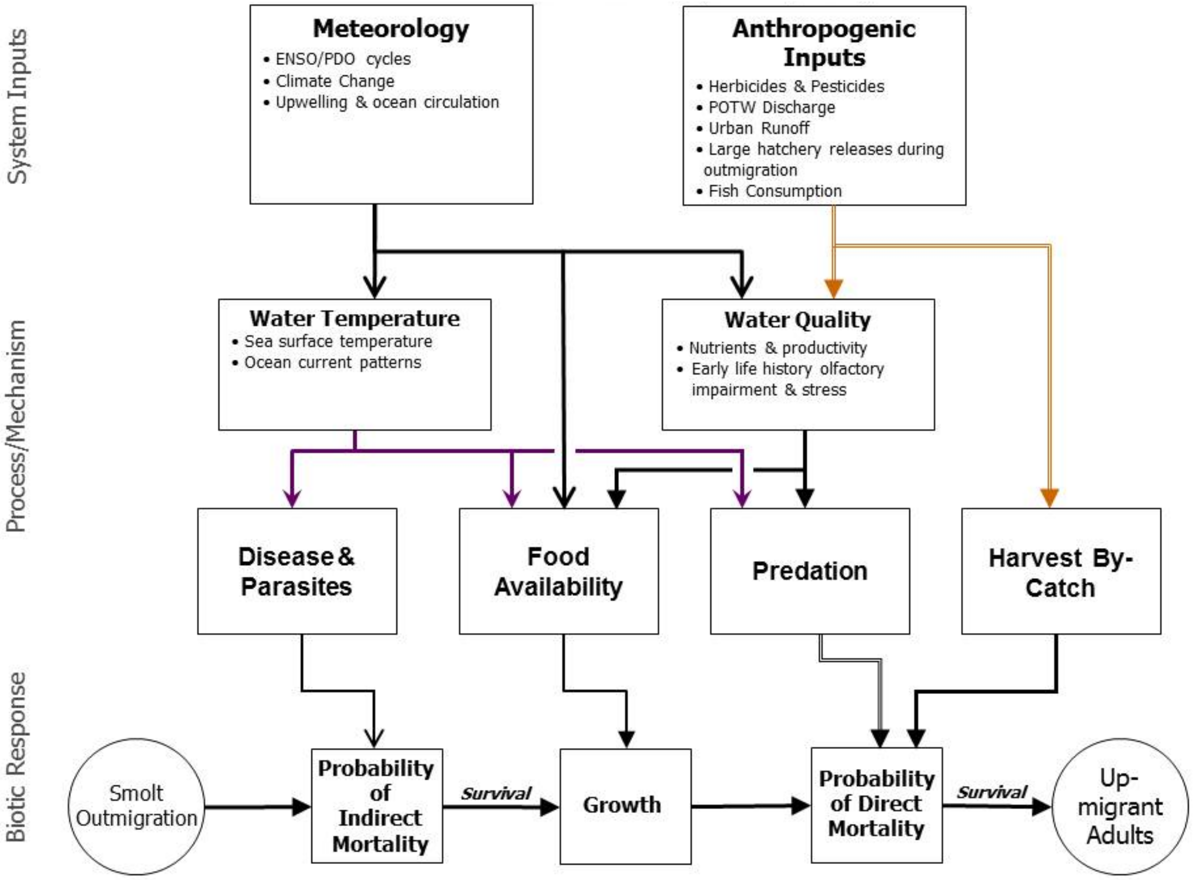


Figure C-8. **Potential issues affecting any Central Valley steelhead adults from the Tuolumne River during adult rearing in the Pacific Ocean.**

7.1 Processes/Mechanisms Affecting Adult Growth

7.1.1 Food Availability

The Pacific Decadal Oscillation (PDO) and shorter-term El Niño/Southern Oscillation (ENSO) influence water temperature and ocean circulation patterns that, in turn, influence coastal productivity through a series of complex interactions. Mantua and Hare (2007) provide a historical review of the PDO that suggests large changes in ocean productivity and Chinook salmon harvest, with peaks in abundance off the California and Oregon coasts occurring during periods of low abundance off the coast of Alaska. Less is known about how steelhead respond to ocean productivity patterns. Steelhead are thought to migrate quickly to the open ocean upon smoltification (Burgner et al. 1992 as cited by Quinn et al. 2012) where they feed primarily on fish and squid (Atcheson 2010). For North Pacific ecosystems, Atcheson (2010) identified age-dependent factors influencing growth of the steelhead at sea. Using a bioenergetic model, Atcheson (2010) further concluded that food consumption and interannual changes in sea surface temperatures are limiting factors on steelhead growth at sea and that hatchery sourced steelhead were consistently smaller in size than naturally produced steelhead.

7.2 Processes/Mechanisms Affecting Direct Mortality

7.2.1 Predation

Predation of steelhead smolts following ocean entry has not been well documented, but could present potential population level impacts. Since steelhead are capable of spending years in freshwater and brackish habitats before migrating to the ocean as smolts, they tend to be larger than Chinook smolts and, as a result, not likely avian prey. For adult salmon rearing in the Pacific Ocean, as part of the West Coast Pinniped Program, Scordino (2010) reviewed monitoring results of pinniped predation on Pacific coast salmonids and found that predation by Pacific harbor seals and California sea lions can adversely affect the recovery of ESA-listed salmonid populations, but conceded that more research is needed to better estimate this impact.

7.2.2 Harvest By-catch

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

7.3 Processes/Mechanisms Affecting Indirect Mortality

7.3.1 Disease and Parasites

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

8.0 REFERENCES

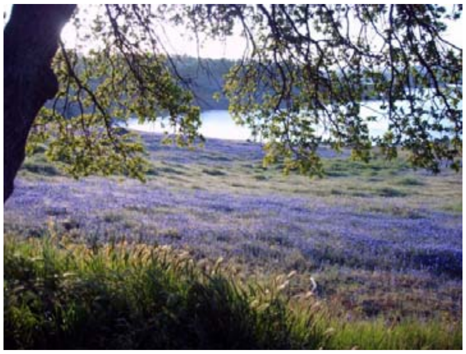
References for this information review are provided in the accompanying synthesis document.

FISH ASSEMBLAGE AND POPULATION BETWEEN DON PEDRO DAM AND LA GRANGE DAM

STUDY REPORT

DON PEDRO PROJECT

FERC NO. 2299



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

Prepared by:
HDR Engineering, Inc.

January 2013

Fish Assemblage and Population Between Don Pedro and La Grange Dam 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
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
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
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
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
ISR	Initial Study Report
ITA	Indian Trust Assets
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
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
ppb	parts per billion
ppm	parts per million
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
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	microSeimens per centimeter

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.

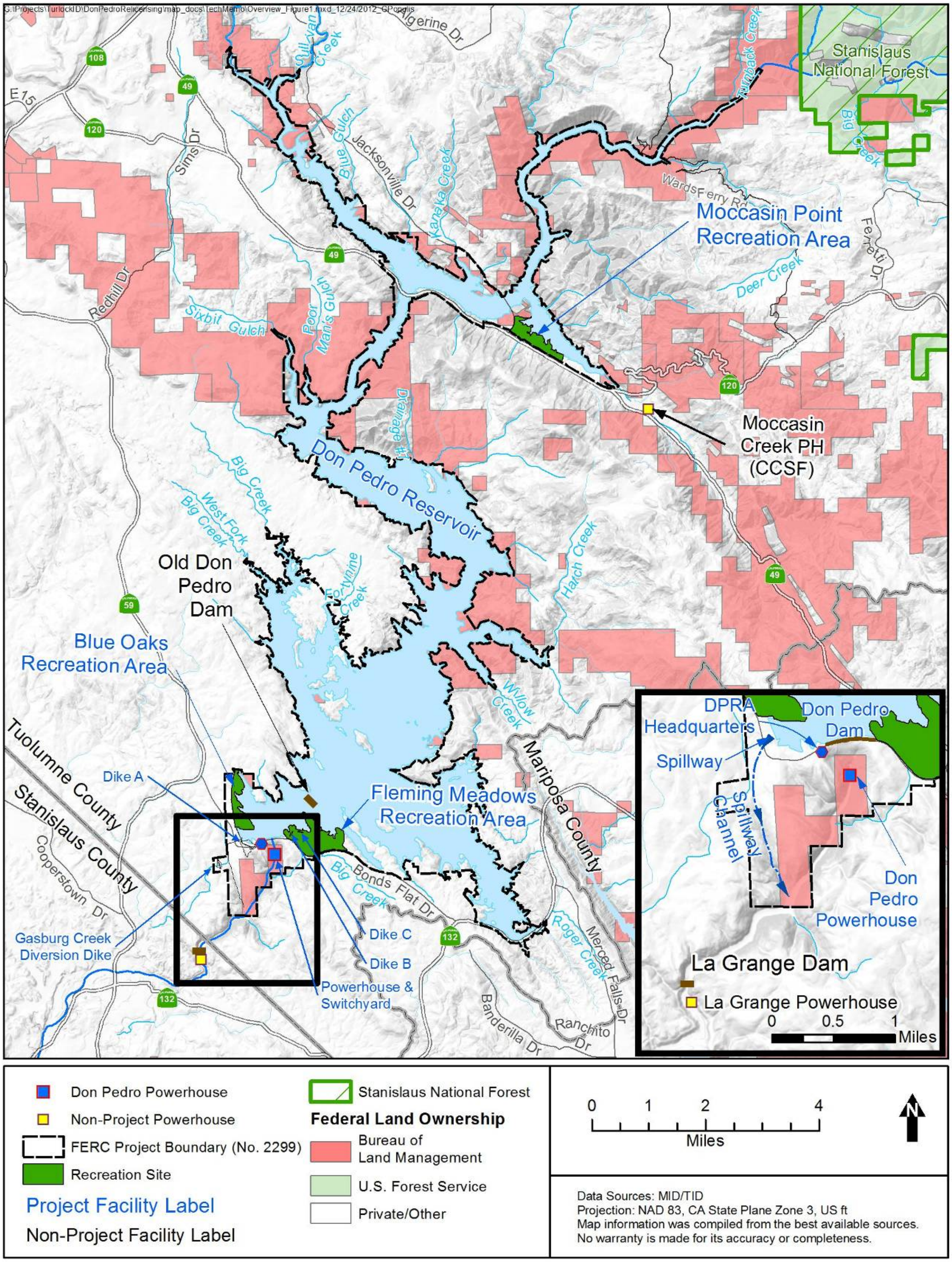

Figure 1.1-1. Don Pedro Project location.

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 Fish Assemblage and Population Study (W&AR-13) 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

FERC's Scoping Document 2 identified potential effects of the Project on fish resources. The Districts' continued operation and maintenance (O&M) of the existing Project has the potential to affect the fish assemblage and fish populations between Don Pedro Dam and La Grange Dam. In order to evaluate potential effects on fish populations, the Districts identified the need for additional baseline information on the fish community in this reach of the Tuolumne River and developed the Fish Assemblage and Population between Don Pedro Dam and La Grange Dam Study Plan.

In response to a U.S. Fish and Wildlife Service (USFWS) request for a genetic study of the salmonid fish population upstream of Don Pedro Dam, the Districts agreed to take fin clips of Chinook salmon and rainbow trout (*Oncorhynchus mykiss*) in the Tuolumne River upstream of La Grange Dam as part of this and other relevant proposed studies. In accordance with FERC's SPD, the Districts obtained fin clips of salmonids as part of this fish resources survey.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study is to characterize the fish assemblage and populations between Don Pedro Dam and La Grange Dam. Fish assemblage and population information is very limited for this section of river and is based on a single known sampling event occurring in 2008 (Stillwater Sciences 2009). No known angler harvest or stocking data exist for these waters. The Districts undertook this study to provide baseline information for determining potential effects from Project operations. The four objectives of the study were:

(1) characterize fish species composition, relative abundance (e.g., catch per unit effort [CPUE]), and size, length and weight) between Don Pedro Dam and La Grange Dam;

(2) characterize the functional habitat in the reach as either riverine or lacustrine;

(3) characterize fish condition factor of species present; and

(4) collect tissue samples (fin clips) from salmonids.

3.0 STUDY AREA

The study area is the reach of the Tuolumne River between La Grange Dam and Don Pedro Dam located at RM 52.2 and 54.8, respectively (Figure 3.0-1). The approximate length of the study reach is 2.3 mi (La Grange Dam to the Don Pedro powerhouse located approximately 0.3 mi downstream from Don Pedro Dam).

1 - Stream channel is a depiction and is not intended to represent the actual location of the banks and channel of the river.

Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Data Sources: Survey Data - HDR; FERC Boundary - MID/TID; Service Layer Credits: Sources: USGS, ESRI, TANA, AND Data is CA SPCS, Zone III, ft.

Figure 3.0-1. Study reaches.

4.0 METHODOLOGY

4.1 Field Reconnaissance

To develop an appropriate sampling design, reconnaissance surveys were conducted on February 20 and October 25, 2012 to evaluate the existing habitat, identify the number of potential sampling reaches that would sufficiently represent the study area, and identify those areas where each of the proposed four sampling techniques (i.e., gillnetting, seining, boat electrofishing, and backpack electrofishing) might be most effectively employed. During field reconnaissance, sampling stations were designated on orthophotographs of the study reach and documented using a Global Positioning System (GPS). Sites were determined so that they were spatially separated to prevent any potential influences on catch. The reconnaissance surveys concluded that boat electrofishing would be the most efficient method to sample fish populations within all available habitat types within the study area. Furthermore, the range of depths in the study area was not complimentary to backpack electrofishing and gillnetting was restricted per the fish sampling permit issued by the California Department of Fish and Game (CDFG).

4.2 Fish Sampling and Habitat Approach

Fish sampling sites were selected throughout the study area to represent the diversity of identified near-shore habitats. The approximate locations and boundaries of each sampling site were determined using GPS coordinates which were recorded during the sampling of each site. General information recorded included location, crew member names, a qualitative habitat characterization (e.g., qualitative description, riverine or lacustrine, etc.), weather conditions, and air temperature. Mean water depths and water chemistry at approximate fish sampling location (i.e., water temperature, dissolved oxygen, and conductivity) were also recorded.

Daily water surface elevation information for the sampling period were acquired at two locations; the Don Pedro tailrace (representative of the riverine reach below Don Pedro Dam) and just upstream of La Grange Dam as measured by TID water level equipment. The measurement frequency was every 15 minutes over a 24-hour period.

Boat electrofishing was implemented using standard methods (Reynolds 1996). One or two electrode booms were employed, and the booms and boat were outfitted with standard non-conductive material in appropriate places for safety. Electrofisher “time on” was recorded for each sampling site and a consistent effort and pace was employed while sampling all sites. Electrofishing was conducted in a direction parallel to the shoreline.

At each sampling location, all fish captured were enumerated, identified to species, measured to the nearest mm (total length), and weighed by electronic scale to the nearest gram. All fish captured during sampling were identified, where possible, as to origin; hatchery or wild stock (i.e., basic visual identification, such as a clipped adipose fin). Scale and tissue samples were collected on all salmonids captured. Mortalities were recorded. After biological data collection was completed, all fish were released within or near the sampling site.

Field data was entered into an excel database. The database was organized per the metrics discussed above and subjected to quality assurance/quality control procedures. Data was analyzed graphically and summarized species composition, length frequency distribution, and location. The relative abundance of fish species captured at each site was calculated to identify composition and distribution patterns throughout the study area. Catch-per-unit-effort (CPUE) for each fish species was also calculated per all sampling sites. Fish size and weight was summarized by fish species and site.

Weight and length data were used to calculate condition factors for individual species. These data were used to compute Kn, a relative condition factor, where:

$$Kn = W/W'$$

where W equaled individual fish weight and W' equaled length-specific weight from the weight-length relationship. The individual fish weight can also be determined as a function of length, specifically:

$$W = a(FL)b$$

where a and b are population specific coefficients (Anderson and Gutreuter 1983).

Relative condition factor provides a general indication of the fish condition and health, where a value of Kn greater than or equal to 1.0 indicates fish of average or better condition. The condition factor was calculated by pooling length-weight data for all collected fish of a species.

Age composition and growth information on salmonids within the study area were determined using collected scales as described by DeVries and Fries (1996) which states the relationship between annuli radii and fish length represents the individual’s size at annulus formation.

Tissue samples (fin clips) were taken from all salmonids captured during sampling. Preservation methods included air drying of fin clips and individual placement of each fin clip into prescribed envelopes. All envelopes were cross-referenced to the relevant biological information collected for each fish. Tissue samples were provided to CDFG for archiving.

5.0 RESULTS

Field sampling was conducted on October 29 and 30, 2012. All field activity was conducted during daylight hours due to safety concerns. The estimated daily flow within the reach for these two days was approximately 315 cfs. Water surface elevations remained relatively stable during each of the two days of sampling. On October 29 and 30 the mean water level at the Don Pedro tailrace was approximately 296 ft and the mean water level at the La Grange Dam was approximately 294 ft.

Six sites were sampled throughout the study area (see previous Figure 3.0-1) with the start of site 1 occurring at the downstream end of the 2.3 mi reach near La Grange Dam and each subsequent sample site moving upstream toward the Don Pedro tailrace (i.e., site 6 being the furthest upstream sample location). Table 5.0-1 provides general information for each of the sample sites. The average site length for the six sites was approximately 0.30 mi. Five of the sites were approximately a quarter of a mile in length and the furthest upstream site (#6) was approximately 0.40 mi long (Table 5.0-1). Sample width for all sites ranged between 10-20 ft.

Table 5.0-1. Boat electrofishing sites between Don Pedro Dam and La Grange Dam in 2012.

Site No.	Site Length (Miles)	Field Width (feet)	UTM Start	UTM End
1	0.28	10	N37.67326W120.4436	N37.67579W120.43889
2	0.28	10	N37.67556W120.43924	N37.67791W120.43502
3	0.29	10	N37.67771W120.43468	N37.68021W120.43031
4	0.28	10	N37.68203W120.42903	N37.68530W120.42609
5	0.28	20	N37.68518W120.42599	N37.68847W120.42319
6	0.40	20	N37.68855W120.42359	N37.69407W120.42072

For both days of field sampling, the weather was clear with air temperatures ranging from 49-82°F and water temperatures were steady at 54°F (Table 5.0-2). Dissolved oxygen measurements ranged from 7.2 to 8.3 mg/L with the highest values at upstream sampling locations near Don Pedro Dam. Depths at each site ranged from 2 to 20 feet with an average site depth of eight feet (Table 5.0-2). The low specific conductivity measured at all sites (mean of 27.4 µS/cm) required electrofisher settings to be at their maximum safe settings to effectively capture fish. At all sites, electrofishing voltage was set between 25-30% and the frequency was set at 60DC Hz. Boat electrofishing efforts ranged from 1190 seconds to 1562 seconds for the six sites. The average effort per site was 1356 seconds or approximately 22 minutes (Table 5.0-2).

Table 5.0-2. Site conditions during boat electrofishing between Don Pedro Dam and La Grange Dam in 2012.

Site No.	Date of Survey	Weather	Average Depth (feet)	Air Temperature (°F)	Water Temperature (°F)	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Shock Time (min)
1	10/29/2012	Clear	6	54	53.8	24.9	7.2	1562
2	10/29/2012	Clear	6	75	54	24.9	7.2	1443
3	10/29/2012	Clear	2	82	54	24.9	7.2	1412
4	10/29/2012	Clear	9	82	54	24.9	7.2	1215
5	10/30/2012	Clear	20	49	54	32.4	8.3	1190
6	10/30/2012	Clear	5	68	54	32.4	8.3	1312

5.1 Fish Assemblage and Population

5.1.1 Species Composition

In total, 133 fish consisting of 86 rainbow trout (*Oncorhynchus mykiss*) and 47 prickly sculpin (*Cottus asper*) were collected during the boat electrofishing sampling effort conducted in the study area (Table 5.1-1). Rainbow trout made up 64.7 percent of the overall catch in the study area and lengths ranged from 85 mm to 344 mm with a mean length of 153.5 mm. Weights of rainbow trout ranged from 5.5 to 469.5g with a mean weight of 67.1g. Prickly sculpin made up 35.3 percent of the overall catch with lengths ranging from 48 mm to 110 mm and a mean length of 80.1 mm. Weights of sculpin ranged from 1.3g to 106.1g with a mean weight of 14.8g (Table 5.1-1).

Table 5.1-1. Summary of relative abundance, length, and weight of all fish species collected at all sites between Don Pedro Dam and La Grange Dam in 2012.

Species	N	%	Length (mm)			Weight (g)		
			Min	Max	Mean	Min	Max	Mean
Rainbow Trout (*O. mykiss*)	86	64.7	85	344	153.5	5.5	469.5	67.1
Prickly sculpin (*C. asper)*	47	35.3	48	110	80.1	1.3	106.1	14.8
Total	133	100						

Rainbow trout and prickly sculpin were captured during sampling at all sites (Table 5.1-2). Highest total catch for rainbow trout and prickly sculpin were at site 1 (34 fish) and site 6 (22 fish), respectively. Rainbow trout catch with greatest mean lengths were from site 2 whereas trout catch with greatest mean weights were from site 4. Prickly sculpin catch with greatest mean lengths and mean weights were from site 1.

Table 5.1-2. Summary of length and weight of all fish species collected at each individual site between Don Pedro Dam and La Grange Dam in 2012.

Site	Rainbow Trout Count	Length (mm)			Weight (g)		
		MIN	MAX	AVE	MIN	MAX	AVE
Site 1	34	93	275	168.8	8.8	250.5	69.0
Site 2	7	98	273	181.1	10.1	264.5	100.4
Site 3	16	87	344	124.3	6.6	469.5	44.0
Site 4	3	162	290	157.8	43.9	263.5	158.5
Site 5	3	87	114	100.7	9.5	18.9	13.4
Site 6	23	85	317	139.9	5.5	359.9	54.0

Site	Prickly Sculpin	Length (mm)			Weight (g)		
		MIN	MAX	AVE	MIN	MAX	AVE
Site 1	5	82	110	91.8	7.6	20	12.3
Site 2	2	84	84	84	8.1	12.1	10.1
Site 3	2	83	95	89	9.7	11.8	10.8
Site 4	4	79	95	86	7.6	12.3	10.3
Site 5	12	52	105	78.8	1.4	13.8	7.0
Site 6	22	48	96	76	1.3	11.8	6.4

5.1.2 Length-Frequency Distributions

Fish length data were used to develop length-frequency distributions for the two fish species collected (Figures 5.1-1 and 5.1-2). The rainbow trout length-frequency data (10 mm size categories) indicate four age classes may be present in the study area. These age classes included young-of-year (YOY) at age 0 and year 1, year 2 and year 3 classes and was also confirmed through age analysis using collected scales (section 5.1.4 below). The sculpin length-frequency data (5 mm size categories) indicate that three age classes for this species may exist in the study area. Presumably, these three age classes would consist of YOY, age 1, and age 2, however, no age analysis from scales was conducted for this species.

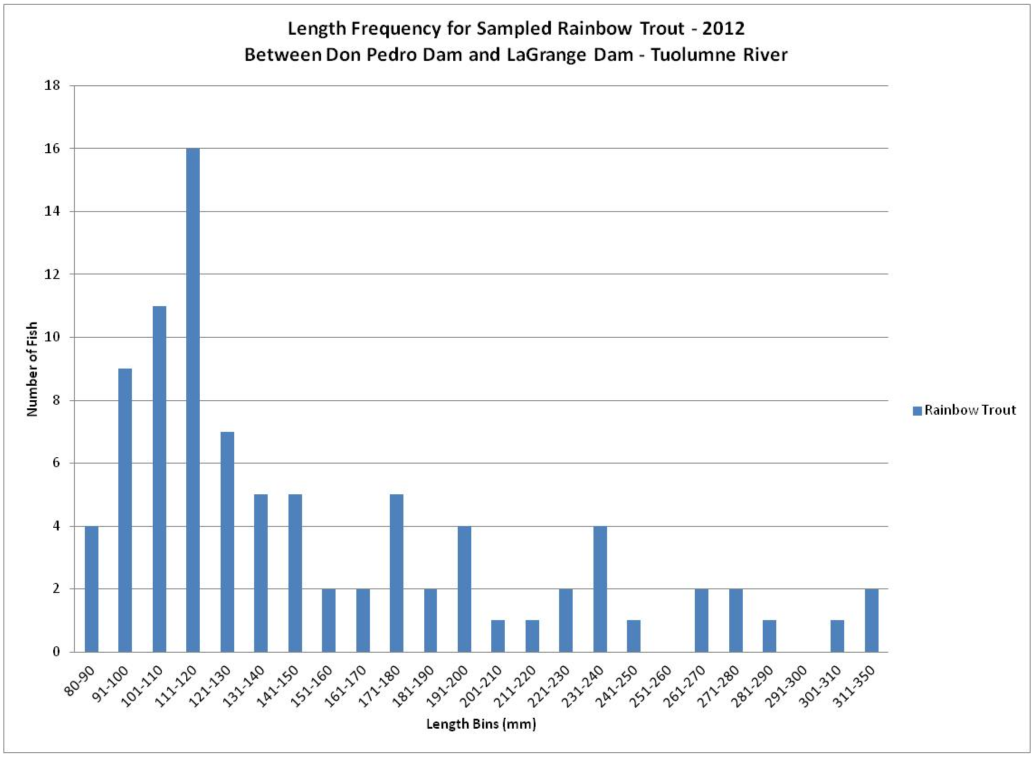

Figure 5.1-1. **Rainbow trout length-frequency distributions for the Tuolumne River between Don Pedro and La Grange dams.**

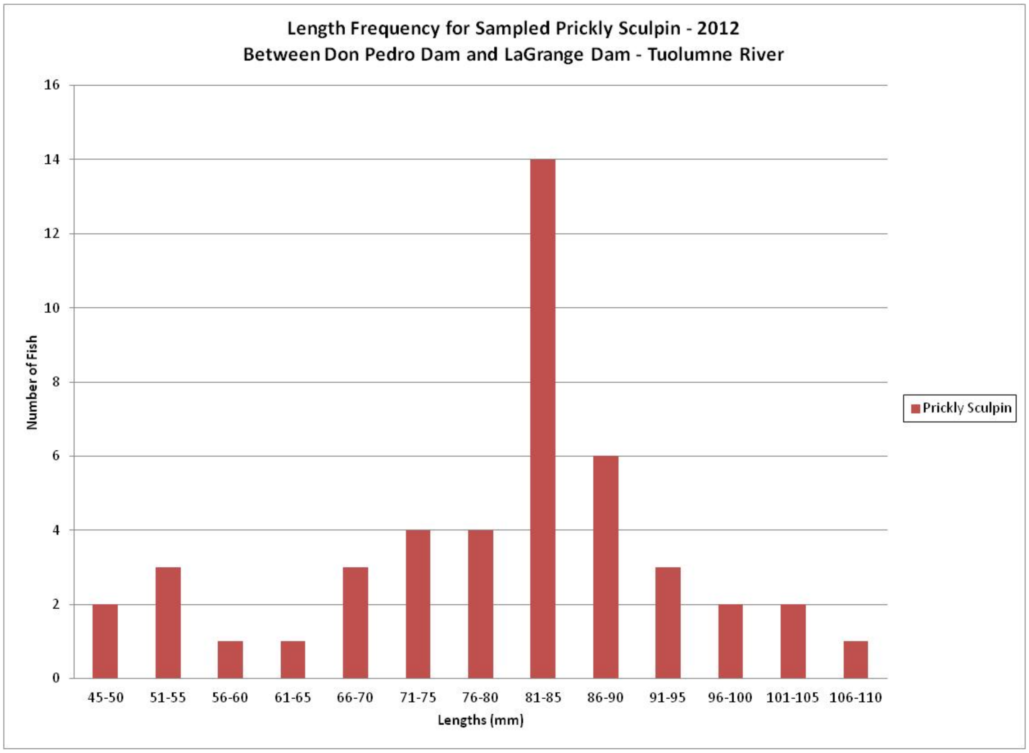

Figure 5.1-2. **Prickly sculpin length-frequency distributions for the Tuolumne River between Don Pedro and La Grange dams.**

5.1.3 Relative Abundance and CPUE

Relative abundance for the two fish species captured at each site was calculated using the number of fish of a species divided by the overall fish captured per site (Table 5.1-3). Relative abundance ranged from 0.20 to 0.89 for rainbow trout and 0.13 to 0.80 for prickly sculpin over the study area. Results indicate that rainbow trout are proportionally more abundant in the lower reaches of the study area (sites 1-3). Sculpin had higher relative abundance values in sites 4-5. In site 6, both species made up a near equal proportion of the catch. Overall, rainbow trout were more abundant in the catch by an approximate 2:1 ratio.

Table 5.1-3. Summary of relative abundance for all fish species collected between Don Pedro Dam and La Grange Dam in 2012.

Site	RBT #	PRS #	RA-trout	RA-sculpin
Site 1	34	5	0.87	0.13
Site 2	7	2	0.78	0.22
Site 3	16	2	0.89	0.11
Site 4	3	4	0.43	0.57
Site 5	3	12	0.20	0.80
Site 6	23	22	0.51	0.49
Total	**86**	**47**	**0.65**	**0.35**

CPUE for boat electrofishing is summarized below in Table 5.1-4 for each species, by sample site, and over the entire study area. CPUE is defined as the numbers of fish of a species captured divided by the time it took to sample them. CPUE for rainbow trout ranged from 0.15 to 1.31 fish per hour with CPUE highest and lowest and sites 1 and 5, respectively. CPUE for prickly sculpin ranged from 0.08 to 1.01 fish per hour with CPUE highest at site 6 and lowest at sites 2 and 3. Mean CPUE for boat electrofishing for rainbow trout and prickly scuplin overall all sites were 0.61 and 0.36, respectively.

Table 5.1-4. Summary of CPUE for all fish species collected between Don Pedro Dam and La Grange Dam in 2012.

Site	RBT CPUE (fish/hour)	PKS CPUE (fish/hour)
1	1.31	0.19
2	0.29	0.08
3	0.68	0.08
4	0.15	0.20
5	0.15	0.61
6	1.05	1.01
Mean CPUE/species	**0.61**	**0.36**

5.1.4 Age Composition and Growth

Age composition and growth analyses were done on a total of sixty-four rainbow trout scale samples that were collected from the six sites. The final number of scales analyzed was consistent with the approved study plan which stated that up to 10 fish for each 25 mm size group of salmonids would be sampled. The 3 smallest size groups included more than 10 samples each, totaling an extra 24 scales which were not analyzed. Several scale sample slides were not readable after mounting. Results indicated that multiple year classes (from YOY to

Age 3) exist within the reach and the majority of rainbow trout found in the reach are Age 1 fish. Information relating to lengths for the various age classes is presented in Table 5.1-5. The raw data is presented in Attachment A.

Table 5.1-5. Summary age composition for rainbow trout age groups collected between Don Pedro Dam and La Grange Dam in 2012.

	Rainbow Trout Age Groups			
	YOY	1	2	3
Number Captured	9	38	11	3
Minimum Length (mm)	85	99	225	310
Maximum Length (mm)	104	231	290	344
Average Length (mm)	93	153	252	324

Growth analyses, based on the average growth rates for each of the four age classes, indicated the rainbow trout population in this reach put on the greatest average length increase during the YOY stage. This annual mean growth rate was 93 mm for the nine YOY fish scales processed. Age 1 (38 individuals) and Age 3 (3 individuals) fish put on the next highest annual mean growth rate of 73 mm/year. Age 2 fish (11 individuals) had the lowest average annual growth rate at 69 mm. Table 5.1-6 presents the maximum, minimum, and mean growth rates for each rainbow trout age class.

Table 5.1-6. Summary age composition for rainbow trout age groups collected between Don Pedro Dam and La Grange Dam in 2012.

Growth by Year (mm)				
	YOY	Age 1	Age 2	Age 3
Minimum Growth (mm)	85	48	54	69
Maximum Growth (mm)	104	107	85	80
Average Growth (mm)	93	73	69	73

5.2 Functional Habitat of the Reach

Two types of habitat were identified in the study area: riverine and lacustrine. Riverine sites (#4, #5, and #6) were located at the upstream section of the reach above Twin Gulch. Observable currents, large substrate dominated by boulders and a lack of rooted macrophyte beds were common at these three sites. Very little habitat complexity was noted as bedrock cliffs were the dominant habitat types with sparse overhead vegetation at some limited shoreline locations. Large shallow areas dominated by boulders were common at site #6. The riverine habitat appears to extend downstream to below the Twin Gulch area. Below this location, the study reach becomes more lacustrine in nature due to influences of La Grange Dam. Figure 5.1-3 shows the typical habitat below the Don Pedro powerhouse.

Sites #1-3 were farther downstream of the Don Pedro Project and were identified as lacustrine by field crews. Observations at these three sites found a lack of observable currents. Smaller substrate including cobbles and gravels were more common along with numerous boulders and the frequency of rooted macrophyte beds increased (mainly at site #1). Habitat complexity was again simple with bedrock cliffs and very limited observed overhead cover dominating the landscape. Figure 5.1-4 shows the typical habitat upstream of La Grange Dam.

Figure 5.1-3. Typical habitat (near site 6) below the Don Pedro tailrace area in the Tuolumne River.

Figure 5.1-4. Typical habitat (near site 1) above the La Grange dam area in the Tuolumne River.

5.3 Fish Condition Factor for Species Collected

Relative condition (Kn) was calculated for all fish captured. For rainbow trout, Kn ranged from 0.60 to 1.29. For the rainbow trout "population" in the study reach, mean Kn was 0.99 which indicates that the fish condition and health of this population is average.

For prickly sculpin caught during the study, Kn ranged from 0.71 to 1.44. For the prickly sculpin "population" in the study reach, mean Kn was 0.99 which indicates that the fish condition and health of this population is average.

5.4 Tissue Sample Collection

During the study, tissue samples (fin clips) were taken from eighty-six rainbow trout, preserved and forwarded along with scale samples to CDFG for archiving.

6.0 DISCUSSION AND FINDINGS

The study results indicate this reach of the Tuolumne River is limited to two fish species; rainbow trout and prickly sculpin with both species having distributions that span the entire reach. The current trout population exhibits multiple age classes (4) likely indicating that some successful natural reproduction is ocurring in the reach. No known stocking has occurred in this reach. Highest rainbow trout abundance was observed at sites 1 and 6 which were characterized as lacustrine and riverine reaches, respectively, suggesting that rainbow trout are able to effectively occupy the range of available habitat within the study area. Condition factors for the rainbow trout captured in this reach ranged from poor to above average. Overall, the fish condition and health of the species in the study area is average (Kn=0.99).

Data suggests that the prickly sculpin population also exhibits multiple age classes (potentially 3). The presence of YOY fish indicates that successful natural reproduction may be ocurring in the study area. Highest scuplin abundance were observed in sample sites that were characterized as riverine (i.e., upstream sampling sites). Relative condition for prickly sculpin in this reach ranged from poor to above average. Similar to rainbow trout, the overall fish condition and health of prickly sculpin in the study area is average (Kn=0.99).

7.0 STUDY VARIANCES

Two variances from the final study plan are described below.

The final study plan indicated four sampling methods would be employed including boat and backpack electrofishing, seining, and gill nets to collect fish. The study team did not use all proposed methods due to permit limitations (on use of gill nets) and reconnaissance results which indicated that boat electrofishing would be an effective sampling method for all available habitat types within the study reach.

The final study plan states that upon habitat documentation as part of the field reconnaissance surveys, the Districts would notify relicensing participants of the area and extent to which each method would be utilized. Notification of relicensing participants did not occur as it was determined that only one method, boat electrofishing, would be an effective method over the entire study reach.

8.0 REFERENCES

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STUDY REPORT W&AR-13
FISH ASSEMBLAGE AND POPULATION

ATTACHMENT A

SCALE SAMPLE COLLECTION, AGE, AND GROWTH DATA

Table 1. Growth rate analysis for rainbow trout collected in La Grange Reservoir, 2012.

		Number of annuli (filename)					Distance: Nucleus to annuli (in pixels)					Distance: Nucleus to annuli (in mm)			Calculated length of fish at annuli (in mm)			Growth by year (in mm)		
ID #	Fish length (mm) at capture (TL)	Scale sample 1	Scale sample 2	Scale sample 3	Age	Radius of scale (in pixels)	1	2	3	4	Radius of scale (mm)	1	2	3	1	2	3	1	2	3
78	85	0 (s78sc9)	0 (s78sc8)	0 (s78sc6)	YOY	251					0.301									
47	87	0 (s47sc1)	0 (s47sc14)	0 (s47sc15)	YOY	320					0.384									
61	87	0 (s61sc2)	0 (s61sc6)	0 (s61sc9)	YOY	338					0.405									
83	90	0 (s83sc5-7)	0 (s83sc5-7)	0 (s83sc2)	YOY	388					0.465									
86	92	0 (s86sc2)	0 (s86sc3)	0 (s86sc10)	YOY	310					0.372									
52	95	0 (s52sc_mid_btm)	0 (s52sc8)	0 (s52sc7)	YOY	352					0.422									
85	97	0 (s85sc_btm_lft)	0 (s85sc1)	0 (s85sc4)	YOY	450					0.539									
79	99	1 (s79sc2)	1 (s79sc9)	1 (s79sc11)	1	406	343				0.487	0.4			89			53		
82	99	1 (s82sc15)	1 (s80sc7)	1 (s82sc4)	1	455	380				0.545	0.5			89			52		
48	99	0 (s48sc3)	0 (s48sc_mid_lft)	0 (s48sc_mid)	YOY	385					0.462									
81	104	0 (s81sc2)	0 (s81sc5)	0 (s81sc_btm_rt)	YOY	391					0.469									
84	106	1 (s84sc11)	1 (s84sc7)	1 (s84sc5)	1	365	292				0.438	0.4			92			55		
76	109	1(s76sc10)	1 (s76sc13)	1 (s76sc15)	1	384	318				0.460	0.4			97			60		
63	114	1 (s63sc14)	1 (s63sc3)	1 (s63sc1)	1	563	410				0.675	0.5			93			56		
70	115	1 (s70sc11)	1 (s70sc8)	1 (s70sc5)	1	425	329				0.509	0.4			97			61		
80	116	1 (s80sc18)	1 (s80sc16)	1 (s80sc8)	1	449	304				0.538	0.4			90			54		
69	117	1 (s69sc17)	1 (s69sc5)	1 (s69sc19)	1	420	333				0.503	0.4			100			64		
72	117	1 (s72sc4)	1 (s72sc13)	1 (s72sc16)	1	462	330				0.554	0.4			94			57		
75	117	1 (s75sc3)	1 (s75sc9)	1 (s75sc10)	1	360	274				0.432	0.3			98			61		
73	123	1 (s73sc2)	1 (s73sc_btm)	1 (s73sc7)	1	444	366				0.532	0.4			108			71		
33	128	1 (s33sc_mid)	1 (s33sc_btm_lft)	1 (s33sc1)	1	450	236				0.539	0.3			85			48		
9	129	1 (s9sc18)	1 (s9sc7)	1 (s9sc2)	1	536	372				0.643	0.4			101			64		
41	130	1 (s41sc3)	1 (s41sc9)	1 (s41sc_btm_Rt)	1	509	327				0.610	0.4			97			60		
77	130	1 (s77sc3)	1 (s77sc1)	1 (s77sc4)	1	512	405				0.614	0.5			110			74		
38	132	1 (s38sc9)	1 (s38sc4)	1 (s38sc3)	1	460	293				0.551	0.4			97			61		
32	135	1 (s32sc2)	1 (s32sc16)	1 (s32sc_mid_btm)	1	592	343				0.710	0.4			94			57		
16	144	1 (s16sc6)	1 (s16sc1)	1 (s16sc3)	1	486	294				0.583	0.4			102			65		
39	144	1 (s39sc3)	1 (s39sc1)	1 (s39sclft)	1	495	350				0.593	0.4			113			76		
29	146	1 (s29sc_Rt)	1 (s29sc_last)	1 (s29sc1)	1	445	262				0.533	0.3			101			64		
68	149	1 (s68sc10)	1 (s68sc13)	1 (s68sc6)	1	544	294				0.652	0.4			97			61		
74	149	1 (s74sc1)	1 (s74sc2)	1 (s74sc10)	1	591	422				0.708	0.5			117			80		
71	154	1 (s71sc1)	1 (s71sc2)	na	1	868	564				1.041	0.7			113			76		
17	158	1 (s17sc6)	1 (s17sc7_flipped)	1 (s17sc6)	1	635	334				0.761	0.4			100			64		
58	162	1 (s58sc16)	1 (58sc12)	1 (s58sc2)	1	578	375				0.693	0.4			118			81		
11	170	1 (s11sc_mid)	1 (s11sc3)	1 (s11sc8)	1	638	313				0.765	0.4			102			65		
34	171	1 (s34sc3)	1 (s34sc5)	1 (s34sc9)	1	797	428				0.955	0.5			109			72		
7	172	1 (s7sc_btm_Rt)	1 (s7sc_btm_Lft)	1 (s7sc10)	1	647	353				0.776	0.4			110			74		
15	177	1 (s15sc8)	1 (s15sc2)	1 (s15sc1)	1	659	355				0.790	0.4			112			76		

Table 1. Growth rate analysis for rainbow trout collected in La Grange Reservoir, 2012.

ID #	Fish length (mm) at capture (TL)	Number of annuli (filename)				Radius of scale (in pixels)	Distance: Nucleus to annuli (in pixels)				Radius of scale (mm)	Distance: Nucleus to annuli (in mm)			Calculated length of fish at annuli (in mm)			Growth by year (in mm)		
		Scale sample 1	Scale sample 2	Scale sample 3	Age		1	2	3	4		1	2	3	1	2	3	1	2	3
3	180	1 (s3sc2)	1 (s3sc3)	na	1	755	402				0.905	0.5			113			76		
13	184	1 (s13sc5)	1 (s13sc4)	na	1	520	277				0.623	0.3			115			78		
14	187	1 (s14sc9)	1 (s14sc10)	1 (s14sc2)	1	604	301				0.724	0.4			112			75		
66	192	1 (s66sc5)	1 (s66sc10)	1 (s66sc1)	1	855	411				1.025	0.5			111			75		
24	198	1 (s24sc3)	1 (s24sc4)	1 (s24sc7)	1	623	323				0.747	0.4			120			84		
19	199	1 (s19sc2)	1 (s19sc1)	1 (s19sc3)	1	630	323				0.755	0.4			120			83		
1	205	1 (s1sc3)	1 (s1sc5)	1 (s1sc7_flipped)	1	757	431				0.907	0.5			133			96		
25	213	1 (s25sc16)	1 (s25sc11)	1 (s25sc5)	1	785	404				0.941	0.5			127			91		
6	225	2 (s6sc9_flipped)	2 (s6sc11)	na	2	902	340	632			1.081	0.4	0.8		108	169		71	61	
35	226	2 (s35Rsc5)	2 (sc35R11)	2 (s35Rsc4)	2	970	352	627			1.163	0.4	0.8		105	159		69	54	
67	231	1 (s67sc1)	1 (s67sc4)	1 (s67sc7)	1	780	407				0.935	0.5			138			101		
23	231	2 (s23Rsc1)	2 (s23Rsc2)	s23Rsc4)	2	864	358	653			1.036	0.4	0.8		117	184		81	66	
59	236	2 (s59sc4)	2 (s59sc7)	2 (s59sc10)	2	874	311	595			1.048	0.4	0.7		108	172		71	65	
2	240	2 (s2sc6)	2 (s2sc4)	na	2	1022	350	650			1.225	0.4	0.8		106	166		70	60	
18	244	2 (s18sc1)	2 (s18sc3)	2 (s18sc5)	2	970	438	767			1.163	0.5	0.9		130	201		94	70	
21	265	2 (s21sc3)	2 (s21sc4)	na	2	1348	480	933			1.616	0.6	1.1		118	195		81	77	
37	265	2 (s37Rsc1)	2 (s37Rsc2)	2 (s37sc3)	2	1109	472	844			1.329	0.6	1.0		134	210		97	77	
36	273	2 (s36Rsc1)	2 (s36Rsc2)	2 (s36Rsc4)	2	1155	394	763			1.385	0.5	0.9		117	193		81	76	
22	275	2 (s22Rsc6)	2 (s22Rsc7)	2 (s22Rsc8)	2	1070	418	800			1.283	0.5	1.0		130	215		93	85	
60	290	2 (s60Rsc6)	2 (s60Rsc4)	2 (s60Rsc8)	2	1111	470	769			1.332	0.6	0.9		144	212		107	68	
65	310	3 (s65sc7)	3 (s65sc1)	na	3	1295	463	779	1112		1.552	0.6	0.9	1.3	134	201	271	98	67	70
64	317	3 (s64sc4_flipped)	3 (s36sc5)	3 (s64sc2)	3	1421	376	767	1118		1.703	0.5	0.9	1.3	111	188	257	74	77	69
42	344	3 (s42sc10)	3 (s42sc3_flipped)	3 (s42sc5_flipped)	3	1486	364	674	1061		1.781	0.4	0.8	1.3	112	176	256	75	64	80

STURGEON
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299

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

Prepared by:
FISHBIO and HDR Engineering, Inc.

December 2013

Sturgeon
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
BRT	Biological Review Team
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
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
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
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
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
ISR	Initial Study Report
ITA	Indian Trust Assets
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
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
ppb	parts per billion
ppm	parts per million
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
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
TL	Total length
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	microSeimens per centimeter

1.0 INTRODUCTION

1.1 Background

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 has a 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). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

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. The “water bank” within Don Pedro Reservoir provides significant benefits for CCSF’s 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 RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at an elevation corresponding to the 845 ft contour (31 FPC 510 [1964]). 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) 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.

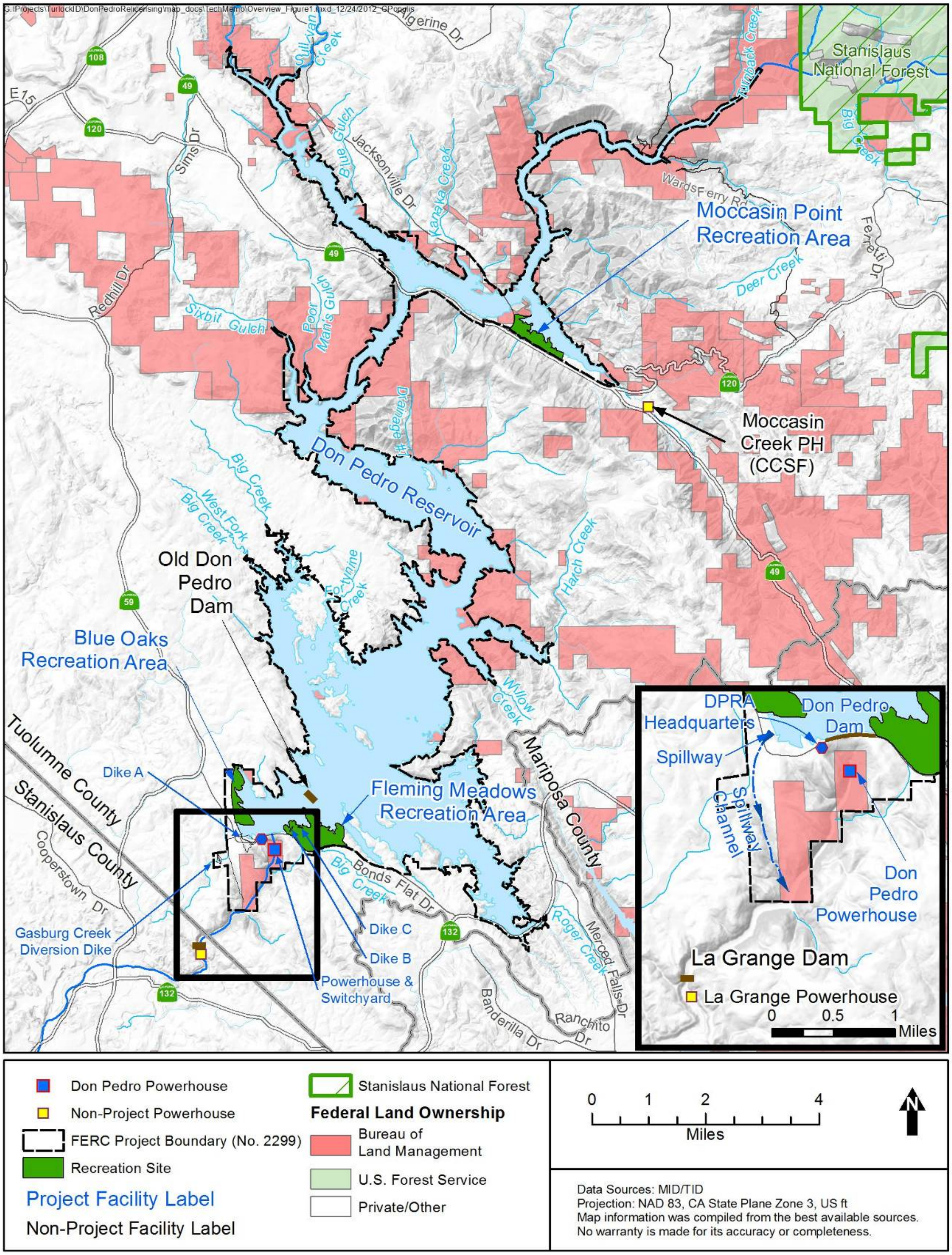

Figure 1.1-1. Don Pedro Project location.

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 Sturgeon Study (W&AR-18) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. On January 17, 2013, the Districts filed the Initial Study Report for the Don Pedro Project. The U.S. Department of the Interior, Fish and Wildlife Service (USFWS), the State Water Resources Control Board (SWRCB) and the Conservation Groups[1] filed comments on the Initial Study Report on March 11, 2013; the Districts replied to study comments on April 9, 2013. The Districts have edited the Don Pedro W&AR-18 Sturgeon Study Report in response to the USFWS comments to acknowledge that green sturgeon spawning occurs in the Sacramento River Basin. The Districts have also edited the report to provide further clarification. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

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[1] The "Conservation Groups" consists of American Rivers, American Whitewater, California Sportfishing Protection Alliance, California Trout, Central Sierra Environmental Resource Center, Friends of the River, Golden West Women Flyfishers, Northern California Council Federation of Fly Fishers, Trout Unlimited, and the Tuolumne River Trust.

1.3 Study Plan

The continued operation and maintenance (O&M) of the Project may potentially contribute to cumulative effects on habitat availability for in-river life stages of the Southern Distinct Population Segment (DPS) of North American green sturgeon (*Acipenser medirostris*) and the potential for green sturgeon to occur in the lower Tuolumne River. The Districts filed the Sturgeon Study Plan (W&AR-18) with FERC on February 28, 2012, and FERC approved the study on July 25, 2012.

2.0 STUDY GOALS AND APPROACH

The goals of this study are to conduct a literature review and synthesize applicable studies and reports on green sturgeon life history and habitat requirements in the Central Valley and San Joaquin Basin, and to evaluate the potential for green sturgeon to be affected by Project operations and maintenance activities. The study approach developed to meet these goals includes:

- collect and summarize available information on green sturgeon distribution in order to evaluate the likely presence of green sturgeon in the lower Tuolumne River;
- characterize green sturgeon habitat requirements;
- evaluate potential habitat availability for in-river life stages of green sturgeon in the lower Tuolumne River; and
- identify if there are Project-related factors that could potentially limit green sturgeon habitat in the Tuolumne River.

3.0 STUDY AREA

The study area includes the lower Tuolumne River from La Grange Dam (RM 52) downstream to its confluence with the San Joaquin River (RM 0). The lower Tuolumne River watershed covers approximately 430 square miles of drainage area, and contains one major tributary, Dry Creek at RM 16. Other contributions come from Peaslee Creek as well as McDonald Creek (via Turlock Lake) primarily during and after storm events. In this reach, the Tuolumne River extends from about elevation 35 feet at the confluence with the San Joaquin River to elevation 300 feet at the tailrace of the Don Pedro powerhouse. The lower Tuolumne River watershed is long and narrow and is dominated by irrigated farmland and the urban/suburban areas associated with the City of Modesto, Waterford, and Ceres.

The lower Tuolumne River watershed below Don Pedro Dam transitions from gently rolling hills near its easterly reaches to uniformly flat floodplain and terrace topography in the downstream direction. Soils are deep and fertile and irrigated agriculture and urban land use dominates the landscape. The Tuolumne River downstream of La Grange Dam flows 52 river miles to its confluence with the San Joaquin River. The Tuolumne River leaves its steep and confined bedrock valley and enters the eastern Central Valley downstream of La Grange Dam near La Grange Regional Park, where hillslope gradients in the vicinity of the river corridor are typically less than five percent. From this point to the confluence with the San Joaquin River, the modern Tuolumne River corridor lies in an alluvial valley. Within the alluvial valley, the river can be divided into two geomorphic reaches defined by channel slope and bed composition: a gravel-bedded reach that extends from La Grange Dam (RM 52) to Geer Road Bridge (RM 24); and a sand-bedded reach that extends from Geer Road Bridge to the confluence with the San Joaquin River (McBain & Trush 2000). The gravel- and sand-bedded zones have been further subdivided into seven reaches based on present and historical land uses, the extent and influence of urbanization, valley confinement from natural and anthropogenic causes, channel substrate and slope, and salmonid use (McBain & Trush 2000).

Large-scale anthropogenic changes have occurred to the lower Tuolumne River corridor since the California Gold Rush in 1848. Gold mining, grazing, and agriculture encroached on the lower Tuolumne River channel before the first aerial photographs were taken by the Soil Conservation Service in 1937. Excavation of bed material for gold and aggregate to depths below the river thalweg eliminated active floodplains and terraces and created large in- and off channel pits. Agricultural and urban encroachment in combination with reduction in coarse sediment supply and high flows has resulted in a relatively static channel within a narrow floodway confined by dikes and agricultural fields. Although the tailing piles are primarily the legacy of gold mining abandoned in the early 20th century, gravel and aggregate mining continued alongside the river for a number of miles, particularly upstream of the town of Waterford around RM 34.

4.0 METHODOLOGY

In accordance with the FERC-approved study plan, this study relied upon information from previous studies and ongoing fisheries monitoring activities in the study area and in the Central Valley to (1) describe the distribution and habitat requirements of the in-river life stages of green sturgeon, (2) analyze potential habitat availability in the lower Tuolumne River, and (3) analyze the potential influence of Project-related factors on habitat availability. Relicensing Participants were encouraged to provide additional relevant information for this study.

A number of studies and databases were reviewed to determine green sturgeon distribution, life history timing, instream habitat requirements, and habitat conditions within the San Joaquin Basin. References included peer reviewed scientific literature, grey literature, instream habitat and water quality studies conducted by and for the Districts, and the California Department of Fish and Game (CDFG) catch report card data.

Higher priority reviews and consideration were given to data and reports specific to the Tuolumne River, then to data and reports related to the San Joaquin Basin, followed by information from other rivers and tributaries within the Central Valley. Information obtained was compiled and supplemented with relevant biological, hydrologic, physical habitat, and water quality data in the study area.

The findings are organized into the following major sections:

- Southern DPS of Green Sturgeon Distribution;
- Green Sturgeon In-River Habitat Requirements;
- Potential Green Sturgeon Habitat Availability in the lower Tuolumne River; and
- Potential influence of Project-related Factors on Green Sturgeon Habitat Availability in the Tuolumne River

4.1 Green Sturgeon Distribution

A literature review of the historical and current distribution of the Southern DPS of green sturgeon within the Central Valley was performed. The Southern DPS of green sturgeon is listed as threatened under the federal Endangered Species Act (NMFS 2006). The Southern DPS includes green sturgeon that spawn and live within the Sacramento River Basin, Sacramento-San Joaquin Delta [Delta], and the San Francisco Bay estuary. Adult migrations and spawning of this DPS have only been confirmed within the Sacramento River Basin (NMFS 2006). Critical habitat for the Southern DPS of green sturgeon was designated in 2009, and includes the Sacramento-San Joaquin Delta, except for specific excluded areas as described in NMFS (2009a). The San Joaquin River and its tributaries upstream of the Delta, including the Tuolumne River, are not designated as critical habitat.

4.2 Green Sturgeon In-River Habitat Requirements

For purposes of evaluation, in-river habitat requirements were taken directly from the primary constituent element (PCE) concept used for the Southern DPS of green sturgeon critical habitat designation (NMFS 2009a) and include those biological and physical habitat features necessary for survival and successful reproduction within freshwater riverine systems, as follows:

(1) **Food Resources.** Abundant prey items for larval, juvenile, subadult, and adult life stages.

(2) **Substrate.** Substrates suitable for egg deposition and development (e.g., bedrock sills and shelves, cobble and gravel, or hard clean sand, with interstices or irregular surfaces to ‘‘collect’’ eggs and provide protection from predators, and free of excessive silt and debris that could smother eggs during incubation), larval development (e.g., substrates with interstices or voids providing refuge from predators and from high flow conditions), and subadults and adults (e.g., substrates for holding and spawning).

(3) **Water Flow.** A flow regime (i.e., the magnitude, frequency, duration, seasonality, and rate-of-change of fresh water discharge over time) necessary for normal behavior, growth, and survival of all life stages.

(4) **Water Quality.** Water quality (e.g., salinity, temperature, oxygen content, etc.) necessary for normal behavior, growth, and viability of all life stages.

(5) **Migratory Corridor.** A migratory pathway necessary for the safe and timely passage of Southern DPS fish within riverine habitats and between riverine and estuarine habitats (e.g., an unobstructed river or dammed river that still allows for safe and timely passage).

(6) **Water Depth.** Deep (>□5 m) holding pools for both upstream and downstream holding of adult or subadult fish, with adequate water quality and flow to maintain the physiological needs of the holding adult or subadult fish.

(7) **Sediment Quality.** Sediment quality (i.e., chemical characteristics) necessary for normal behavior, growth, and viability of all life stages.

4.3 Potential Habitat Availability

Information on instream habitat attributes within the Tuolumne River was compared with in-river habitat requirements identified in Section 4.2 to gain an understanding of potential habitat availability in the Tuolumne River.

4.4 Potential Influence of Project-related Factors on Habitat Availability

The potential of Project-related factors to influence green sturgeon habitat availability was evaluated based on information compiled regarding distribution, habitat requirements, and habitat availability.

5.0 RESULTS

5.1 Southern DPS of Green Sturgeon Distribution

The only spawning population of the Southern DPS of green sturgeon known to have spawned historically or currently in the Central Valley occurs in the Sacramento River Basin (NMFS 2006, Adams et al. 2002), where spawning migrations have been documented to extend upstream to Cow Creek (RM 280) (Heublein et al. 2009), and eggs, larvae, and post-larval green sturgeon are commonly captured during sampling efforts (Beamesderfer et al. 2004; Brown 2007). Juveniles have also been observed in the Sacramento River around the Red Bluff Diversion Dam (NMFS 2009a).

NMFS critical habitat determination notes that the San Joaquin River is accessible to green sturgeon (i.e., there are no physical barriers blocking upstream migration into the system), yet they do not appear to currently occupy this river system upstream of the Delta (NMFS 2009a) and there is no evidence that spawning has ever occurred in the San Joaquin River or its tributaries, including the Tuolumne River (Adams et al. 2002; CDFG 2002; Beamesderfer et al. 2004; BRT 2005; NMFS 2009a). Numerous fisheries studies have been conducted in the Tuolumne River since the 1980s, and no adult, larval, or juvenile green sturgeon have ever been found (Ford and Brown 2001).

Juvenile green sturgeon have been collected in the San Joaquin Delta at water diversion facilities (ranging from 17 to 7,313+ annually between 1968 and 2001; Adams et al. 2002) and at Santa Clara Shoal (Radtke 1966), and a single specimen was collected from Old River (CAS collection, D. Catania, pers. comm. as cited in Moyle et al. 1995). Although it is unclear whether these fish originated from the San Joaquin or Sacramento rivers, CDFG (2002) concluded that "based on movement of other fishes in the Delta, young green sturgeon found in the lower San Joaquin River could easily, and most likely, come from known spawning populations in the Sacramento River." This conclusion is understandable given that the south Delta pumping facilities result in reverse flows (i.e., upstream from the Delta) in the Old and Middle rivers of between 2,000 and 7,500 cubic feet per second (cfs) during the spring and summer months (USDI 2008).

Israel and Klimley (2008) and Moyle (2002) have suggested that green sturgeon may have historically spawned in the San Joaquin River based on the presence of juvenile green sturgeon at Santa Clara Shoal (Radtke 1966) in the "lower San Joaquin." This location is near the confluence with the Sacramento River and is in the tidally influenced portion of the San Joaquin River (i.e., the Delta) where negative flows occur, which led the original author (Radtke 1966, page 126) to surmise that these juveniles "probably moved upriver [into the San Joaquin] from the bay, perhaps to feed."

Since 2007, CDFG has implemented a Sturgeon Fishing Report Card (Card) Program that requires anglers in California to identify any white or green sturgeon retained (only white sturgeon allowed to be retained) or released and the river reach where they were captured. In the San Joaquin River, the Card defines two reaches (1) Stockton to HWY 140 bridge and (2) upstream of HWY 140 bridge. Based on annual Card reports (Gleason et al. 2008; DuBois et al.

2009, 2010, and 2011), six green sturgeon have been self-reported by three anglers in the San Joaquin River, including one captured upstream of HWY 140 bridge and five between Stockton and HWY 140 Bridge, ranging in size from 0.6 to 0.8 m (24 to 31 inches). The capture records were from the spring of 2009 and 2010. Although these data could indicate the occasional presence of juvenile green sturgeon in the San Joaquin River, the reach between Stockton and HWY 140 Bridge where most of the individuals were reported includes a portion of the Delta and thus extends into the zone of critical habitat.

White sturgeon are regularly observed in the San Joaquin River upstream from the Delta (Beamesderfer et al. 2004) and spawning has long been suspected to occur in wet years (Shaffter, CDFG retired, 2004 personal communication as cited in Beamesderfer et al. 2007). A recent study (Gruber at al. 2012) provided the first documented evidence of white sturgeon spawning in the San Joaquin River. This evidence was based on the collection of white sturgeon eggs that were believed to be from a single spawning event on the San Joaquin River upstream of the confluence with the Tuolumne River at RM 88 (Gruber et al. 2012). Average daily discharge in the San Joaquin River in early 2011 was two to three times higher than those experienced for water years 1991 to 2010 (Gruber et al. 2012). The authors speculated that river discharge levels of this magnitude triggered white sturgeon to enter and spawn within the San Joaquin River system (Gruber et al. 2012). Anglers and game wardens report that white sturgeon caught in prior years in the San Joaquin River commonly expel eggs or milt during handling, which suggests that spawning of white sturgeon has occurred near traditional fishing locations in other years (Gruber et al. 2012).

No information was found to suggest that adult green sturgeon migrate into, spawn, or in any way occupy the Tuolumne River. Despite the numerous Tuolumne River fisheries studies that have been conducted for the Districts since the 1980s, there is no information documenting occurrence of larval, juvenile, or adult green sturgeon in the Tuolumne River.

5.2 Southern DPS of Green Sturgeon In-River Habitat Requirements

Although green sturgeon habitat requirements have not been extensively studied, general in-river habitat requirements relative to seven different PCEs are discussed below.

5.2.1 Food Resources

While very little information is available on the specific food and nutrient requirements of Southern DPS green sturgeon (Klimley et al. 2006) juvenile and adult sturgeon are generally described as benthic feeders (Moyle 2002). Radtke (1966) found the diet of juveniles in the San Francisco Estuary included opossum shrimp and amphipods. The diets of green sturgeon in the Pacific Northwest have been found to include sand lances, callianassid shrimp, anchovies and clams (Wydoski and Whitney 1979 as cited in Moyle 2002; P. Foley, pers. comm. 1992 as cited in Moyle 2002).

5.2.2 Substrate Type or Size

Spawning may occur over a wide range of substrates, such as clean sand to bedrock (Moyle 2002); however, there appears to be a preference for gravel, cobble, and boulders (Poytress et al.

2010, 2011). Substrates suitable for egg deposition and development include bedrock sills and shelves, boulders, or cobbles and gravel with interstices or irregular surfaces to “collect” eggs; free of excessive silt and debris that could smother eggs during incubation; and suitable for providing protection from predators (BRT 2005, NMFS 2009a; Deng et al. 2002). Substrates suitable for larval development include those that contain spaces (e.g., interstices or voids) providing refuge from predators and high flow conditions (NMFS 2009a). Newly hatched larvae have poor swimming ability and prefer to stay in contact with structure, cover, and dark (very low light) habitat as opposed to open river bottoms (Kynard et al. 2005 as cited in NMFS 2009a).

5.2.3 Water Flow

Specific flow ranges are unknown, but suitable flows are considered by NMFS (2009a) to be those that would provide for adult upstream migration, trigger spawning, trigger post-spawning downstream migration, maintain water temperatures within the optimal range for eggs, larvae, and juveniles, reduce fungal infestations of eggs, and flush silt and debris from substrates.

5.2.4 Water Quality

NMFS (2009a) considers suitable water temperatures for green sturgeon to be: 11–17°C in spawning reaches for egg incubation during March–August (Van Eenennaam et al. 2005); <20°C for larval development (Werner et al. 2007); <24°C for juveniles (Mayfield and Cech 2004; Allen et al. 2006); and NMFS (2009b) states that subadults and adults may need a minimum dissolved oxygen level of at least 6.54 mg O_2/l (Kelly et al. 2007; Moser and Lindley 2007).

5.2.5 Migratory Corridor

An unimpeded migration pathway (i.e., no physical, chemical or biological human-induced impediments) within and between riverine and estuarine spawning and rearing habitats is necessary for adults and juveniles (NMFS 2009a).

5.2.6 Water Depth

Spawning and holding adults prefer pools that are >5 m (16.4 ft) deep with complex hydraulic features and upwelling, bedrock shelves, and cobble/boulder substrate (Moyle 2002; Adams et al. 2002; BRT 2005; Heublein et al. 2009).

5.2.7 Sediment Quality

Sediment quality (i.e., chemical characteristics) that is sufficient to provide for normal behavior, growth, and viability of all life stages is necessary (NMFS 2009a). This includes sediments free of elevated levels of contaminants (e.g., selenium, PAHs, and pesticides) that may result in bioaccumulation in green sturgeon from feeding on benthic species.

5.3 Potential Green Sturgeon Habitat Availability in the Lower Tuolumne River

Existing conditions within the Tuolumne River relative to each in-river habitat requirement discussed in Section 5.2 are discussed below. Although criteria for individual habitat requirements may be satisfied within the Tuolumne River, this does not indicate that green sturgeon would be able to complete their life cycle in the river. Based on the more extensively studied white sturgeon, it appears that very specific combinations of "suitable" habitat conditions are necessary for sturgeon to select locations for breeding and subsequent rearing, as indicated by spawning fish that do not utilize many sites containing apparently suitable substrate, velocity, and depths; preference for these specific and suitable combinations of habitat conditions has made it difficult to implement successful habitat restoration (Beamesderfer et al. 2005). As such, the presence of apparently suitable, or restorable habitat elements is not an indication that those elements would actually function to support green sturgeon.

NMFS (2009a) did not designate the San Joaquin River or any of its tributaries as critical habitat for green sturgeon because there was insufficient information to determine that these areas were essential for conservation of the species, and the unknown "likelihood that habitat conditions within these unoccupied areas will be restored to levels that would support green sturgeon presence and spawning (e.g., restoration of fish passage and sufficient water flows and water temperatures)."

5.3.1 Food Resources

Although specific data are lacking for juvenile green sturgeon in the Tuolumne River, limited information from previous studies in the Central Valley system and other regions indicate that green sturgeon prey items include amphipods, shrimps, bivalves and various small fishes (Moyle 2002). Many of these prey types are found in the Tuolumne River (Stillwater Sciences 2010).

5.3.2 Substrate Type or Size

The Tuolumne River downstream of RM 24 is a sand-bedded reach (McBain and Trush 2000) that does not contain substrate to support spawning, egg incubation, and early larval development of green sturgeon. Habitat mapping between RM 29 and RM 51.8 suggests the possibility of suitable substrate in a 12 mile reach between RM 39.5 and RM 51.8 (Stillwater Sciences 2010).

5.3.3 Water Flow

Since green sturgeon instream flow needs are vaguely defined, poorly understood, and likely stream-specific due to variation in channel geometry and gradient, assessment of specific flows in the lower Tuolumne River relative to the requirements of green sturgeon is not possible.

5.3.4 Water Quality

The Districts have collected continuous water temperature data at numerous locations in the Tuolumne River since 1997. Daily mean water temperatures from 1997–2011, representing all water year types, were averaged across years to calculate historical mean daily water temperatures for each location (Figure 5.3-1). Flow releases during egg incubation, larval development, and juvenile rearing periods provide the coldest water available from the reservoir (<12°C year-round), and ambient air temperatures are the driving influence for the downstream extent of suitable water temperatures for each life stage dependent on time of year (Stillwater 2011).

Historical mean daily water temperatures are within the optimal range for egg incubation (11-17°C) during the entire incubation period (March-August) at Riffle 13B (RM 45.5), while temperatures are slightly below the optimal range until about June at Riffle 3B (RM 49.1) and La Grange Dam (RM 51.8) (Figure 5.3-1). Temperatures begin to increase above the optimal egg incubation range in early June at RM 36.7 and Roberts Ferry Bridge (RM 39.5) but generally remain within the optimal water temperatures for larvae (<20°C) and juveniles (<24°C) through the entire larval (mid-March to mid-September) and juvenile (year-round) periods, respectively. For sites further downstream (Hughson at RM 23.6 and Shiloh at RM 3.4), temperatures increase above optimal egg incubation beginning in late May and above optimal larval development by mid-June, but remain within optimal juvenile temperatures year-round.

Table 5.3-1. Water temperature station locations in the Tuolumne River and periods of record.

RM	Location	Start Date	End Date
3.5	Shiloh Bridge	12/11/1997	11/2/2011
23.6	Hughson Treatment Plant	12/10/1997	11/2/2011
36.7	Ruddy Gravel	12/10/1997	11/2/2011
39.5	Roberts Ferry Bridge	8/11/1998	11/2/2011
45.5	Riffle 13B	11/14/2001	11/2/2011
49.1	Riffle 3B	12/10/1997	11/2/2011
51.8	La Grange Power House	11/14/2001	11/2/2011

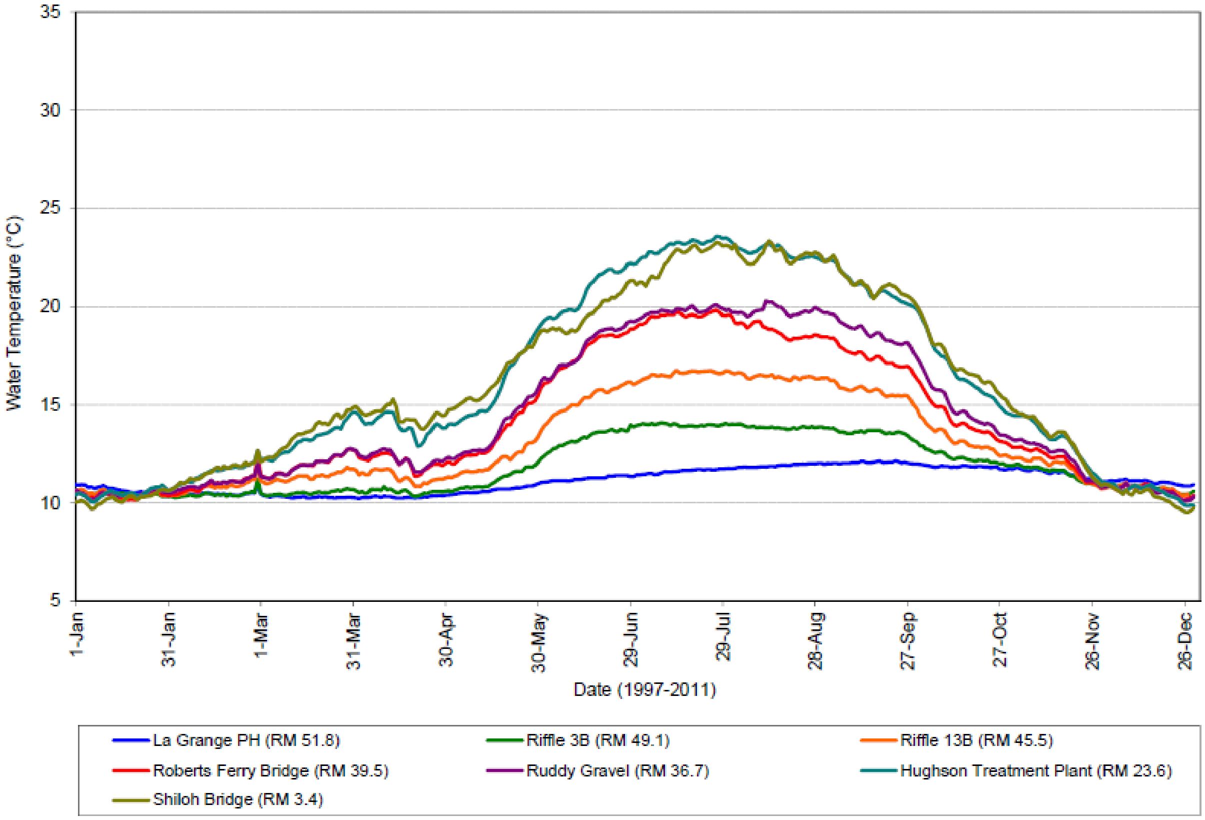

Figure 5.3-1. Average mean daily water temperatures in the Tuolumne River (1997–2011).

Dissolved oxygen measurements have been recorded periodically at six riffles between RM 25.4 and RM 51.6 during annual BMI sampling (July/August in years 2001-2005, 2007-2009) and have ranged from 8.0 to 13.1 mg/L (Stillwater Sciences 2010). Additionally, instantaneous dissolved oxygen measurements were recorded 3-7 days per week at the Tuolumne River Weir (RM 24.5) from September 16 to December 31, 2011, and ranged between 8.29 mg/L and 12.79 mg/L (10.60 mg/L season average; Cuthbert et al. 2012). Based on these data, it appears that dissolved oxygen is within suitable ranges for various life stages upstream of RM 25.4 from July-December.

5.3.5 Migratory Corridor

NMFS critical habitat determination notes that that the San Joaquin River is accessible to green sturgeon; there are no physical barriers blocking upstream migration into the system. There are no known physical impediments to passage of migrating fish in the Tuolumne River between La Grange Dam (RM 51.8) and the confluence with the San Joaquin River.

5.3.6 Water depth

The Tuolumne River downstream of RM 24 is a sand-bedded reach (McBain and Trush 2000) that does not contain suitable water depths for adult spawning and holding. Habitat mapping conducted between RM 29 and 51.8 indicates that more than 75 percent of the reach was riffles, runs, and glides (Stillwater Sciences 2010). All riffles, runs, and glides were too shallow to support adult holding and spawning. Several pools exceeding 5 m in depth were reported between RM 39.5 and 51.8 (TID/MID 2013).

5.3.7 Sediment Quality

Studies have not been conducted in the Tuolumne River to assess levels of contaminants in sediments, and no data were found to support any conclusions about sediment quality.

5.4 Potential Influence of Project-related Factors on Green Sturgeon Habitat Availability in the Lower Tuolumne River

FERC's scoping document directed the Districts to evaluate Project O&M that could contribute to cumulative effects to aquatic resources in the Tuolumne River between La Grange Dam and the confluence with the San Joaquin River. However, most of the river has conditions that do not support several of the life stages of green sturgeon, and downstream conditions (in the Tuolumne or San Joaquin rivers) would preclude spawning migrations into the area in most years. The lack of historical documentation of green sturgeon in the Tuolumne River, and rarely in the San Joaquin River, is consistent with these observations.

Project O&M does not have the potential to influence green sturgeon as there is no evidence that green sturgeon historically or currently exist in the Tuolumne River. Project- O&M also does not have the potential to influence critical habitat availability for Southern DPS of green sturgeon because the Tuolumne River is not designated by NMFS to be critical habitat (NMFS 2009a).

Fisheries monitoring has been conducted in the Tuolumne River since at least 1973, including annual seining surveys since 1983, rotary screw trap monitoring since 1995, and weir monitoring since 2009 (Table 5.4-1). While the objectives, methods, and locations of sampling have varied, there has been a general trend of increasing monitoring effort over this period. Despite intensive fisheries research and monitoring efforts over the past 40 years, sturgeon have never been observed.

Table 5.4-1. Summary of fisheries monitoring efforts in the lower Tuolumne River.

Sampling Activity	Location	Duration	References
Seining	Old La Grange Bridge to Shiloh Bridge	1983-2012	Ford and Brown 2001; TID/MID 2005; Stillwater Sciences 2012a
Fyke netting	TLSRA to McClesky Ranch	1973-1974; 1977; 1980-1983; 1986	Ford and Brown 2001
Predation Studies (electrofishing)	Roberts Ferry to Grayson	1990; 1998-1999; 2003; 2012	TID/MID 1992; Stillwater Sciences and McBain and Trush 2006; TID/MID 2013
RST Monitoring	Grayson	1995-2012	Ford and Brown 2001; Fuller 2006; Fuller et al. 2007; Fuller 2008; Palmer and Sonke 2008; Palmer and Sonke 2010; Sonke and others 2010; Sonke and others 2012

Sampling Activity	Location	Duration	References
	TLSRA/7-11/ Deardorff	1998-2000	TID/MID 2005
	Hughson/ Charles Rd	1998-2000	TID/MID 2005
	Waterford	2006-2012	Fuller et al. 2007; Fuller 2008; Palmer and Sonke 2008; Palmer and Sonke 2010; Sonke and others 2010; Sonke and others 2012
Summer Surveys (seining, snorkeling, and electrofishing)	Riffle A3 to Shiloh Bridge	1988-1994	Ford and Brown 2001
Snorkel Surveys	La Grange Dam to Waterford	1982-2011	Stillwater Sciences 2012b
Weir Monitoring	Hughson	2009-2012	Cuthbert et al. 2010; Becker et al. 2011; Cuthbert et al. 2012; FISHBIO 2013

6.0 SUMMARY AND CONCLUSIONS

The pre-historical (pre-human disturbance) presence of green sturgeon within the San Joaquin Basin remains unknown, and there is no evidence that adult, larval, or juvenile green sturgeon currently or historically occupied the Tuolumne River. There are some habitat features within the river that meet requirements for various lifestages; however, this does not imply that the green sturgeon could utilize this habitat, particularly since spawning adults appear to select areas containing a suite of habitat suitability components that are not readily separable. Based on the long-term unoccupied status of the river, NMFS' determination that the river does not provide critical habitat for green sturgeon, and 36 years of fisheries monitoring without encountering any sturgeon, Project operations are not likely to affect or influence habitat availability for green sturgeon in the Tuolumne River.

7.0 STUDY VARIANCES AND MODIFICATIONS

As stated in Section 2, the goals of this study were to synthesize applicable studies and reports on green sturgeon distribution, life history, and habitat requirements in the Central Valley and San Joaquin Basin, and to evaluate the potential for this species to be cumulatively affected by the Project. There were no variances from the Study Plan.

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LOWER TUOLUMNE RIVER RIPARIAN INFORMATION AND SYNTHESIS STUDY

STUDY REPORT
DON PEDRO PROJECT
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Prepared for:
Turlock Irrigation District – Turlock, California
Modesto Irrigation District – Modesto, California

Prepared by:
Stillwater Sciences

December 2013

Lower Tuolumne River Riparian Information and Synthesis Study
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
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
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
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
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
ISR	Initial Study Report
ITA	Indian Trust Assets
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
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
ppb	parts per billion
ppm	parts per million
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
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	microSeimens per centimeter

1.0 INTRODUCTION

1.1 Background

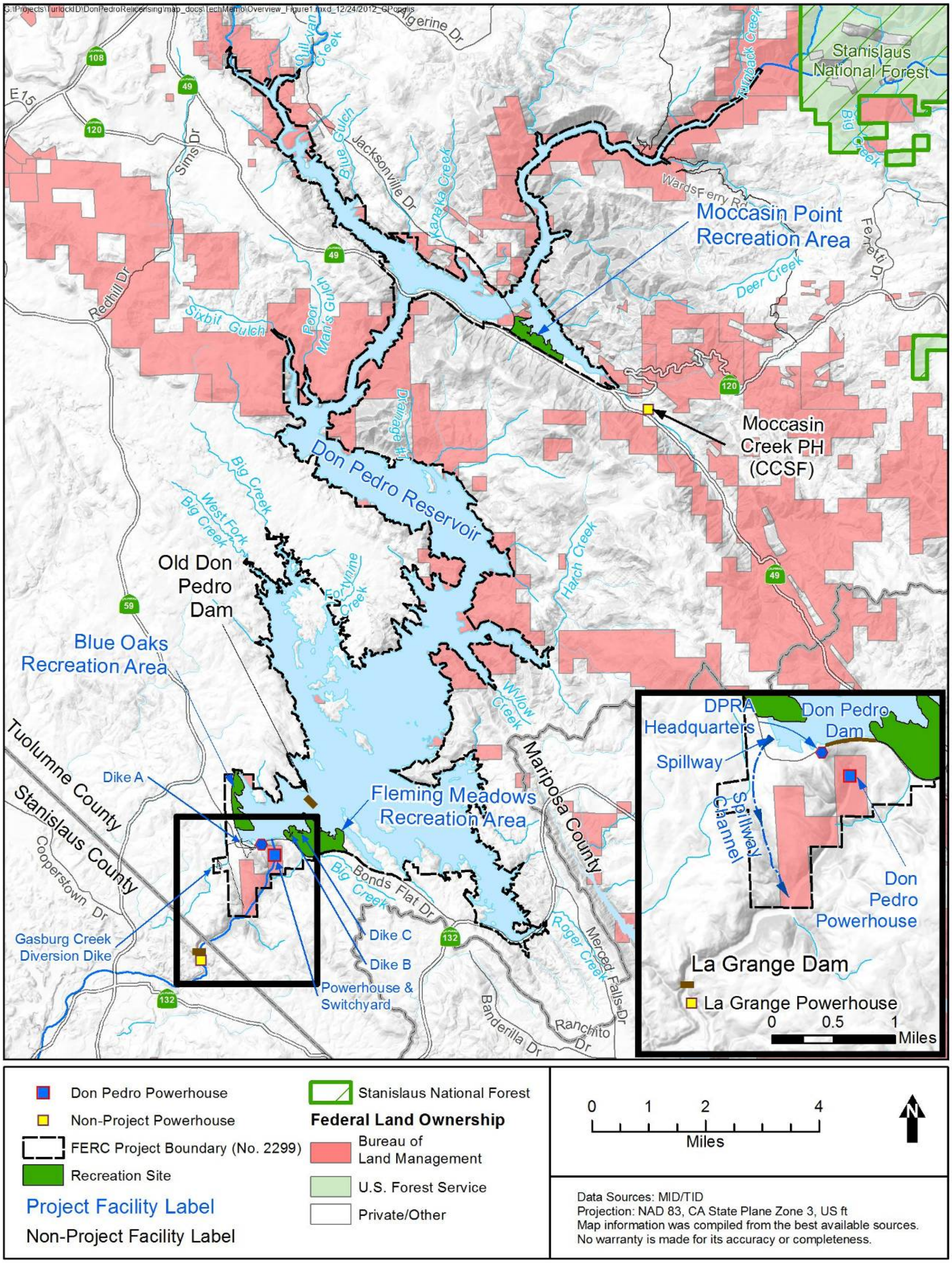
Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir has a 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). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

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. The “water bank” within Don Pedro Reservoir provides significant benefits for CCSF’s 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 RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at an elevation corresponding to the 845 ft contour (31 FPC 510 [1964]). 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) 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.



Data Sources: MID/TID
Projection: NAD 83, CA State Plane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

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 Lower Tuolumne River Riparian Information and Synthesis Study (W&AR-19) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. On January 17, 2013, the Districts filed the Initial Study Report for the Don Pedro Project. In response to comments filed by the U.S. Department of the Interior, Fish and Wildlife Service (USFWS) on March 11, 2013, the Districts modified Section 4.2 of this report to address USFWS concerns. No other changes were made to the report. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

FERC's Scoping Document 2 determined that continued operation and maintenance (O&M) of the Don Pedro Project (Project) may contribute to cumulative effects to the distribution, extent, composition, and structure of riparian vegetation along the lower Tuolumne River. FERC's SPD approved with modifications the Districts' Lower Tuolumne River Riparian Information and

Synthesis Study plan as provided in the Districts' RSP filing. In its SPD, FERC directed the Districts to (1) update the riparian vegetation inventory originally developed in 1996-1997 (McBain and Trush 2000); (2) provide a summary and synthesis of literature and other sources to characterize riparian vegetation distribution in the study area; and (3) identify and describe in the final study report riparian vegetation conditions, and linkages between these conditions and factors potentially contributing to cumulative effects to riparian resources in the study area.

The Study Plan was modified in February 2012 to include performing an update to the 1996-1997 riparian vegetation inventory. FERC approved the study plan on July 25, 2012 and directed the Districts to include the USFWS' 1995 and 2001 Final Restoration Plan for Anadromous Fish Restoration Program as one of the literature sources. The Districts completed the Riparian Information and Synthesis study consistent with these directives.

2.0 STUDY GOALS AND OBJECTIVES

2.1 Objectives

The goal of this study is to review, summarize and report information describing the condition of the riparian resources and habitats along the lower Tuolumne River. Study tasks performed to meet this goal include:

- update the 1996-1997 riparian vegetation inventory of the lower Tuolumne River;
- summarize and synthesize literature and other sources to characterize riparian vegetation distribution in the study area; and
- identify and describe factors potentially contributing to cumulative effects on riparian resources in the study area.

2.2 Background

The roughly 150 mi-long Tuolumne River drains a 1,960 mi^2 watershed, ranging in elevation from nearly 11,000 ft in Yosemite National Park, to 35 ft at the confluence with the San Joaquin River in the Central Valley. The Tuolumne is the largest tributary to the San Joaquin River. La Grange Dam is the lowest dam on the river and is located 2.3 mi downstream of Don Pedro Dam. The lower Tuolumne River includes 84 km (52 mi) of river below La Grange Dam that drops gradually from elevation 170 ft to 35 ft above sea level at the San Joaquin confluence. The lower Tuolumne River corridor is part of the Great Valley floristic region and the San Joaquin Valley sub-region (Baldwin et al. 2012). The San Joaquin Valley sub-region includes five large rivers that drain waters from the Sierra Nevada and flow into the San Joaquin to the Delta: the Mokelumne, Stanislaus, Tuolumne, Merced, and San Joaquin rivers. Similar riparian plant communities can be found now, and were found historically, along all of these rivers (Thompson 1961, Warner 1984, Katibah 1984, Vaghti and Greco 2007, Sawyer et al. 2009).

Historically, the lower Tuolumne River supported approximately 13,000 ac of riparian forest (Katibah 1984); however, with European settlement in the mid-to-late 1800s came large changes in land use, water use, and river and riparian area management. The cumulative result of these factors leaves the lower Tuolumne River corridor with roughly 2,200 ac of riparian forest, approximately 17 percent of the pre-European settlement area. Since the Don Pedro Project was completed in 1971, and particularly since the 1995 Don Pedro Project FERC Settlement Agreement, changes in flow regime, as well as ongoing implementation of the Habitat Restoration Plan for the lower Tuolumne River corridor (McBain and Trush 2000), are expected to cause changes in riparian vegetation quality and extent.

The physical processes associated with Central Valley alluvial rivers that control regeneration and survival of riparian vegetation are fairly well understood and include flooding, stream meander, sediment scour, and deposition. Native riparian plant species have evolved with these physical processes and have life history strategies that take advantage of those disturbances (Grime 1977, Scott et al. 1996, Karrenberg et al. 2002, Gurnell et al. 2005, Stella et al. 2006). Examples of such strategies include: seed release timed to catch the high or receding spring snow melt flows to aid in dispersal, seeds adapted for germinating on freshly deposited sand and silt along river margins, vegetative reproduction from parts broken off and carried downstream during high floods, and fast root and shoot growth to enable rapid seedling establishment in a transient environment (Scott et al. 1996, Mahoney and Rood 1998, Karrenberg et al. 2002, Stella et al. 2006, Stillwater Sciences 2006).

In general, riparian plant communities require periodic seedling recruitment and subsequent establishment to replace mature and dying trees to maintain the stand through time, or to reset the process of vegetation succession (Campbell and Green 1968, Johnson 1994, Naiman et al. 2005). In meandering river systems, rejuvenation of riparian plant communities can occur as mature forests located on the outside edge of a migrating river bend collapse into the channel due to bank erosion while new riparian cohorts colonize bare surfaces created on the newly created inside bend point bars (Campbell and Green 1968, Johnson 1994, Naiman et al. 2005). Under such unconstrained conditions, the continuous demise of mature and senescent forests on the outside of meander bends and regeneration of young forests on the inside of these bends results in a relatively consistent age-distribution of dominant riparian tree species (McBain and Trush 2000). In sand-bedded reaches, this process results in frequent disturbance directly adjacent to the channel that can support a mixture of willow and white alder cohorts, while increasingly mature and complex cottonwood and valley oak forest develop on 5- to 20-yr and 20- to 100-yr floodplains, respectively (Katibah 1984, McBain and Trush 2000, Franz and Bazzaz 1977, Auble et al. 1994, Auble and Scott 1998, Friedman et al. 2006).

In contrast, along slightly steeper gravel and cobble-bedded reaches of an unconstrained river, channel migration and floodplain renewal can often be punctuated by episodic disturbances and establishment events (Grant et al. 2003, McBain and Trush 2004a, Polzin and Rood 2006, Stella et al. 2011). The vegetation successional pattern can, therefore, be patchy and dependent upon flood history, site topography, and local variations in physical disturbance (Franz and Bazzaz 1977, Auble and Scott 1998, Polzin and Rood 2006, Friedman et al. 2006, Stella et al. 2011). A second reported result of high annual peak flows observed along western North American alluvial rivers is the scouring of certain riparian species from the active channel, that otherwise can become encroached by native and non-native species (Friedman et al. 1996, Merritt and Cooper 2000, Shafroth et al. 2002, Dewine and Cooper 2007). Decreased annual peak flows on riparian vegetation along alluvial rivers has been reported to potentially result in encroachment, reduced diversity in age, seral status, and species composition, as well as reduced lateral extent and diversity of native riparian habitat (Shafroth et al. 2002, Rood et al. 2005, Naiman et al. 2005).

These relationships between riparian vegetation and the physical environment of an unconstrained river indicate that, if biologically important physical conditions change in a river corridor such that pioneer species are no longer able to establish, the riparian plant community composition will shift from pioneer species to later successional, as well as invasive non-native species, and plant diversity and habitat complexity can become simplified (McBain and Trush 2000, Shafroth et al. 2002, Rood et al. 2005, Naiman et al. 2005).

The quality of riparian vegetation, in terms of being self-sustaining and capable of supporting native plants and wildlife, can also be evaluated based on extent and connectivity, structural and compositional diversity, and indications of natural recruitment. Large intact riparian stands accommodate territories of more species (bird territories can range in size from 0.5 to >25 acres; Seavy et al. 2009). Similarly, connectivity of native riparian stands along the river corridor provides important refuge and transportation corridors for many bird and wildlife species (Gardali et al. 2006, Norris and Stutchbury 2001, Cooper and Walters 2002). Diversity in tree species and age provides structural and therefore habitat diversity along the riparian corridor, and increases the number of different species that are supported (Naiman et al. 2005, RHJV 2004). Finally, channel edge and overhanging vegetation provides local areas of shade and refuge for aquatic species; large trees provide coarse woody debris for in-channel habitat complexity, and channel edge vegetation can stabilize banks to lessen sediment inputs from bank erosion. Vegetation types expected for Central Valley riparian communities include those dominated by valley oak (*Quercus lobata*), Fremont cottonwood, Goodding's black willow, Western sycamore (*Platanus racemosa*), Oregon ash (*Fraxinus latifolia*), California buckeye (*Aesculus californica*), white alder (*Alnus rhombifolia*), box elder (*Acer negundo*), narrow-leaf, arroyo, red and shining willow (*Salix exigua, S. lasiolepis, S. laevigata*, and *S. lucida*) (Vaghti and Greco 2007).

3.0 STUDY AREA

The study area consists of the Tuolumne River from the La Grange Dam (RM 52.2) downstream to its confluence with the San Joaquin River (RM 0). This study uses the reach delineations established by McBain and Trush (2000), which were based on gross differences in geomorphology, land use, and disturbance histories in the study area (Table 3.0-1, also see Figure B-1 in Attachment B).

Table 3.0-1. Summary of reaches along the lower Tuolumne River.

Reach number	River Miles	Landmarks	Dominant channel bottom material
1	0.0 to 10.5	Lower sand-bedded reach	Sand
2	10.5 to 19.3	Urban sand-bedded reach	Sand
3	19.3 to 24.0	Upper sand-bedded reach	Sand
4	24.0 to 34.2	In-channel gravel mining reach	Gravel
5	34.2 to 40.3	Gravel mining reach	Gravel
6	40.3 to 46.6	Dredger tailing reach	Gravel
7	46.6 to 52.1	Dominant spawning reach	Gravel

4.0 METHODOLOGY

4.1 Update Riparian Vegetation Inventory

The extent and distribution of vegetation types (vs. condition and structure) were surveyed and mapped for the lower Tuolumne by McBain and Trush in 1996, just prior to the record flows of January 1997 (McBain and Trush 2000). During the summer of 2012, the 1996 riparian vegetation inventory map was updated in two steps. First, GIS maps of the riparian inventory of the lower Tuolumne River developed in 1996–1997 for the Habitat Restoration Plan for the Tuolumne River (McBain and Trush 2000) were updated using 0.5' color photography orthorectified to the March 2012 LiDAR, and flown on April 6, 2012. Stream flows at the La Grange gage at this time were 317 cfs (provisional data subject to revision from USGS Surface-Water Daily Data for the Nation website for gage number 11289650). The 1996 inventory was updated by first overlaying the April 2012 aerial photography onto the 1996 polygon layer and correcting the polygon extent and shape for visible differences in land use and channel position. The 1996-1997 classification was left unchanged, except when land cover changes were extreme and obvious (e.g., change in vegetation form from herbaceous to woody shrubs or vice versa).

The second step in this process was to perform a field accuracy assessment of the updated vegetation map. The lower Tuolumne River was stratified into 13 three–to–five mile reaches based on accessibility. Four of these ‘accessible reaches’ were randomly selected, and within each of these four ‘accessible reaches’, over ten randomly selected polygons, adding up to 8 percent of the mapped riparian vegetation extent, were ground-truthed during an August 2012 field survey. For each randomly selected polygon, observed vegetation composition and class were recorded in the field. The results were used to assess the accuracy of the updated vegetation map. The minimum mapping unit was 0.5 ac.

Data collected during this field effort was used to assess the accuracy of the updated vegetation map. Mapped vs. observed vegetation types were tabulated side-by-side and accuracy scores were assigned according to mapped vs. ground-truthed vegetation type as follows:

0 = no match;
1 = correct vegetation layer (e.g., tree/shrub/forb-graminoid);
2 = 10-50 percent cover of mapped species was observed in the polygon;
3 = 50-80 percent cover of mapped species was observed in the polygon;
4 = >80 percent cover of mapped species was observed in the polygon.

Summary values of percent accuracy were calculated as percent of potential scores if all polygons had been mapped with 100 percent accuracy (e.g., the vegetation types for all randomly selected polygons perfectly matched what was observed on the ground).

Observations of possible factors contributing to the change in distribution of riparian vegetation types compared to the 1996-1997 mapping were also recorded during the field survey, including human disturbance and development within the riparian corridor, occurrence of non-native invasive plants, condition of active restoration projects, and occurrence of young or multiple age-cohorts of native riparian species within the riparian corridor.

4.2 Summarize and Synthesize Literature and Other Sources

The existing conditions and processes that support and maintain riparian systems along the lower Tuolumne River have been the subject of multiple original research and secondary literature review and analysis efforts in recent years. These include the EIS/EIR for the San Joaquin Flow Objectives Agreement published in 1999, which included a chapter on impacts to riparian and terrestrial vegetation using the lower Tuolumne River as an example (San Joaquin River Group Authority 1998). The Habitat Restoration Plan for the lower Tuolumne River corridor (McBain and Trush 2000) also provides a particularly valuable and comprehensive review of material available up through 1999. Since that time, riparian restoration projects along the lower Tuolumne River, field research projects, and additional relevant scientific journal and “white” papers have been published, notably USFWS (2001), McBain and Trush (2004), Stella et al. (2006), Stillwater Sciences (2006), Null et al. (2010), and Stella et al. (2010).

These and other documents describing current riparian community structure, composition, distribution, and restoration efforts in the study area were compiled. A preliminary list of literature sources was included as Attachment A of the study plan. That list was reviewed and sorted by topic category and relevance to the Tuolumne River watershed; additional references were added during the review process. A final list of literature sources reviewed, with an indication of relevant topics covered by each, is included as Attachment A of this report. Findings from this effort were described in combination with findings from the Update of Riparian Vegetation Inventory.

4.3 Identify and Describe Factors Potentially Contributing to Cumulative Effects

Documents describing recent past and current riparian community structure, composition, and distribution were reviewed along with available information on factors potentially contributing to cumulative effects on vegetation along the lower Tuolumne River. Linkages between the lower Tuolumne River riparian vegetation structure, composition, and vegetation dynamics (seed production and dispersal, seedling germination, survival, and establishment, mortality vs. recruitment, succession), and cumulative factors potentially affecting vegetation (e.g., river hydrology, geomorphology, land use, invasive plant species, flood control, restoration, and mining) were described. Findings from studies in the lower San Joaquin watershed, as well as studies investigating factors affecting similar riparian communities in other alluvial rivers, were also included in this review. The Habitat Restoration Plan for the lower Tuolumne River corridor (McBain and Trush 2000) as well as reports and updates on restoration plans and monitoring along the lower Tuolumne were also reviewed in order to describe potential linkages between the current state of riparian vegetation along the lower Tuolumne and potential factors contributing to ongoing changes (e.g. USFWS 2001). Levees have not been mapped for the lower Tuolumne River. Instead, the FEMA 100-year and 500-year flood maps were used to indicate areas that could be part of the active floodplain, and therefore potentially support riparian vegetation, in the absence of existing levees (Table 5.2-2, Attachment D).

5.0 RESULTS

The results of the vegetation map update and literature review are presented in two sections below. In the first section, 5.1 Riparian Vegetation in the lower Tuolumne River corridor, findings from the update of the 1996 vegetation map are reported, followed by a detailed description of riparian vegetation and restoration projects along each of seven designated reaches of the lower Tuolumne River. Study task 1 (update riparian vegetation inventory) and task 2 (summarize literature to characterize riparian vegetation in the study area) are folded together into this first results section.

In section, 5.2 Factors Contributing to Existing Conditions, important intersections between the natural history of riparian plant species and physical conditions of the riparian corridor are described, followed by descriptions of seven factors contributing to ongoing changes in riparian vegetation along the lower Tuolumne River. These descriptions are based on literature review as well as findings from the vegetation map update.

5.1 Update Riparian Vegetation Inventory and Characterize Riparian Corridor of Lower Tuolumne River

In this section, existing conditions for riparian vegetation in the gravel (RM 24 to RM 52) and sand sections (RM 0 to RM 24) of the lower Tuolumne River are described, including changes underway through many land preservation and restoration actions. A summary of the different riparian vegetation types and their extent as observed in 1996 and then in 2012 is provided below, along with a review of the accuracy assessment of the 2012 vegetation mapping.

5.1.1 Overview

Overall, the 1996/2012 updated riparian vegetation type mapping identified 17 native riparian vegetation types, three native upland types, 12 non-native invasive plant dominated types, and one more loosely defined type that could include either native or non-native dominant species (‘emergent vegetation’). Altogether, these areas add up to 2,691 acres, a 419 acre increase (18 percent) over the 1996 mapped riparian vegetation area. The majority of this observed increase was due to several large active restoration efforts.

Along the lower Tuolumne River, the most common vegetation types are valley oak, narrow-leaf willow, Fremont cottonwood, and Goodding’s black willow (Table 5.1-1). The extent of areas dominated by invasive non-native plants decreased by 8 percent compared to 1996, due primarily to the overall increase in native riparian area and to the expansion of native vegetation (mostly narrow-leaf willow) into weedy areas observed in the 1996 survey. Edible fig (*Ficus carica*) and tree of heaven (*Ailanthus altissima*), as subdominant plants, were observed throughout the area during the 2012 field survey and appear to be increasing in extent based on the age of observed plants. Maps of the current vegetation, as classified in 1996 and updated in 2012, are provided in Attachment B.

Table 5.1-1. Total surface area of riparian vegetation types mapped within the lower Tuolumne River corridor (1996 data based on GIS layer developed through McBain and Trush 2000).

Vegetation Series or Land Cover Type		1996 Total Area (acres)	2012 Total Area (acres)	Difference 2012-1996 (acres)	2012 Maximum Patch Size (acres)	2012 Number of Patches (any size)	2012 Number of Patches >5 ac
Native Riparian	Arroyo willow	4.1	4.6	0.5	1.3	9	0
	Goodding's black willow	230.6	391.4	160.8	154	200	8
	Blue elderberry	1.5	1.2	-0.3	0.28	13	0
	Box elder	114.0	105	-9.0	6.45	140	1
	Button bush	3.0	2.2	-0.8	0.55	15	0
	California buckeye	10.1	6.3	-3.8	3.44	6	0
	California grape	0.7	0.4	-0.3	0.17	3	0
	California walnut	13.8	11.4	-2.4	9.84	8	1
	Dusky willow	4.2	2.8	-1.4	1.45	6	0
	Fremont cottonwood	463.3	578.9	115.6	110.29	379	20
	Mixed willow	148.5	154.6	6.1	8.7	135	5
	Narrow-leaf willow	523.90	608.4	84.5	14.5	527	24
	Oregon ash	7.0	7.2	0.20	1.67	20	0
	Shining willow	4.8	4.5	-0.3	1.7	7	0
	Valley oak	626.0	714	88.0	61.44	375	35
	Western sycamore	0.1	0	-0.1	0.05	1	0
	White alder	32.0	31.9	-0.1	2.81	66	0
	Total Native Riparian	**2,187.60**	**2,624.80**	**437.2**	**154**	**1,910**	**94**
Emergent	**Total Emergent**	**40.9**	**26.4**	**-14.5**	**5.18**	**32**	**2**
Exotic Riparian	Black locust	0.1	0.1	0	0.13	1	0
	Disturbed/miscellaneous exotics	6.3	2.4	-3.9	1.24	4	0
	Edible fig	1.5	1.3	-0.2	0.62	3	0
	English walnut	1.9	1.7	-0.2	0.67	6	0
	Eucalyptus	11.7	14.4	2.7	7.03	12	1
	Giant reed	5.3	5.3	0.0	0.7	41	0
	Himalayan berry	3.6	3.0	-0.6	0.59	13	0
	Lamb's quarters	1.0	1.1	0.1	1.09	1	0
	Tamarisk	0.2	0.1	-0.1	0.05	1	0
	Tree of heaven	8.4	8.6	0.2	2.23	17	0
	Tree tobacco	2.7	1.2	-1.5	0.37	5	0
	Weeping willow	0.7	0.6	-0.1	0.22	3	0

Vegetation Series or Land Cover Type		1996 Total Area (acres)	2012 Total Area (acres)	Difference 2012-1996 (acres)	2012 Maximum Patch Size (acres)	2012 Number of Patches (any size)	2012 Number of Patches >5 ac
	Total Exotic Riparian	**43.3**	**39.5**	**-3.6**	**7.03**	**162**	**1**
	TOTAL RIPARIAN	**2,271.90**	**2,691.00**	**419.10**	**154**	**2,104**	**97**
Native Upland	Blue oak	33.9	17.1	-16.8	2.8	20	0
	Bush lupine	6.3	2.2	-4.1	1.82	2	0
	Interior live oak	101.2	140.5	39.3	132.03	10	2
	Total Native Upland	**141.40**	**159.80**	**18.40**	**132.03**	**32**	**2**

With several important exceptions, most remaining riparian forest stands in the sand bedded reaches (RM 0 to 24) are only a few acres in size. In the few areas where some channel migration has occurred within the levee confines, McBain and Trush (2000) report incipient native riparian species colonization on growing point bars and floodplains. However, where banks are armored with rip-rap or concrete rubble, riparian regeneration is sparse. The only native tree species that are naturally regenerating in the sand-bedded reaches under contemporary conditions are Goodding's black willow, narrow-leaf willow, and box elder (McBain and Trush 2000). In the gravel-bedded reaches, patches of remnant riparian vegetation are interspersed with areas that have been heavily altered by gravel mining, aggregate extraction and dredger tailing deposits. More than any other native riparian species, narrow-leaf willow dominates the channel edge in many areas along these reaches.

The accuracy assessment of the 2012 updated 1996 map indicates overall accuracy of 84 percent, which is above the state vegetation mapping minimum accuracy requirement of 80 percent (CDFG 2008, Meidinger et al. 2003). As detailed in Table 5.1-2, of the four most common vegetation types, accuracy was highest for areas mapped as valley oak (93 percent) and lowest for areas mapped as Goodding's willow (71 percent). A variety of other vegetated cover types, including emergent wetland and riparian areas dominated by invasive non-native species[1], also occur along the river corridor. Seven of the native terrestrial vegetation types within the Tuolumne River riparian corridor are listed as state-threatened or very threatened (S2 or S3.2 ranking); narrow-leaf willow and white alder are classified as the least threatened (S4) by the Manual of California Vegetation (Sawyer et al. 2009).

Table 5.1-2. Summary of accuracy assessment for 2012 update of 1996 riparian vegetation map of lower Tuolumne River corridor.

Dominant Vegetation Type	Number Polygons Sampled	Accuracy Score (%)
All Vegetation Types	79	84
Box elder	13	94
Fremont cottonwood	15	77
Goodding's black willow	7	71
Narrow-leaved willow	21	76
Valley oak	19	93

* Accuracy scores were assigned according to mapped vs. ground truthed vegetation type as follows 0= no match; 1 = correct vegetation layer (e.g. tree/shrub/forb-graminoid); 2 = 10-50 percent cover of mapped species; 3. 50-80 percent cover of mapped species; 4. >80 percent cover of mapped species. Percentages calculated as percent of potential scores (e.g., all 4's).

5.1.2 Reach Descriptions of Current Riparian Vegetation

Conditions and progress of restoration and preservation efforts in these seven reaches, as mapped by McBain and Trush (2000) and updated for this document (Summer 2012), are summarized in Table 5.1-3 below and described in more detail in the following sections.

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[1] "Invasive non-native plants that threaten wildlands are plants that (1) are not native to, yet can spread into, wildland ecosystems, and that also (2) displace native species, hybridize with native species, alter biological communities, or alter ecosystem processes." (from California Invasive Plant Council definition, published on webpage: http://www.cal-ipc.org/ip/inventory/index.php).

Table 5.1-3. **Summary of riparian vegetation per reach in the 2012 update of 1996 riparian vegetation map of lower Tuolumne River corridor.**

Reach number	River miles	Total riparian vegetation	Native riparian vegetation/mile	Change since 1996 survey	Non-native dominated vegetation
	miles	acres	acres/mile	acres	acres (%)
1	10.5	657.7	62.6	+261.2	2.4 (0.4)
2	8.8	300.7	34.2	+11.6	8.7 (2.9)
3	4.7	177.4	37.7	+23.6	4.3 (2.4)
4	10.2	350.5	34.4	+23.8	14.3 (4.3)
5	6.1	199.2	32.7	-4.5	1.6 (0.8)
6	6.3	727.8	115.5	+58.2	5.9 (0.8)
7	5.4	279.3	80.3	+42.3	2.3 (0.5)
Total	**52.0**	**2,691.0**	**51.7**	**+419.1**	**40.0 (1.5)**

5.1.2.1 Sand-bedded Reaches (RM 0.0- 24.0)

Reach 1. Lower Sand-bedded Reach (RM 0.0–10.5)

Overall there are approximately 63 acres of riparian vegetation per river mile along this low-gradient, sand-bedded reach (Figure 5.1-1). As detailed below, several restoration projects have been implemented along this reach since the 1996 riparian vegetation mapping, so that the overall extent of riparian vegetation has increased by approximately 261 acres, most of which is dominated by cottonwood and Goodding's black willow. The San Joaquin Wildlife Refuge occupies the downstream end of this reach and represents some of the most intact remaining riparian forests along the lower Tuolumne and in the San Joaquin Basin overall (Figure B-2 in Attachment B; McBain and Trush 2000). Along a tight bend in the river roughly four miles upstream of the San Joaquin confluence, are the 143 ac Grayson River Ranch and 250 ac Big Bend restoration sites. Several other pockets of native riparian vegetation exist between these two sites, including part of a former meander cut-off just downstream of Grayson River Ranch.

The surrounding landscape is in agriculture and the formerly expansive floodplain is frequently constrained by levees that run within approximately 1,000 ft of the channel. In the restoration project areas, the riparian vegetation extends up to 0.5 miles from the channel edge, farther than other reaches in the study area. However, beyond these areas of Reach 1, only a few remnant stands of riparian vegetation exceed five acres in size and extend beyond 150 feet from the stream channel. Thus, the larger restoration areas are tenuously linked by strips of one to two tree-width bands of riparian trees and shrubs.

Banks along several areas of this reach are also stabilized with rip-rap, further limiting the formation of fresh and diverse riparian areas through river meandering. Small pockets of riparian vegetation grow along the banks and within the rip-rap and along the upper edge of the levees. Tree of heaven, an invasive non-native species, was recorded in this reach (Stillwater Sciences 2008) as well as giant reed (*Arundo donax*), tree tobacco (*Nicotiana gluaca*), and eucalyptus (2012 surveys). Since the 1996 vegetation survey, the extent of tree tobacco, giant reed, and tree of heaven decreased slightly while the extent of other non-native species appears to have remained stable.

Figure 5.1-1. **Reach 1 supports a very low gradient unshaded channel with eroding, sparsely vegetated banks.**

The San Joaquin Wildlife Refuge

USFWS owns and operates this 6,500 ac wildlife refuge which includes riparian woodlands, grasslands, and frequently flooded wetlands at and upstream of the confluence of the Tuolumne with the San Joaquin River. Established in 1987, this refuge has been critical in the recovery of the Aleutian cackling goose and is an important part of the Pacific Flyway (http://www.fws.gov/sanluis/sanjoaquin_info.htm). As part of a wildlife refuge restoration effort, over 400,000 native trees were planted and native wetlands restored across 2,500 ac of river floodplain in 2009, under contract with River Partners, Inc.

Grayson River Ranch

Grayson River Ranch is a perpetual conservation easement on 143 ac of floodplain located approximately four miles upstream from the San Joaquin River confluence (Friends of the Tuolumne 2010). Construction for the restoration project was implemented in 2000 when two sloughs (each connected to the river at the downstream end and extending in an upstream direction into the floodplain) were excavated to provide seasonally inundated floodplain and wetland habitat. Seven thousand woody plants, including four species of willow, cottonwood, box elder, sycamore, Oregon ash, valley oak, as well as creeping wild rye grass, were planted in 2001 and 2003. Post-project fish monitoring was conducted in 2005 (Fuller and Simpson 2005). Anecdotal evidence, including a number of site photos taken during the 2012 survey, indicates that the plantings are healthy and growing; thus the restoration of riparian vegetation on the floodplain and along the newly constructed sloughs appears successful, but no quantitative monitoring assessments are available (Figure 5.1-2).

Figure 5.1-2. Photograph of Grayson Ranch restoration project, showing different ages of plantings in the foreground vs. the background.

Big Bend

The Tuolumne River Trust (Trust) and other partners acquired approximately 250 ac of property on both sides of the Tuolumne River from RM 5.8 to 7.4 ("Big Bend"). The vegetation-related project goals were to enhance existing native riparian vegetation through (1) planting native riparian vegetation, (2) improving natural recruitment processes through increased flood frequency and duration, and (3) removing existing non-native invasive plant species. Restoration implementation began in late summer 2004 and vegetation planting was completed by March 2005. The primary restoration objective of the project was to re-establish the river's access to the floodplain by notching berms along the floodplain within the project reach, resulting in increased floodplain inundation frequency, duration, and sedimentation within the contemporary (post-Don Pedro Project) flow regime. Vegetation monitoring was conducted from spring 2005 through fall 2007. The results suggest that planting to re-establish native woody riparian species was effective, with >70 percent survival of most species during the monitoring period, and that passive restoration via natural recruitment (especially for cottonwoods and willows) might be an effective supplement, particularly during wet years (Stillwater Sciences 2008). Treatment of the invasive tree of heaven achieved >60 percent mortality during the monitoring period, but long-term effectiveness of the implemented weed control efforts is uncertain.

Reach 2. Urban Sand-bedded Reach (RM 10.5–19.3)

Reach 2 runs through the neighboring cities of Ceres and Modesto and under State Highway 99 (Figure B-3 in Attachment B and Figure 5.1-3 below). This reach supports approximately 34 acres of riparian vegetation per river mile, roughly one-half the density observed along Reach 1. The narrow, 20–150 ft band of native riparian vegetation that lines the channel downstream of Modesto is dominated by box elder and narrow-leaf willow; mature stands of valley oak and cottonwood occur along the upper edge of many of the levees (McBain and Trush 2000). Stands are disconnected at several points along the length of the river, interrupted by urban development or disturbed lands. In some areas, particularly in the area near Ceres and Modesto, the riparian corridor narrows to nearly nothing or to several tree widths. Residential and urban development within 250 ft of the river's edge limits possibilities of river meander and of floodplain naturalization along much of this reach, as well as recruitment of young cottonwood and valley oak stands. Dry Creek flows into the Tuolumne River just east of the Highway 99 overpass; the confluence area supports a relatively large patch of mixed willow, valley oak, tree of heaven, and other non-native plants. Several patches of invasive giant reed were also recorded along this reach during the vegetation surveys, along with stands of planted non-native eucalyptus. Edible fig occurs as an understory tree, mixed into cottonwood and mixed willow stands along the south river bank. The extent of this species appears to have increased between the 1996 and 2012 field surveys.

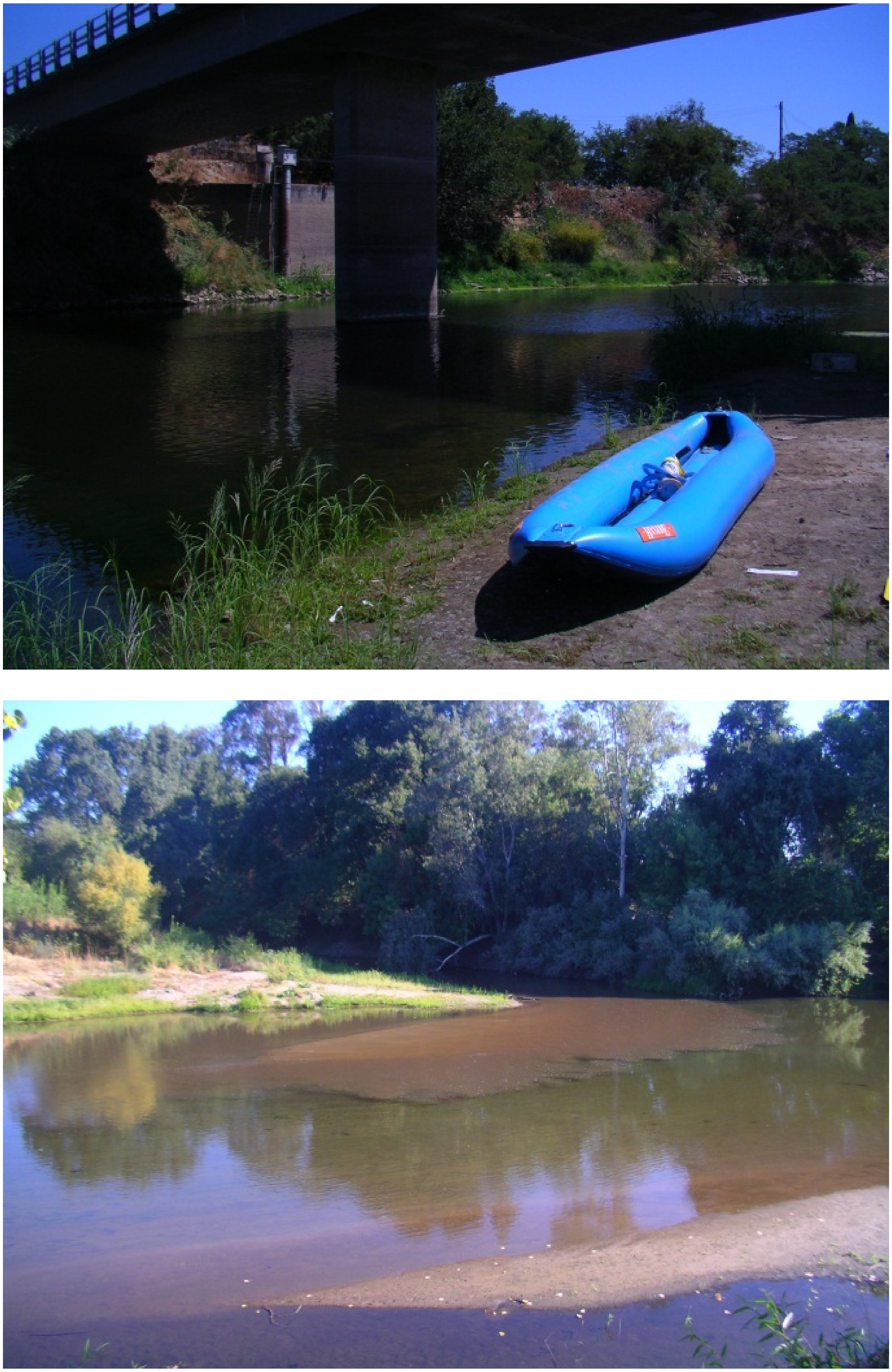

Figure 5.1-3. **Views of lower Tuolumne River along Urban Reach 2; (A) Highway 99 underpass, (B) Dry Creek confluence just upstream of Highway 99.**

Tuolumne River Regional Park

Tuolumne River Regional Park occupies 500 ac along seven miles of river, and includes five open space areas within the Modesto-Ceres urban boundaries including Legion Park/Airport Area, Gateway Parcel, Mancini Park, Dryden Park Golf Course Area and the Carpenter Road Area. Portions of the park are being restored and expanded with oversight through a joint powers agreement with the City of Modesto, City of Ceres and County of Stanislaus. While the emphasis of these parklands is for recreational use, outdoor education, and enjoyment, some floodplains and low terraces were restored to native riparian communities beginning in 2008 (in particular, the Gateway Parcel) (http://www.modestogov.com/prnd/parks/planning/projects.asp). Plans also include restoration of areas at the confluence of Dry Creek, upstream of the current Tuolumne River Park (http://www.modestogov.com/prnd/parks/planning/docs/050913-Precise%20Plan%20Summary%20Report.pdf). Most areas of the Park include mature valley oaks interspersed with manicured grasses, with no regeneration occurring. Box elder and narrow-leaf willow are the most common native riparian plants dominating river banks along this urban reach. Several stands of tree of heaven, and tree of heaven mixed into other vegetation types, were observed during 2012 field survey of Tuolumne River Regional Park.

Reach 3. Upper Sand-bedded Reach (RM 19.3–24.0)

There are approximately 38 acres of riparian vegetation per river mile along this river reach that runs just upstream of major urban areas. As described for Reach 1, larger parcels of riparian vegetation are linked by narrow (50–100 ft wide) strips of native riparian vegetation. The most common riparian vegetation types along the channel edge are narrow-leaf willow (roughly one-third of the area) and box elder; just above this narrow band are mature stands of valley oak and Fremont cottonwood, often intermixed with residential lawns and gardens. Adjacent suburban areas, along with agricultural lands and pockets of commercial development, constrain the channel width and characterize lands surrounding Reach 3 (Figure B-4 in Attachment B). Several pockets of native riparian vegetation occupy sections of floodplain and adjacent terrace, including valley oak and Fremont cottonwood, although narrow-leaf willow is most common along the water front. Patches of giant reed occur at multiple points along this reach. Between the 1996 and 2012 field surveys, a 24 acre increase in riparian vegetation was observed, including a 16 acre (36 percent) increase in the extent of narrow-leaf willow filling in several formerly open weedy patches observed in the 1996 survey. Edible fig was observed nested within other vegetation types along this reach, as well as along Reach 2. Although the extent of vegetation types *dominated* by non-native species appears to be holding steady along this reach, the amount of non-native *inclusions* within other vegetation types appears to have increased between the 1996 and 2012 surveys.

5.1.2.2 Gravel-bedded Reaches (RM 24.0–52.0)

Most historical riparian floodplain and terrace forests in the gravel-bedded reaches have been replaced by other land uses, including gravel mining and deposits of dredger tailings, rangeland, and cultivated farmland. Small patches of remnant riparian forest exist along with riparian shrubs and wetlands found on floodplains that have been heavily altered by gravel mining, aggregate extraction and dredger tailing deposits. Narrow-leaf willow dominates the channel edge in many areas along these reaches, as it does along the sand-bedded reaches. Recruitment and survival of other native riparian species is less common. Other native species are less common along the channel edge.

Reach 4. In-channel Gravel Mining Reach (RM 24.0–34.2)

This ten mile reach includes a series of gravel pits adjacent to the channel and skirts the southern edge of the community of Waterford (Figure B-5 in Attachment B). Overall, there are 34 acres per river mile mapped along Reach 4, largely dominated by valley oak along the upper terrace and levees, and by narrow-leaf willow along banks and flood prone areas. Smaller amounts of Fremont cottonwood and box elder also occur. Some gravel pit areas have been restored and replanted with native vegetation, resulting in a net decrease in non-native riparian vegetation and an overall increase in native riparian vegetation by approximately 24 ac. The greatest shift since the 1996 mapping was conversion of tree tobacco and open patches to valley oak and narrow-leaf willow. However the percent of the riparian vegetation dominated by non-native species along this reach -- over 4 percent -- is high compared to other parts of the lower Tuolumne corridor.

Except in restored areas, riparian vegetation is constrained to a narrow corridor and typically includes a strip of narrow-leaf willow along the water's edge, backed by stands of mature valley oak along the levee crest. Riparian vegetation rarely extends over 200 feet from the active channel. The first set of in-channel gravel mining pits along this reach, Special Run Pools 9 and 10, were the focus of a 2001 restoration project because they harbored non-native bass, a predator of salmon fry and smolts (McBain and Trush 2000). Tree of heaven, eucalyptus, and giant reed occur in small patches along this reach.

Special Run-Pool 9

The SRP 9 restoration project was among the first high-priority projects selected by the Tuolumne River Technical Advisory Committee (TRTAC) for implementation as part of the Tuolumne River Restoration Program. The project involved constructing a bankfull channel and floodplain where there were two in-channel pits located at RM 25.7 and 25.9 (SRPs 9 and 10), and isolating a terrace mine from the reconstructed channel by repairing a breach in the embankment. River and floodplain habitat reconstruction was completed in fall 2001 and 4.5 ac were planted with native riparian vegetation between November 1 and December 31, 2001. Irrigation and maintenance continued through September 2003. Post-project vegetation monitoring was limited to quantifying planted vegetation survival and to replacing plants as stipulated in the construction contract (TID/MID 2006). Percent cover and growth of planted vegetation was not monitored. Results from a brief survey of tree survival conducted in December 2002 indicate that survival typically exceeded 60 percent for most species one year after planting (but before irrigation ended) (TID/MID 2006). Beaver damage to some trees was noted during this survey. No survival monitoring has been conducted since 2002.

Reach 5. Gravel Mining Reach (RM 34.2–40.3)

The channel along nearly the entire extent of this reach is bounded by gravel pits that have been excavated out of former floodplain (Figure B-6 in Attachment B). Between the existing channel and gravel pits, and along edges of gravel pits and excavated lands, narrow strips of riparian vegetation exist, dominated by valley oak and narrow-leaf willow. Several other native riparian trees, such as Fremont cottonwood and Oregon ash (*Fraxinus latifolia*), also occur in several locations. Active management of these gravel mines has resulted in changes in riparian vegetation cover since the 1996 surveys: a net loss of five acres, mostly classified as Fremont cottonwood, was mapped, as well as a net increase in valley oak cover. The gravel mining areas create a wider, although heavily disturbed, band of riparian habitat along Reach 5, so that overall, this reach supports approximately 33 acres of riparian vegetation per river mile (similar to Reach 4). The vegetated areas are discontinuous both perpendicular to and parallel to the river channel, but extend up to 1,200 feet away from the channel itself at several locations.

Occurrences of vegetation types dominated by non-native species remains a small fraction of the riparian area (<1 percent). These types include tree of heaven, edible fig, and Himalayan blackberry (*Rubus armeniacus*), all of which were recorded during the 1996 and 2012 surveys (McBain and Trush 2000). Gravel bars with sparse vegetation are fairly common along this reach, as well as some rip-rapped and sparsely vegetated channel banks.

7/11 Mining Reach Restoration Project

The 7/11 restoration project is the first phase of the Gravel Mining Reach project, part of the Tuolumne River Restoration Program. The project goals included setting back gravel pit embankments, widening the floodway to 500 ft, constructing a bankfull channel and floodplain within the widened floodway, and establishing native riparian vegetation on 114 ac of newly constructed floodplain along 0.6 mi of Reach 5 (McBain and Trush 2000). In 2003, river and floodplain habitat was restructured and planted, with some follow-up planting in January 2004. Vegetation monitoring extended through 2006 (TID/MID 2006), but was limited to quantifying planted vegetation survival and replacing plants as stipulated in the construction contract. Percent cover, growth rates, and natural recruitment were not monitored.

Reach 6. Dredger Tailing Reach (RM 40.3–46.6)

Gravel mining pits and dredger tailings line the floodplain along this reach, creating off-channel water ways and pockets where native riparian vegetation has taken hold across the 1,000–2,500 ft-wide floodplain (Figure B-7 in Attachment B). The relatively wide, but highly disturbed floodplain supports over 121 acres of riparian vegetation per river mile, more than any of the other six reaches along the lower Tuolumne. Stands of Fremont cottonwood, Goodding’s black willow, valley oak, mixed willow and narrow-leaf willow are interspersed by unvegetated mounds of dredger tailings and gravel pits. Since the 1996 surveys, approximately 69 additional acres of riparian vegetation has been mapped along Reach 6, composed of valley oak, narrow-leaf willow, and sparsely vegetated open areas. A large restoration project called ‘Bobcat Flat’ involved the re-contouring the area to create accessible floodplain where there were mounds of mine tailings and sparsely vegetated lands. The re-contoured lands were actively replanted and now support patches of recently planted cottonwood (2005), valley oak, and mixed willow (Figure 5.1-4). As an unintended consequence of this restoration, excavated ponded areas are also supporting rich populations of the highly invasive aquatic weed, water hyacinth (*Eichhornia crassipes*) (Figure 5.1-5). Areas on the south side of the channel have not been re-contoured and the large ridges of tailings separate portions of the floodplain from the main channel and create local low relative elevation pockets of high moisture colonized by native riparian plants (Figure 5.1-6). Other areas of this reach support a patchwork of riparian vegetation interspersed with open European grasses and weeds and/or sparsely vegetated tailings. This reach includes the only sites where McBain and Trush (2000) reported finding multiple age classes of Fremont cottonwood that were not actively planted, indicating that natural recruitment continues to occur in this area, in contrast to other areas of the lower Tuolumne.

Surrounding land use is rangeland and some crop production. Some native upland vegetation, including live oak (*Quercus wislizeni*), coyote brush (*Baccharis pilularis*), and other upland shrubs provide transition habitat areas between the riparian areas and surrounding agricultural lands.

Figure 5.1-4. Several patches of young Fremont cottonwood occupy areas of low relative elevation along the north side of Reach 6 in the Bobcat Flat restoration area.

Figure 5.1-5. Water hyacinth crowds ponded areas created by depressions in the low elevation portions of Reach 6.

Figure 5.1-6. View looking south, with main channel in back of photographer, from top of mine tailing pile along Reach 6. Valley oaks and mixed willows in foreground have colonized side channel area created by tailings.

Bobcat Flat

In 2001, a land trust called Friends of the Tuolumne, Inc. purchased the 303 acre Bobcat Flat parcel adjacent to 1.6 miles of Tuolumne River. With land acquisitions in 2010, Bobcat Flat now totals 334.09 acres. Since its purchase in 2001, two major restoration efforts have been completed. The first restoration effort (Phase 1) was constructed in 2005, and restored 10.5 acres of floodplain by excavating remnant tailings. Floodplains were then planted with approximately 1,040 trees, 300 shrubs, and 730 herbaceous plants (McBain and Trush 2004b, McBain and Trush 2006). Tailings excavated from the floodplain were sieved and washed, rebuilding riffles and point bars by placing approximately 12,000 yd^3 of clean coarse sediment into 2,000 feet of channel (McBain and Trush 2006). The second project (Phase II) was constructed in 2011, restoring approximately 12 acres of floodplain. Coarse sediment excavated from the floodplain was sieved, and approximately 15,000 yd^3 of coarse sediment was placed into 2,200 feet of mainstem Tuolumne River channel (McBain and Trush 2012). Phase II coarse sediment placement included resupplying the high flow recruitment pile at the upstream end of the Phase I project (McBain and Trush 2011). Monitoring of Bobcat Flat began in 2003 and has continued through 2012. Bobcat Flat monitoring includes: (1) photo point documentation of floodplains and the mainstem channel features; (2) topographic and cross section surveys; (3) marked rock experiments, pebble counts, and bulk samples; (4) groundwater monitoring; and (5) habitat mapping, invertebrate monitoring, and spawning surveys (McBain Trush 2004b, 2006, 2008, 2011, and 2012).

Reach 7. Dominant Spawning Reach (RM 46.6–52.1)

Reach 7 is the most important reach for spawning salmon along the lower Tuolumne River (Figure B-8 in Attachment B). This 5.4 mile reach supports over 80 acres of riparian habitat per river mile, including nearly 50 ac of narrow-leaf and Goodding’s black willow that appears to have grown along the channel since the 1996 mapping effort. Narrow-leaf willow covers the greatest area of mapped riparian vegetation in Reach 7, followed by valley oak and Goodding’s black willow. As in Reach 6, Reach 7 includes areas that have been subject to gravel mining and swaths of the floodplain that have been re-contoured by mining and include ponds that are disconnected from the channel during low flow periods. Some of the dredger tailings were removed during construction of the Don Pedro Project and the channel was partially reconstructed in 1971 to create a low confinement channel with a broad and frequently flooded floodplain. Some dredger tailings remain and, as in Reach 6, create pits and backwaters that currently support native riparian vegetation (McBain and Trush 2000). Channel banks are occupied by white alder and narrow-leaf willow, while other native riparian trees (Fremont cottonwood, Goodding’s black willow, valley oak) grow in patches along the rumpled floodplain surface.

The surrounding uplands are used for rangeland and crop production, and the riparian corridor is confined by levees or bluffs along short sections of the lower and upper ends of the reach, leaving the majority of the channel along this reach ‘loosely’ confined. Adjacent uplands support California buckeye, blue and interior live oak, (*Quercus douglasii, Q. wislizeni*) in an annual grassland matrix. Directly downstream of La Grange Dam, the valley is confined by bedrock and supports small patches of riparian vegetation (RM 50.5–52.1) (McBain and Trush 2000). A few small patches of giant reed were recorded along this reach but invasive species cover less area in Reach 7 than in most other reaches.

Basso Ecological Reserve Land Purchase

In 2000, two large county-owned parcels were connected through the purchase of a 42-ac ‘bridge’ parcel called the Basso Ecological Reserve. This land purchase, located between La Grange Bridge and Basso Bridge, was coordinated by CDFG and funded by CALFED. The County parcels are 185 and 350 ac, and the combined protected lands are intended to help protect critical spawning habitat in this reach (McBain and Trush 2000).

5.2 Factors Contributing to Existing Condition of Riparian Vegetation

The lower Tuolumne River has been subject to the cumulative effects of over 100 years of intensive land use and water management. The current condition of the riparian vegetation along the lower Tuolumne River is the result of cumulative ongoing effects associated with European settlement and ongoing changes in the physical conditions along the river. Placer mining and subsequent dredger mining during the Gold Rush affected the channel and associated floodplains (USFWS 2001). Also during this period, steamship transportation along the major rivers was fueled by cordwood harvested from adjacent lands and likely resulted in the first wave of riparian forest clearing in some areas (Rose 2000, as cited in McBain and Trush 2002). This initial phase of settlement was followed by berm and levee construction, land use conversion, and changes in regional hydrology that occurred with pre-1860 dryland farming. Subsequent irrigated cropland production, beginning in the late 1800s, co-occurred with increased stream water withdrawals for irrigation and municipal uses. During the nineteenth century, hydraulic mining, sluicing, and dredging also rearranged large areas of the river and adjacent lands. During the twentieth century, gravel mining along the lower Tuolumne further constrained and altered the riparian floodplain. Wheaton Dam, a small irrigation dam constructed in 1871, was supplemented or replaced by much larger dams along the Tuolumne main stem and tributaries in the twentieth century, affecting downstream flows and coarse and fine sediment transport. Finally, urbanization has accelerated along the lower Tuolumne River riparian corridor and is expected to continue to increase into the future (American Farmland Trust 1995, State of California 2007).

The effects of these changes, excluding initial land clearing, continue to limit the regeneration of native riparian vegetation along the lower Tuolumne River. In the following section, factors contributing to important changes in the riparian physical environment along the lower Tuolumne River are described, along with observations on how those factors could be contributing to the existing condition of riparian vegetation. A list of the dominant factors and their potential cumulative effects on riparian processes and structures is provided in Table 5.2-1 below.

Table 5.2-1. Known and/or hypothesized linkages between cumulative factors affecting current riparian vegetation condition, as well as reaches where effects are evident along the lower Tuolumne River.

Factor Affecting Riparian Resources	Effect on Riparian Structure	Effect on Processes that Support Riparian Vegetation	Reaches Where Effects are Evident
Land use conversion to agriculture	Largely reduced width of riparian vegetation, especially valley oak terraces.	Prevents recruitment and regeneration of native vegetation on former floodplains and terraces. Flood protection requirements not as high as urban areas.	RM 0 to 20
Land use conversion to urban areas	Vegetation removal, isolated and aging remnant riparian vegetation; constrains channel migration; simplifies planform.	Prevents recruitment and regeneration of native vegetation on urbanized former floodplains and terraces; geomorphically and biologically "freezes" surrounding floodplains due to flood protection requirements.	RM 15 to 30
Levees and bank revetment	Greatly constrains channel migration; simplifies planform; reduces bank vegetation	Prevents floodplain inundation which nourishes native riparian plants and delivers propagules; constrains meander; reduces recruitment along banks	RM 0 to 52
Aggregate mining	Leaves large pits in floodplain area - converting floodplain vegetation to open water; levees built to isolate pits from river constrain river.	Precludes regeneration of riparian vegetation (no habitat) and associated levees limit lateral movement of river, reducing amount and diversity of riparian habitat surfaces created.	RM 34 to 50
Dredger tailings	Dredger tailings of unconsolidated sediments on floodplain replace rich soils with depauperate ones, resulting in change in riparian species composition and reduced extent and diversity of riparian vegetation.	Stymied development of native riparian vegetation on spoil piles; reduced riparian habitat connectivity.	RM 38 to 52
Invasive plants	Change in plant species composition, structure and habitat quality.	Reduces and/or precludes native species through competition for water, light and soil nutrients and allelopathic effects; can alter frequency of disturbance associated with bank erosion and fire, favoring plant species that are adapted to less frequent flooding and/or more frequent fire.	RM 0 to 52

Factor Affecting Riparian Resources	Effect on Riparian Structure	Effect on Processes that Support Riparian Vegetation	Reaches Where Effects are Evident
Altered hydrograph	Vegetation encroachment into active channel and lower floodplain; reduced extent of rejuvenating riparian vegetation, reduced diversity and lateral extent of riparian community types; reduced channel migration and simplified planform.	Reduces scour of vegetation within active channel floodplain; reduced frequency of avulsions, channel meander, creation of new recruitment sites for riparian vegetation; distribution of river-transported riparian propagules; survival of native riparian seedlings, and diversity of riparian vegetation types on floodplain; increased competitive advantage for upland and invasive non-native species.	RM 0 to 52
Reduced sediment delivery	Reduced availability of bare mineral soil for recruitment; diminished extent of riparian vegetation; reduced age and structural diversity of riparian vegetation.	Diminished riparian recruitment and establishment of diverse riparian community types.	N/A
Restoration	Increases extent of existing riparian vegetation	Provides seed and propagule sources for downstream recruitment; increases organic material content of soil	RM 0 to 52
Climate change	Uncertain, and dependent on flow regulation response to changes in snow storage and snowmelt patterns as well as changes in user needs; increasing air temperatures may change riparian vegetation structure and composition.	Uncertain effect on flow regulation; potential increase in drought stress and favoring of drier site plant species with increased temperatures; potential changes in seed release timing of cottonwoods and willows with increased air temperatures may result in further decoupling of natural recruitment processes.	RM 0 to 52

5.2.1 Land Use Change, Levees and Flood Control

Following the Gold Rush of the 1840s and 1850s, agriculture activities including crop production and ranching increased rapidly in the Central Valley. During this period, woody vegetation was cleared along the river bottomlands to support crop production in these rich alluvial soils; levees were constructed to protect the new farm lands from flooding in the spring and irrigation canals were constructed to provide irrigation water during the growing season (Thompson 1961, Katibah 1984). Some landowners in the nineteenth century held extensive tracts of land in the Central Valley, and large areas of marshland in the Central Valley were leveed and drained for agricultural uses (Katibah 1984). Clearing riparian forests has the obvious initial effect of simply removing the vegetation, associated habitat, and halting many attendant ecosystem processes (Katibah 1984, Naiman et al. 2005). Grazing and intensive row crop production on these former riparian forest lands suppresses cottonwood sapling survival, as observed on the lower Tuolumne (McBain and Trush 2000) and documented through a research project along the Nacimiento River in coastal central California (Shanfield 1984). Clearing woody plant cover also creates openings within the lower Tuolumne riparian corridor where non-native plant species can secure a foothold and proliferate (McBain and Trush 2000).

The lateral extent of riparian vegetation within the Tuolumne River valley is greatly diminished, in many areas to less than three tree crown widths across or to no riparian vegetation at all. Comparison with historical 1937 aerial photographs revealed that contiguous riparian forests on the southern bank often exceeded 120 ac; these stands were reduced to 30 ac or less by 1993 (McBain and Trush 2000). At a slightly broader scale, land conversion and levee construction constrains the channel migration process, including both the gradual meander bend and meander cutoff/oxbow formation along sand-bedded reaches, and the avulsion process along the gravel-bedded reach (McBain and Trush 2000, Grant et al. 2003). These processes are important for sustaining a diversity of successional community types in the riparian landscape (Scott et al. 1996, Friedman et al. 1998, McBain and Trush 2000, Polzin and Rood 2006, Stella et al. 2011), including the landscape of the lower Tuolumne River.

Natural levees can form alongside rivers as the coarse sediment load suspended during the higher flood flows is deposited during the receding flows (Katibah 1984, Scott 1996). Rivers in the San Joaquin Basin that carried sufficient sediment to their lower reaches to create natural levees include the Tuolumne, as well as the Stanislaus, Merced, Mokelumne, Cosumnes, and northern San Joaquin (Katibah 1984). With land conversion to agriculture and urban uses, these natural levees were augmented to prevent flows from accessing adjacent floodplains, thereby cutting these areas off from seasonal to less frequent inputs of water, sediment, nutrients, and water-borne propagules (Warner 1984, Junk et al. 1989, Tockner et al. 1999). Similarly, man-made levees limit channel migration, narrowing and simplifying the planform, and prevent high flows from scouring vegetation on the land-side of the levee, prohibiting creation of areas for natural riparian vegetation recruitment in these levee protected floodplains. Without these disturbances and deliveries, riparian plant communities behind levees cease to regenerate and become senescent, and vegetation on the water-side of the levees becomes more stable and homogeneous (Stillwater Sciences 1998, McBain and Trush 2000).

While levees have not been mapped along the lower Tuolumne River, the FEMA 100-year flood zone provides an indication of the areas that could be part of the active floodplain, and therefore potentially support riparian vegetation. Although these areas are clearly defined in large part based on the presence of levees, the degree to which areas within the defined 100-year flood zone is occupied by riparian vegetation can be used as a rough indicator of the extent to which levees, as well as other factors, are limiting riparian vegetation (Table 5.2-2, and Attachment D). The comparison of the FEMA 100-year flood zone with the updated map of riparian vegetation illustrates the effect that levees and other land use changes have had on limiting the extent of riparian vegetation, particularly along the lowest reaches of the Tuolumne River (Table 5.2-2, and Attachment D). In Reaches 1 and 3, only 15 percent and 16 percent of the 100-year flood zone supports riparian vegetation, respectively (Table 5.2-2, and Attachment D); the remaining flood zone is not available to support riparian vegetation largely due to levees and land use change to agriculture. Reaches 2 and 4 run through urban areas, and 26 percent and 25 percent of the 100-year flood zone is covered by riparian vegetation, respectively. The conversion of floodplain to urban uses requires more intense flood protection (i.e., higher levees) than conversion to agricultural lands due to the increased risk of costly flood damage and to human life. Thus, where the river runs through or adjacent to Waterford and Modesto, the 100-year flood zone is more constrained by levees, as indicated by the more extensive 500-year flood zone (Attachment D).

The non-urban reaches are less fortified against a 100-year flood and, as a result, there is little to no difference between the extents of the 100-year and 500-year flood zones. Gravel pits and bare soils within active gravel mining areas limit the extent of riparian vegetation within the 100-year flood zone of Reach 5. In Reaches 6 and 7, riparian vegetation extends roughly to the 100-year flood zone limits (Attachment D). Thus, the difference in 100-year flood zone and mapped riparian vegetation is likely due to the combined effects of aggregate extraction, dredger tailings, and to a lesser extent, land use change and associated levees.

Table 5.2-2. Area within the FEMA 100-y flood zone per reach, compared to the existing area of mapped riparian vegetation.

Reach	100 year Flood Zone (acres)	Mapped Riparian Vegetation (acres)	Percent of 100yr FZ Currently Mapped with Riparian Vegetation
1	4,542	658	15
2	1,159	301	26
3	1,107	177	16
4	1,416	350	25
5	1,868	199	11
6	1,737	728	44
7	545	279	52
Overall	**12,374**	**2,691**	**22**

5.2.2 Aggregate Extraction and Dredger Mining

In-channel and floodplain dredging and tailings deposition along the lower Tuolumne converted very large areas of historically diverse riparian habitat to an essentially barren landscape of cobble ridges interlaced with narrow sloughs. The effects are evident along nearly one-third (16 out of the 52 river miles) of the river corridor. The profound impacts of channel and floodplain dredging and gravel mining on riparian vegetation extend from just upstream of Waterford to La Grange (RM 34–50). Several restoration projects, including Special Run Pools 9 and 10, the 7/11 Mining Reach Restoration, and Bobcat Flat have re-contoured these otherwise greatly altered floodplains. Upstream of Turlock Lake State Park (RM 42), some of the dredger tailings area was reclaimed during construction of the Don Pedro Dam. The remaining floodplains along this 16-mile stretch are littered with unconsolidated tailing piles, excavated gravel pits, and frequently scraped and re-surfaced mining areas.

Although dredge mining along the lower Tuolumne ended by 1952, dredger tailing piles extend from river mile 40 to 46 along the lower Tuolumne River. Piles of dredger tailings rise over 20 feet above the channel water surface, excluding any natural recruitment from water born propagules, and have extremely low water holding capacity. Thus, these areas do not offer hospitable habitat for native riparian plant species (Stillwater Sciences 2007, McBain and Trush 2000). Between the tailing deposits are low-lying swales, some of which may be connected to perennial or seasonal groundwater supplies and support a variety of native and non-native riparian and wetlands species (narrow-leaf willow, cattails, and aquatic plants such as duckweeds, water fern, and water hyacinth [*Lemnaceae, Azolla filiculoides, and Eichhornia crassipes*]) (McBain and Trush 2000, Stillwater Sciences 2007).

Aggregate mining continues in localized areas from Hughson to La Grange (RM 24-50). Gravel mining of historic floodplains leaves deep ponds precariously close to the channel, protected from channel capture by levees. Space available for riparian vegetation development is also highly constrained due to the replacement of floodplain surface by gravel pits and, since the top soil has been removed from the active gravel mining operations, few or no native species can become established in the remaining open floodplain areas (Figure 5.2-1). Riparian vegetation along the steep levee banks is cleared and regeneration prevented with the intent of maintaining levee integrity. Gravel pits become filled with ground water and support populations of non-native aquatic plant species, such as water hyacinth. These gravel pits are deep (up to 38 ft deep) and up to 400 ft wide, and by occupying large portions of the floodplain, constrain the channel to a stationary and narrow area (McBain and Trush 2000). Therefore, channel meander is prevented in these reaches, along with associated riparian vegetation development and diversity.

Figure 5.2-1. Active and legacy gravel mining operations can preclude development of riparian vegetation in areas of the historical floodplain that extend from River Mile 24-50 along the lower Tuolumne River.

In summary, the effects of ongoing and historical in-channel and floodplain aggregate extraction and dredger mining continues to alter and limit revegetation of the floodplain with native riparian vegetation along 16 of the 26 gravel-bedded river miles, translating to over 60 percent of the gravel-bedded reach and roughly one-third of the entire river extent along the lower Tuolumne River.

5.2.3 Invasive Plant Species

Invasive non-native species are, by definition, strong biotic competitors for resources such as light and water and can, given the time and space, out-compete existing native riparian plants and alter the composition and structure of the riparian community (Stromberg et al. 2002, Shafroth et al. 1995). Dominance of invasive non-native plants in the riparian corridor interferes with recruitment and survival of native woody plants by occupying the available recruitment sites and by competing for resources with young seedlings (Friedman et al. 2005, Stromberg et al. 2002, Else and Zedler 1996, McBain and Trush 2000, Coffman 2007). The common effect of invasive non-native species is a simplification of the structure and composition of the riparian plant community, in some cases towards monotypic stands (Holt 2002, Dudley 2000, Coffman 2007). Depending on the non-native species characteristics, this often decreases the suitability of the riparian corridor for invertebrates and wildlife, and compromises adjacent aquatic and terrestrial habitat (Bell 1994, Herrera and Dudley 2003). Invasive exotic plant species can affect large alterations on the riparian plant and dependent wildlife community (e.g., Scoggin et al. 2000). Many invasive non-native species can alter ecological processes, such as fire frequency and intensity, litter decomposition, soil richness, and foodweb dynamics (D'Antonio and Hobbie 2005, Brooks et al. 2004, Corbin and D'Antonio 2004, Coffman 2007, Coffman et al. 2010). Such changes in physical conditions or processes that define the riparian habitat make the space less compatible with native species niche requirements and often have no or even a positive effect on the invading species habitat needs (Busch and Smith 1995, Alpert et al. 2000, Coffman 2007, Shafroth et al. 1995).

Non-native species have been introduced to the lower Tuolumne riparian corridor through intentional plantings (e.g., Eucalyptus windrows), as garden and agricultural escapes (e.g., edible fig, tree of heaven, and giant reed), unintentional seeds or vegetative fragments brought in by vehicle or boat, and numerous other ways. The further spread of these introduced species is often facilitated by human activities and alterations, such as vegetation clearing, construction and maintenance of roads and other development, and changes in hydrology and other natural conditions that support non-native over native species.

Overall, non-native dominated vegetation comprise approximately 1.5 percent of the riparian vegetation in the lower Tuolumne River corridor (about 40 ac, or just under one ac per river mile; see Table 5.2-3 below). Since the 1996 mapping effort, the area classified as dominated by non-natives has decreased by 3.8 acres, or 0.4 percent of the total area of mapped riparian vegetation. For most non-native vegetation types, the extent has held steady of time, with minor changes in eucalyptus, Himalayan blackberry, and 'disturbed miscellaneous exotics'. Reaches with the greatest area of riparian vegetation dominated by non-native species are Reach 2 (largely urban area near Modesto, RM 10.5 -19.3) and Reach 4 (in-channel gravel mining reach, RM 24.0 to 34.2).

Table 5.2-3. Acres of non-native dominated riparian vegetation mapped along the lower Tuolumne River in 2012.

Reach	Acres	Acres per River Mile
1	2.40	0.23
2	8.66	0.98
3	4.34	0.92
4	14.28	1.40
5	1.60	0.26
6	5.89	0.93
7	2.30	0.43
Total	**39.50**	**0.77**

Four invasive non-native species, classified as such by the California Invasive Plant Council (CALIPC), make up two-thirds of all mapped non-native dominated vegetation along the lower Tuolumne River: eucalyptus, edible fig, giant reed, and tree of heaven. These species received overall threat ratings of high (giant reed) or moderate (the other three) by CALIPC and are described in more detail in Attachment C. Himalayan blackberry (rated as a high threat by CALIPC) was also frequently observed as an associated understory species during the 2012 field survey.

5.2.4 Changes in the Hydrograph

Like dams on other large tributaries to the San Joaquin River, major dams on the Tuolumne River regulate flow from the upper watershed downstream to the lower Tuolumne River. Overall an average of 60 percent of the river's total flow reaches the San Joaquin confluence 52 mi downstream of La Grange Dam (McBain and Trush 2000). Over the past 120 years, each increment of flow regulation (Wheaton, La Grange, O'Shaughnessy, old Don Pedro, and new Don Pedro dams along the mainstem as well as dams constructed along tributaries above O'Shaughnessy Dam, including Cherry and Eleanor Creeks) has added changes to the lower Tuolumne River flow regime. These changes continue to contribute to the cumulative effects to riparian vegetation along the river corridor. The general mechanisms by which changes in the hydrograph can potentially affect riparian vegetation are summarized in Figure 5.2-2. The two most important hydrologic changes related to riparian vegetation along the lower Tuolumne River are altered annual peak flows and changes in the descending limb of the spring hydrograph.

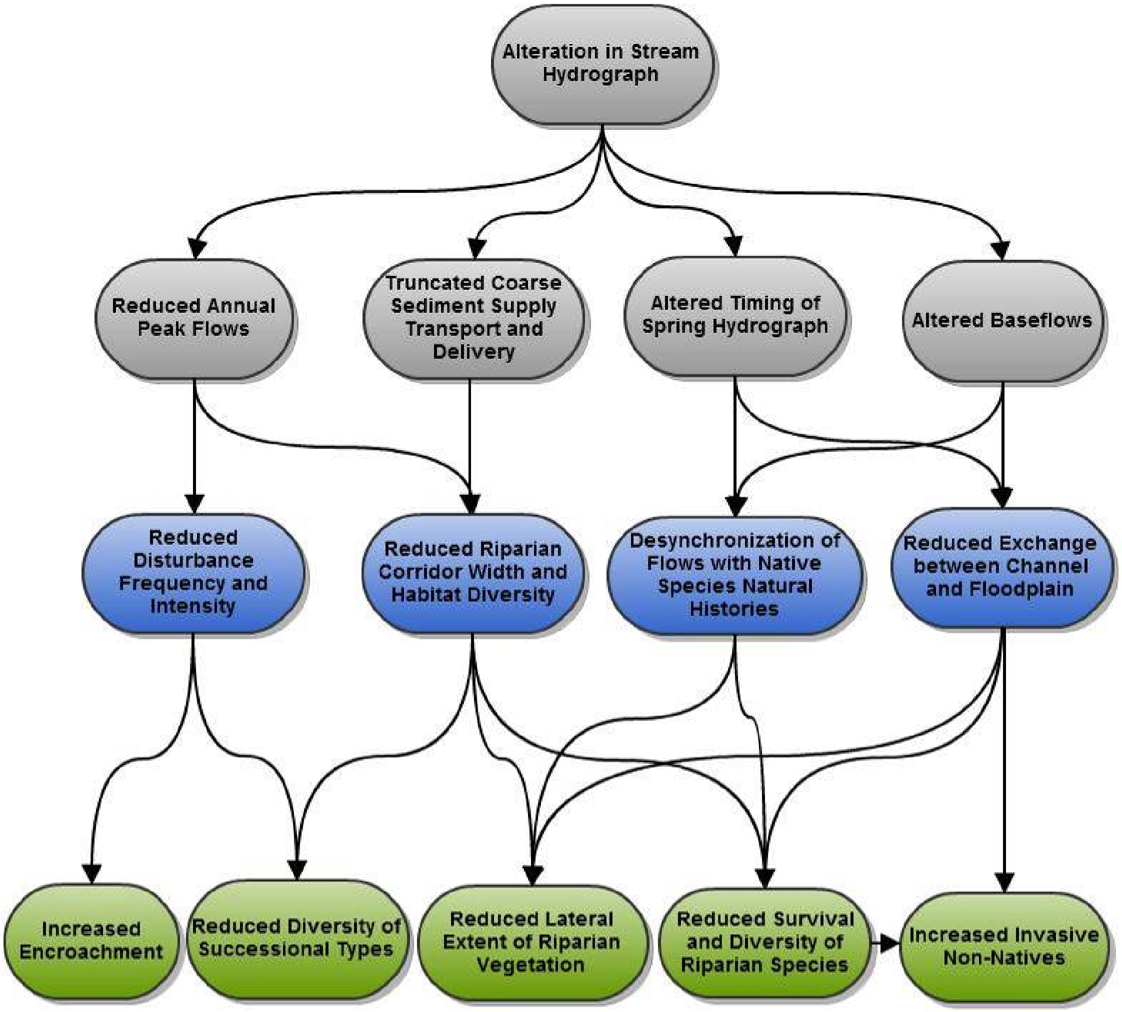

Figure 5.2-2. Flow diagram showing potential linkages between changes in the hydrograph (gray), the physical condition (blue), and vegetation (green) of riparian corridors.

5.2.4.1 Reduced annual peak flows

Evidence of vegetation response to reduced annual peak flows along the lower Tuolumne River has been reported as a frequent line of narrow-leaf willow and/or box elder thickets, located directly along or within the active channel banks (McBain and Trush 2000, see Attachment B maps). Under more frequent high flow conditions, the distribution of these species would be lower compared to other native riparian species because increased mortality would balance with the greater recruitment capacity of these species (McBain and Trush 2000, Stella et al. 2006). Bendix (1999) found that narrow-leaved willow was moderately resistant to high flows, possibly due to its stems and strong roots. For this species, reduced annual peak flow suspends otherwise frequent thinning of cohorts growing adjacent to and into the stream channel. Again, observations of dense and frequent thickets of narrow-leaved willow and box elder along the lower Tuolumne River suggest that reduced annual peak flows make it possible for these thickets to remain in place.

McBain and Trush (2000) inferred that the reduced frequency and magnitude of winter floods along the lower Tuolumne River has reduced scour-mortality of narrow-leaf willow seedlings that recruit along the riverbank, while limiting recruitment of Fremont cottonwood by reducing available bare mineral soil for germination and access to appropriate relative elevation surfaces (McBain and Trush 2000, Stella 2005, Stella et al. 2010). The limited natural recruitment of Fremont cottonwood, Goodding’s black willow, and other willow species (excluding narrow-leaf willow, e.g. red and shining willow [*Salix laevigata* and *S. lucida*]) outside of actively replanted restoration areas is evidenced by the lack of young cohorts of these species observed during both the 1996 and 2012 field surveys (McBain and Trush 2000; also see vegetation maps presented in Attachment B). Other tree willows known to have high water demands, such as arroyo and shining willow, were very infrequently observed along the lower Tuolumne River in 1996 surveys, although they are common in other relict riparian stands in the region (e.g., Caswell State Park; Hickson and Keeler-Wolf 2007). In contrast, large areas of new and recent narrow-leaf cohorts were observed along the lower Tuolumne River corridor in the 2012 survey (and by McBain and Trush 2000; also see vegetation maps presented in Attachment B).

5.2.4.2 Truncated sediment supply and delivery

Changes in the availability of fresh sediment deposits, which for many native riparian plant species represent recruitment sites, can affect the extent of riparian vegetation along alluvial rivers (Naiman et al. 2005). The ongoing effect of sediment interception can include sediment-depleted conditions and reduction in riparian recruitment sites, which can be expressed as channel incision or channel widening, downstream if the sediment supply is less than the transport capacity of the downstream channel (Williams and Wolman 1984, Ligon et al. 1995, Kondolf 1997, Grant et al. 2003, McBain and Trush 2004a).

Starting in 1871 with the construction of Wheaton Dam, coarse sediment delivery from the upper to the lower reaches of the Tuolumne River has been intercepted (McBain and Trush 2004a). With construction of Don Pedro Dam, storage capacity was sufficient to withhold both coarse and fine sediment during all but the largest flow events (McBain and Trush 2004a). The primary effect of this change in sediment supply that has been observed on the lower Tuolumne River is the lack of synchrony between recently deposited fine sediment at suitable elevations and the seed release timing of pioneer riparian tree species (Stella et al. 2010) (see next section for additional discussion).

5.2.4.3 Altered timing of spring hydrography

Changes in the spring snowmelt hydrograph away from the historical extent and timing can dampen recruitment of native riparian plants in the floodplain of alluvial rivers, since many of these species have reproduction and survival strategies that are adapted to the timing and shape of the historical spring snowmelt flood hydrograph (Johnson 1994, Karrenberg et al. 2002, Dixon 2003, Lytle and Poff 2004). For example, seed release for Fremont cottonwood and Goodding's black willow is synchronized with the timing of the historical peak or retreating spring snowmelt flood (Merritt and Wohl 2002, Dixon 2003, Stillwater Sciences 2006, Stella et al. 2006, Naiman et al. 2005). Wind- and water-dispersed seeds released by Fremont cottonwood, Goodding's black willow, and other native riparian species are thereby distributed downstream and across the floodplain; as the floodwaters recede, seeds are deposited on moist bare mineral seedbeds (Johnson 1994, Merigliano 1998, Merritt and Wohl 2002, Lytle and Merritt 2004, Stillwater Sciences 2006, Stella et al. 2006). The relative elevation where these seeds land is important, since seeds situated too low are in danger of being scoured by subsequent high winter flows (<2-yr RI), and seeds deposited too high above the summer groundwater table are in danger of desiccation (Mahoney and Rood 1998, Kalischuk et al. 2001, Karrenberg et al. 2002, Johnson 2000, Rood et al. 2003a, Dixon 2003). This optimal position in relation to the declining spring hydrograph and seed release timing has been formalized by Mahoney and Rood (1998) into the 'recruitment box' model.

The slope of the receding limb of the spring hydrograph is also important. Along the sand-bottomed reaches of the lower Tuolumne River, Stella and colleagues (Stella 2005, Stillwater Sciences 2006, Stella et al. 2010) recently demonstrated that the speed at which the saturated soil front descends through the soil column in the spring affects survival of newly germinated Fremont cottonwood and Goodding's black willow seedlings, and is controlled by the slope of the receding limb of the snowmelt hydrograph (also demonstrated for an analogous river corridor in Europe by Guilloy et al. 2011). When the receding limb of snowmelt runoff, or a simulated April to June high flow, occurs too rapidly, the seedling roots are unable to grow downwards at a pace sufficient to access the descending front of saturated soil (Stella et al. 2006). Seedling mortality under such conditions is very high, resulting in greatly reduced recruitment of at least these two critical native riparian species on the floodplain of the lower Tuolumne River (Stella et al. 2006, 2010). Narrow-leaf willow has a longer seed dispersal period than cottonwood, and therefore is able to colonize riverbanks and midstream gravel bars during mid-late summer when agricultural return flows raise and stabilize the summer baseflows, thereby avoiding seedling inundation and drowning associated with increased late spring and early summer flows (Stillwater Sciences 2006, McBain and Trush 2000). Thus, reduced spring flows continue to create conditions that would increase the extent of narrow-leafed willow and decrease the extent of naturally recruited Fremont cottonwood and Goodding's black willow as evidenced by the observed skewed age distribution of these species on the lower Tuolumne River.

5.2.5 Active Riparian Restoration

Active restoration involves 'actively' reshaping the land (e.g. lowering the floodplain surface to ensure a target frequency and duration of flooding) and/or active planting the riparian area with native species. Passive restoration involves only removing a source of stress or a factor that is limiting natural recruitment and survival of native riparian vegetation; for example, notching or setting back a levee to allow for more frequent flooding from the river channel can sometimes be sufficient for restoring a native riparian forest.

As demonstrated during the update of the riparian vegetation inventory, active restoration of riparian vegetation has directly affected the amount, distribution and quality of riparian vegetation along the lower Tuolumne River. The restoration efforts that have been implemented and are directly increasing the extent and quality of native riparian restoration along the lower Tuolumne River are summarized in Table 5.2-4 below. All of these restoration projects have involved active planting of native riparian species.

Table 5.2-4. Restoration efforts implemented along the lower Tuolumne River to-date.

Reach number	River miles	Restoration Name	Acres Actively restored in Study Area
1	0	San Joaquin Wildlife Refuge	0
1	4	Grayson River Ranch	143
1	5.8 to 7.4	Big Bend	250
2	12 to 19	Tuolumne River Regional Park	500
4	25	Special Run Pool 9	4.5
5	--	7/11 Mining Reach Restoration Project	114
6	--	Bobcat Flat	334.09

5.2.6 Climate Change

Changes in snowpack and timing of spring peak flows associated with increasing temperatures have already been observed for many watersheds in the Sierra and in the American west overall, and are implicated as evidence of ongoing climate change (Mote et al. 2005, Stewart et al. 2005, Maurer et al. 2007, Kapnick and Hall 2009). In general, recent (1950 to 1999) flow data for the Sierra Nevada indicate that in snowmelt-dominated rivers, there has been a trend toward earlier spring snowmelt peak flows based on the runoff center of mass timing (e.g., the time when half of the annual runoff has occurred) (Cayan et al. 2001, Knowles and Cayan 2002, Mote et al. 2005, Maurer et al. 2007, Kapnick and Hall 2009).

Young et al. (2009) used a water basin hydrologic model (WEAP21; http://www.weap21.org) to predict that the spring mid-snowmelt runoff period on the Tuolumne will occur approximately 2.2, 4.0 and 5.4 weeks earlier than current conditions by the end of the century under the low (2°C), mid (4°C) and high (6°C) global warming scenarios (Young et al. 2009). Null et al. (2010) extended this research, also using the WEAP21 model, to assess reductions in mean annual flow (MAF) and increased duration of low flow conditions, for the Tuolumne watershed and report minor expected changes in MAF (ranging from 2 to 6 percent for the different warming scenarios), and somewhat more significant increases in expected duration of low flows (ranging from one to three weeks for the low, medium and high warming scenarios (Null et al. 2010).

These potential changes associated with climate change, namely earlier peak snowmelt flows and longer duration summer low flows, could become a factor contributing to future conditions along the lower Tuolumne River riparian corridor. (Naiman et al. 2005, Yarnell et al. 2010). Earlier peak snowmelt, especially shifts that move the flows outside or to the edge of the seed release window for native riparian species, are expected to reduce recruitment of native riparian species such as Fremont cottonwood and Goodding's black willow (Shafroth et al. 1998, Rood et al. 2005, Stella et al. 2006, Stillwater Sciences 2006), and a longer duration and lower summer baseflow would be expected to increase water stress, favor more facultative or mesic site species over moist and wet site plant species, and favor increased channel edge recruitment and encroachment of late seed dispersal species, such as narrow-leaf willow. However, with flow regulation, the effects of climate change are largely masked (Yarnell et al 2010).

6.0 DISCUSSION AND FINDINGS

6.1 Summary of Current Conditions

Native riparian vegetation occupies 2,691 acres along a nearly continuous but variable-width band along the lower Tuolumne River corridor. Overall, the 52 ac average of native riparian vegetation per river mile is slowly changing, with 419 ac increases in net extent of native vegetation between 1996 and 2012 brought about primarily through active restoration projects. Areas with the greatest extent of native riparian vegetation per river mile were mapped along the twelve miles downstream of La Grange Dam in Reaches 6 and 7. Closer to the confluence with the San Joaquin River, several large restoration projects along Reach 1 have also increased the extent of native riparian vegetation.

Areas with the least riparian vegetation and narrowest riparian corridor are along Reach 2 (RM 10.5 to 19.3), which runs through the urban areas of Modesto and Ceres. Reaches 3, 4, and 5 are also confined by gravel mining and other land uses, and include large areas that are sparsely vegetated due to historical mining and dredger tailing deposits. Outside the restored areas, the greatest changes have been in small increases in extent of native narrow-leaf willow and mixed willow dominated vegetation along the channel banks and on several small alluvial surfaces.

Qualitative observations for indicators of riparian condition made during the 2012 field survey and reported by others indicate that outside of actively restored areas, most riparian trees are mature and senescent with very few younger seedlings or pole-sized individuals observed. These observations suggest that there is very limited replacement of mature and senescent plants with younger cohorts outside of restored areas along the lower Tuolumne River corridor. Box elder and narrow-leaf willow dominate much of the channel edge vegetation along the 52-mile corridor.

The areal extent and location of lands dominated by non-native plants has decreased over the past 15 years, with minor mapping changes in tree tobacco and ‘disturbed/miscellaneous exotics’ (decrease) and eucalyptus (increase). During the 2012 field survey many areas supporting an understory of edible fig and Himalayan blackberry were noted; however, changes in extent of these species were not tracked since vegetation was mapped based only on dominant species type.

6.2 Factors Contributing to Current Conditions

Land clearing and land use change, coupled with levee construction to protect these lands from flooding, has largely limited the lateral extent of potential river influence, and greatly diminished the former extent of both valley oak forests and the mixed riparian cottonwood forests that historically occupied the lower Tuolumne River corridor. Based on the current assessment of the 100- year flood zone, levee constraints on the extent of riparian vegetation are particularly important in the lower reaches. Several restoration efforts in which levees have been notched to increase river access and associated areas actively replanted with native riparian plant species, have been highly successful in supporting restored native vegetation.

In-channel mining, floodplain gravel mining, soil loss, altered topography, and reduced floodplain inundation associated with mining leave a long-lasting legacy that suppresses recolonization of the floodplain areas with native riparian species along the lower Tuolumne River corridor. Several restoration projects, found mostly along reaches 4, 5 and 6 (river miles 24 to 46) have resulted in local improvements, although even these areas are patchworks of native vegetation interspersed with weeds and bare soil. Nevertheless, these restoration sites clearly demonstrate that some of the ecological functions can be returned to reaches that have been degraded by historical floodplain alteration, mining and dredger tailing deposits.

The ongoing differences between the existing hydrograph and a hydrograph that supports native riparian species (e.g. high annual peak flows and slow descending limb during spring and late summer), continues to limit recruitment and survival of important native riparian species expected to dominate Central Valley riparian forests and shrub lands, such as Fremont cottonwood, Goodding’s black willow, shining and red willow. The growth and survival of these species in large, actively replanted restoration sites (e.g. Grayson Ranch and Big Bend) demonstrate that active restoration can be a workable means of bringing these native community types back to the lower Tuolumne River.

In summary, riparian vegetation along the lower Tuolumne has increased by approximately 18 percent since it was last mapped in 1997, in large part due to steady survival of existing vegetation and to active planting on several restoration sites within the riparian corridor. Physical conditions and processes in the lower Tuolumne River are currently supporting some native riparian species, such as narrow-leaf willow and box elder, while not supporting natural recruitment of other native riparian plants, such as Fremont cottonwood. Some of the most important changes in physical conditions causing ongoing limitation of the recruitment and survival of native riparian vegetation are, in rough order of importance on a spatial basis:

(1) Access to the floodplain (land use change, levees along reaches 1 and 2);

(2) Legacy effects of dredger mining and tailing deposits (reaches 4, 5, and 6)

(3) Ongoing gravel mining operations in the floodplain (reaches 3, 4, and 5)

(4) Changes in the hydrograph and sediment delivery (reaches 1–7)

7.0 STUDY VARIANCES AND MODIFICATIONS

This study has been modified to be consistent with the 25 July 2012 FERC approved Study Plan revision, to include an update of the 1996 riparian vegetation inventory originally performed by McBain and Trush (2000). This modification, repeated below, includes alteration to the originally proposed methods, as described below (and detailed in Section 4.3 Riparian Vegetation Inventory Update):

> *Step 3 – Riparian Vegetation Inventory Update. GIS maps of the riparian inventory of the lower Tuolumne River developed in 1996–1997 for the Tuolumne River Restoration Plan (McBain and Trush 2000) will be updated using aerial photo-interpretation of imagery to be collected during spring 2012. Limited on-the-ground validation of vegetation mapping will be conducted in areas where vegetation distribution has changed from previous surveys. Factors contributing to the current distribution of riparian species will be assessed in the final report (Study Plan W&AR-19, revised on February 24, 2012).*

There were no variances to the modified study plan.

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LOWER TUOLUMNE RIVER RIPARIAN INFORMATION AND SYNTHESIS

ATTACHMENT A

LITERATURE REVIEWED

Table A-1. Literature sources reviewed for lower Tuolumne Riparian Information and Synthesis Study.

References	**3.1 Historical Riparian Vegetation**	**3.2 Current Riparian Vegetation**	**4.1 Natural History and Succession in Native Riparian Plant Communities**	**4.2 Land Clearing and Land Use Change**	**4.3 Levees and Flood Control**	**4.4 Aggregate Extraction and Dredger mining**	**4.5 Invasive Plant Species**	**4.6 Changes in the Hydrograph**	**4.7 Changes in Sediment Delivery and Availability of Riparian Surfaces**	**4.8 Climate Change**
Alpert et al. 2000	--	--	--	--	--	--	√	--	--	--
American Farmland Trust 1995	--	--	--	√	--	--	--	--	--	--
Auble et al. 1994	--	--	√	--	--	--	--	--	--	--
Auble and Scott 1998	--	--	√	--	--	--	--	√	√	--
Baldwin et al. 2012	--	√	--	--	--	--	--	--	--	--
Bean and Russo 1986	--	--	--	--	--	--	√	--	--	--
Bell 1994	--	--	--	--	--	--	√	--	--	--
Bell 1997	--	--	--	--	--	--	√	--	--	--
Bendix 1999	--	--	--	--	--	--	--	√	--	--
Boose and Holt 1999	--	--	--	--	--	--	√	--	--	--
Braatne et al. 2007	--	--	--	--	--	--	--	√	--	--
Brooks et al. 2004	--	--	--	--	--	--	√	--	--	--
Busch and Smith 1995	--	--	--	--	--	--	√	--	--	--
Campbell and Green 1968	--	--	√	--	--	--	--	√	--	--
Cayan et al. 2001	--	--	--	--	--	--	--	--	--	√
CDFG 2008	--	√	--	--	--	--	--	--	--	--
Coffman 2007	--	--	--	--	--	--	√	--	--	--
Coffman et al. 2010	--	--	--	--	--	--	√	--	--	--
Cooper and Walters 2002	--	--	√	--	--	--	--	--	--	--
DeWine and Cooper 2007	--	--	√	--	--	--	--	√	--	--
DiTomaso and Healey 2007	--	--	--	--	--	--	√	--	--	--
Dixon 2003	--	--	--	--	--	--	--	√	--	--
Dudley 2000	--	--	--	--	--	--	√	--	--	--
Else 1996	--	--	--	--	--	--	√	--	--	--
Else and Zedler 1996	--	--	--	--	--	--	√	--	--	--
Franz and Bazzaz 1977	--	--	√	--	--	--	--	--	--	--
Friedman et al. 1996	--	--	--	--	--	--	--	√	--	--
Friedman et al. 1998	--	--	--	√	--	--	--	√	--	--
Friedman et al. 2005	--	--	--	--	--	--	√	--	--	--
Friedman et al. 2006	--	--	√	--	--	--	--	--	--	--
Friend of the Tuolumne 2010	--	√	--	--	--	--	--	--	--	--
Fuller and Simpson 2005	--	√	--	--	--	--	--	--	--	--
Furguson et al. 1990	--	--	--	--	--	--	√	--	--	--
Gardali et al. 2006	--	--	√	--	--	--	--	--	--	--
Grant et al. 2003	--	--	√	√	--	--	--	√	√	--
Grime 1977	--	--	√	--	--	--	--	√	--	--
Gurnell et al. 2005	--	--	√	--	--	--	--	--	√	--
Heisey 1996	--	--	--	--	--	--	√	--	--	--
Herrera and Dudley 2003	--	--	--	--	--	--	√	--	--	--

References	**3.1 Historical Riparian Vegetation**	**3.2 Current Riparian Vegetation**	**4.1 Natural History and Succession in Native Riparian Plant Communities**	**4.2 Land Clearing and Land Use Change**	**4.3 Levees and Flood Control**	**4.4 Aggregate Extraction and Dredger mining**	**4.5 Invasive Plant Species**	**4.6 Changes in the Hydrograph**	**4.7 Changes in Sediment Delivery and Availability of Riparian Surfaces**	**4.8 Climate Change**
Hickson and Keeler-Wolf 2007	--	--	--	√	--	--	--	--	--	--
Holt 2002	--	--	--	--	--	--	√	--	--	--
Hoshovsky 1999	--	--	--	--	--	--	√	--	--	--
Johnson 1994	--	--	√	--	--	--	--	√	√	--
Johnson 2000	--	--	--	--	--	--	--	√	--	--
Junk et al. 1989	--	--	--	--	√	--	--	√	--	--
Kalischuk et al. 2001	--	--	--	--	--	--	--	√	--	--
Kapnick and Hall 2009	--	--	--	--	--	--	--	--	--	√
Karrenberg et al. 2002	--	--	√	--	--	--	--	√	--	--
Katibah 1984	√	√	--	√	√	--	--	--	--	--
Kisner 2004	--	--	--	--	--	--	√	--	--	--
Kjellberg et al. 1987	--	--	--	--	--	--	√	--	--	--
Knowles and Cayan 2002	--	--	--	--	--	--	--	--	--	√
Kondolf 1997	--	--	--	--	--	--	--	√	√	--
Kowarik 1995	--	--	--	--	--	--	√	--	--	--
Labinger and Greaves 2001	--	--	--	--	--	--	√	--	--	--
Ligon et al. 1995	--	--	--	--	--	--	--	√	√	--
Lytle and Merritt 2004	--	--	√	--	--	--	--	√	--	--
Lytle and Poff 2004	--	--	--	--	--	--	--	√	--	--
Mahoney and Rood 1998	--	--	√	--	--	--	--	√	--	--
Maurer et al. 2007	--	--	--	--	--	--	--	--	--	√
McBain and Trush 2000	√	√	√	√	√	√	√	√	√	--
McBain and Trush 2002		√	--	--	--	--	--	--	--	--
McBain and Trush 2004a	√	--	--	--	--	--	--	--	√	--
McBain and Trush 2004b	--	√	--	--	--	--	--	--	--	--
McBain and Trush 2006	--	√	--	--	--	--	--	--	--	--
McBain and Trush 2008	--	√	--	--	--	--	--	--	--	--
McBain and Trush 2011	--	√	--	--	--	--	--	--	--	--
McBain and Trush 2012	--	√	--	--	--	--	--	--	--	--
Meidinger et al. 2003	--	√	--	--	--	--	--	--	--	--
Merigliano 1998	--	--	--	--	--	--	--	√	√	--
Merritt and Poff 2010	--	--	--	--	--	--	√	√	--	--
Merritt and Wohl 2002	--	--	--	--	--	--	--	√	--	--
Merritt and Cooper 2000	--	--	--	--	--	--	--	√	--	--
Michailides et al. 1996	--	--	--	--	--	--	√	--	--	--
Molina et al. 1991	--	--	--	--	--	--	√	--	--	--
Mote et al. 2005	--	--	--	--	--	--	--	--	--	√
Naiman et al. 2005	--	--	√	√	--	--	--	√	--	√
Norris et al. 2001	--	--	√	--	--	--	--	--	--	--
Null et al. 2010	--	--	--	--	--	--	--	--	--	√
Polzin and Rood 2006	--	--	√	√	--	--	--	√	√	--

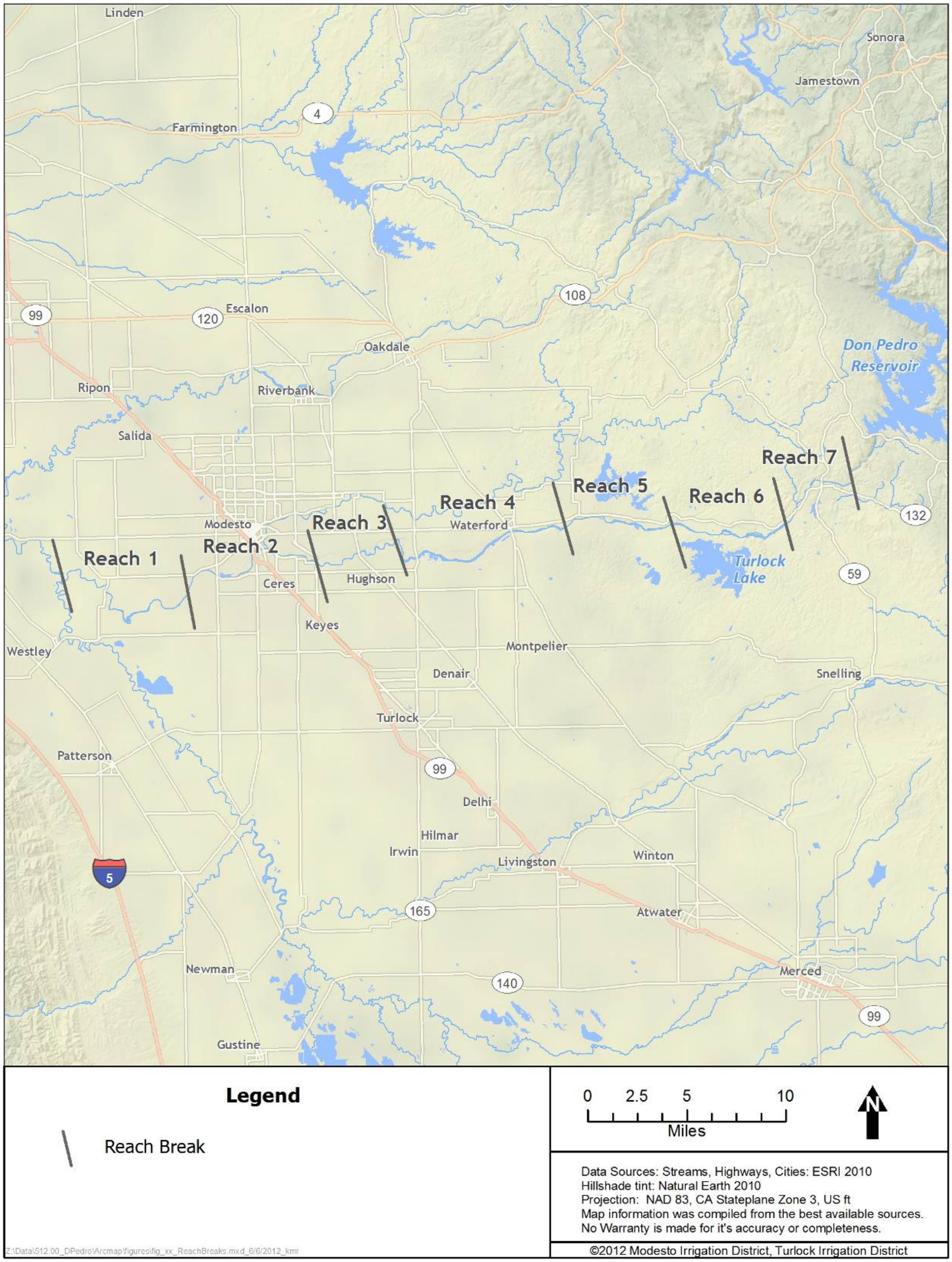
References	**3.1 Historical Riparian Vegetation**	**3.2 Current Riparian Vegetation**	**4.1 Natural History and Succession in Native Riparian Plant Communities**	**4.2 Land Clearing and Land Use Change**	**4.3 Levees and Flood Control**	**4.4 Aggregate Extraction and Dredger mining**	**4.5 Invasive Plant Species**	**4.6 Changes in the Hydrograph**	**4.7 Changes in Sediment Delivery and Availability of Riparian Surfaces**	**4.8 Climate Change**
Randall 2004	--	--	--	--	--	--	√	--	--	--
Rieger and Kreager 1989	--	--	--	--	--	--	√	--	--	--
Rood et al. 2003b	--	--	--	--	--	--	--	√	√	--
Rood et al. 2003a	--	--	--	--	--	--	--	√	--	--
Rood et al. 2005	--	--	√	--	--	--	--	√	√	√
Rose 2000	√	--	--	√	--	--	--	--	--	--
Sawyer and Keeler-Wolf 2009	--	√	--	--	--	--	--	--	--	--
Scott 1994	--	--	--	--	--	--	√	--	--	--
Scott et al. 1996	--	--	√	√	--	--		√	√	--
Shafroth et al. 1995	--	--	--	--	--	--	√	--	--	--
Shafroth et al. 1998	--	--	--	--	--	--	--	√	--	√
Shafroth et al. 2002	--	--	√	--	--	--	--	√	√	--
Shanfield 1984	--	--	--	√	--	--	--	--	--	--
State of California 2007	--	--	--	√	--	--	--	--	--	--
Stella 2005	--	--	--	--	--	--	--	√	--	--
Stella et al. 2006	--	--	√	--	--	--	--	√	--	√
Stella et al. 2010	--	--	√	√	--	--	--	√	--	--
Stella et al. 2011	--	--	√	√	--	--	--	√	--	--
Stewart et al. 2005	--	--	--	--	--	--	--	--	--	√
Stillwater Sciences 1998	--	--	√	--	√	√	--	√	√	--
Stillwater Sciences 2006	--	--	√	--	--	--	--	√	--	√
Stillwater Sciences 2007	--	--	--	--	--	√	--	--	--	--
Stillwater Sciences 2008	--	√	--	--	--	--	--	--	--	--
Stromberg et al. 2002	--	--	--	--	--	--	√	--	--	--
Thompson 1961	√	--	--	--	--	--	--	--	--	--
TID/MID 2006	--	√	--	--	--	--	--	--	--	--
Tockner et al. 1999	--	--	--	--	√	--	--	√	--	--
USFWS 2001	--	--	--	--	--	√	--	√	--	--
Vaghti and Greco 2007	--	--	--	--	--	--	--	√	--	--
Ward and Stanford 1995	--	--	√	--	--	--	--	√	--	--
Warner 2004	--	--	--	--		--	√	--	--	--
Warner 1984	√	√	--	--	√	--		--	--	--
Watson 2000	--	--	--	--	--	--	√	--	--	--
Williams and Wolman 1984	--	--	--	--	--	--		--	√	--
Wijte et al. 2005	--	--	--	--	--	--	√	--	--	--
Yarnell et al. 2010	--	--	--	--	--	--		√	--	√
Young et al. 2009	--	--	--	--	--	--	--	--	--	√

STUDY REPORT W&AR-19

LOWER TUOLUMNE RIVER RIPARIAN INFORMATION AND SYNTHESIS

ATTACHMENT B

EXISTING RIPARIAN VEGETATION MAPS FOR REACHES 1-7 ALONG THE LOWER TUOLUMNE RIVER



Data Sources: Streams, Highways, Cities: ESRI 2010
Hillshade tint: Natural Earth 2010
Projection: NAD 83, CA Stateplane Zone 3, US ft
Map information was compiled from the best available sources.
No Warranty is made for it's accuracy or completeness.

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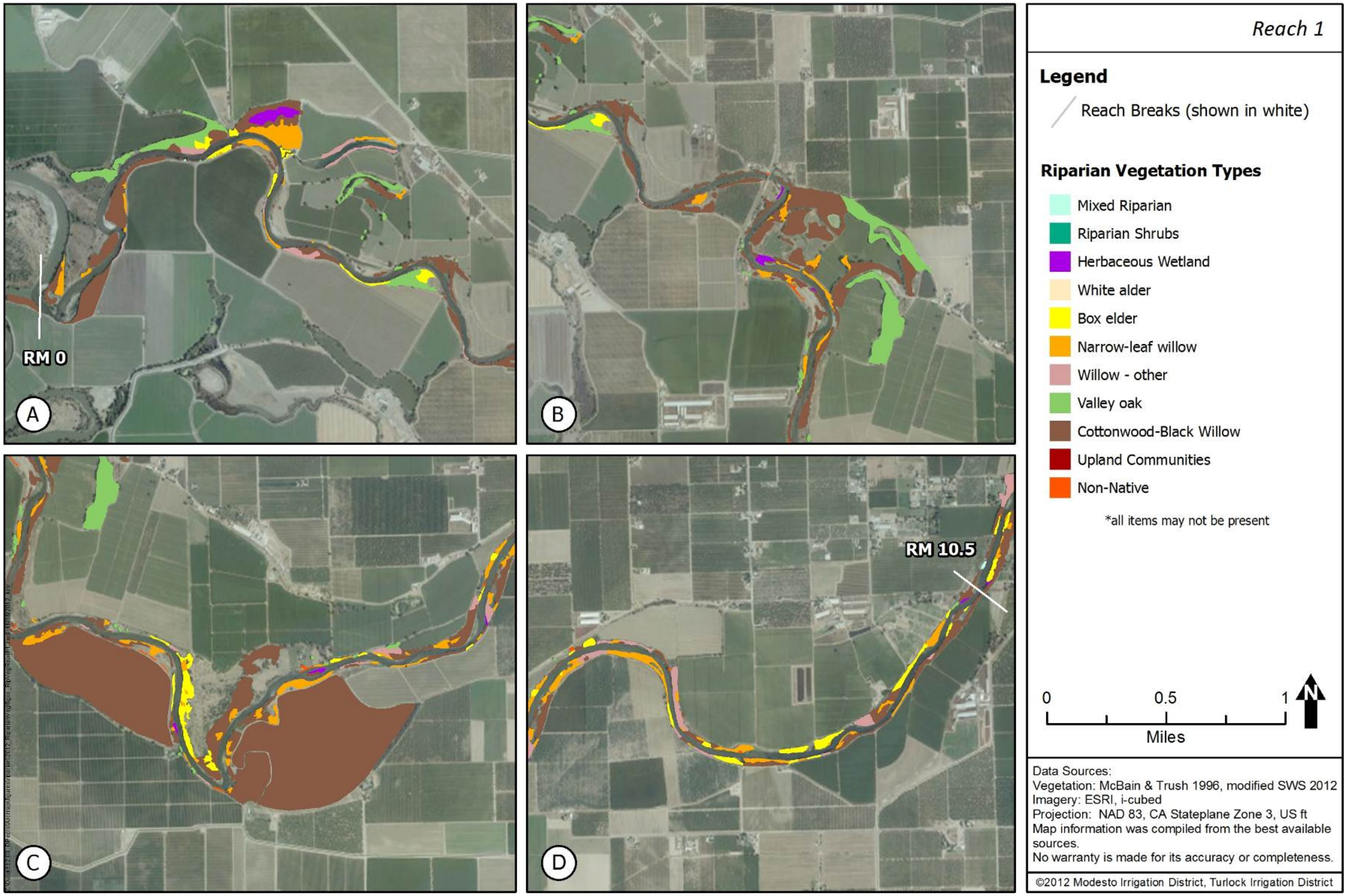
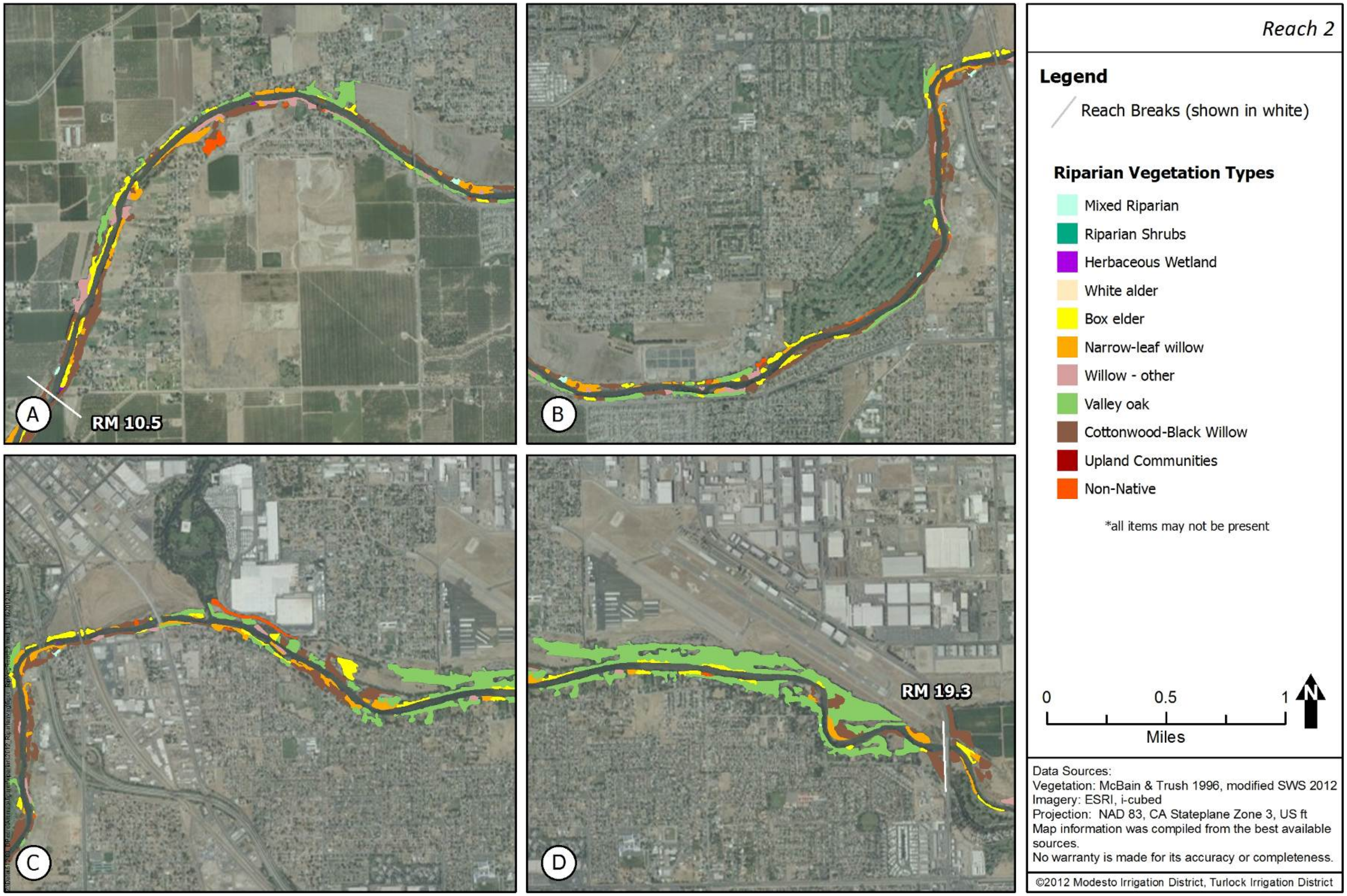
Figure B-1. Reach break locations for Reaches 1-7 along the lower Tuolumne River.



Data Sources:
Vegetation: McBain & Trush 1996, modified SWS 2012
Imagery: ESRI, i-cubed
Projection: NAD 83, CA Stateplane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

Figure B-2. Existing vegetation mapped along Reach 1 of the lower Tuolumne River.



Data Sources:
Vegetation: McBain & Trush 1996, modified SWS 2012
Imagery: ESRI, i-cubed
Projection: NAD 83, CA Stateplane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

Figure B-3. **Existing vegetation mapped along Reach 2 of the lower Tuolumne River.**

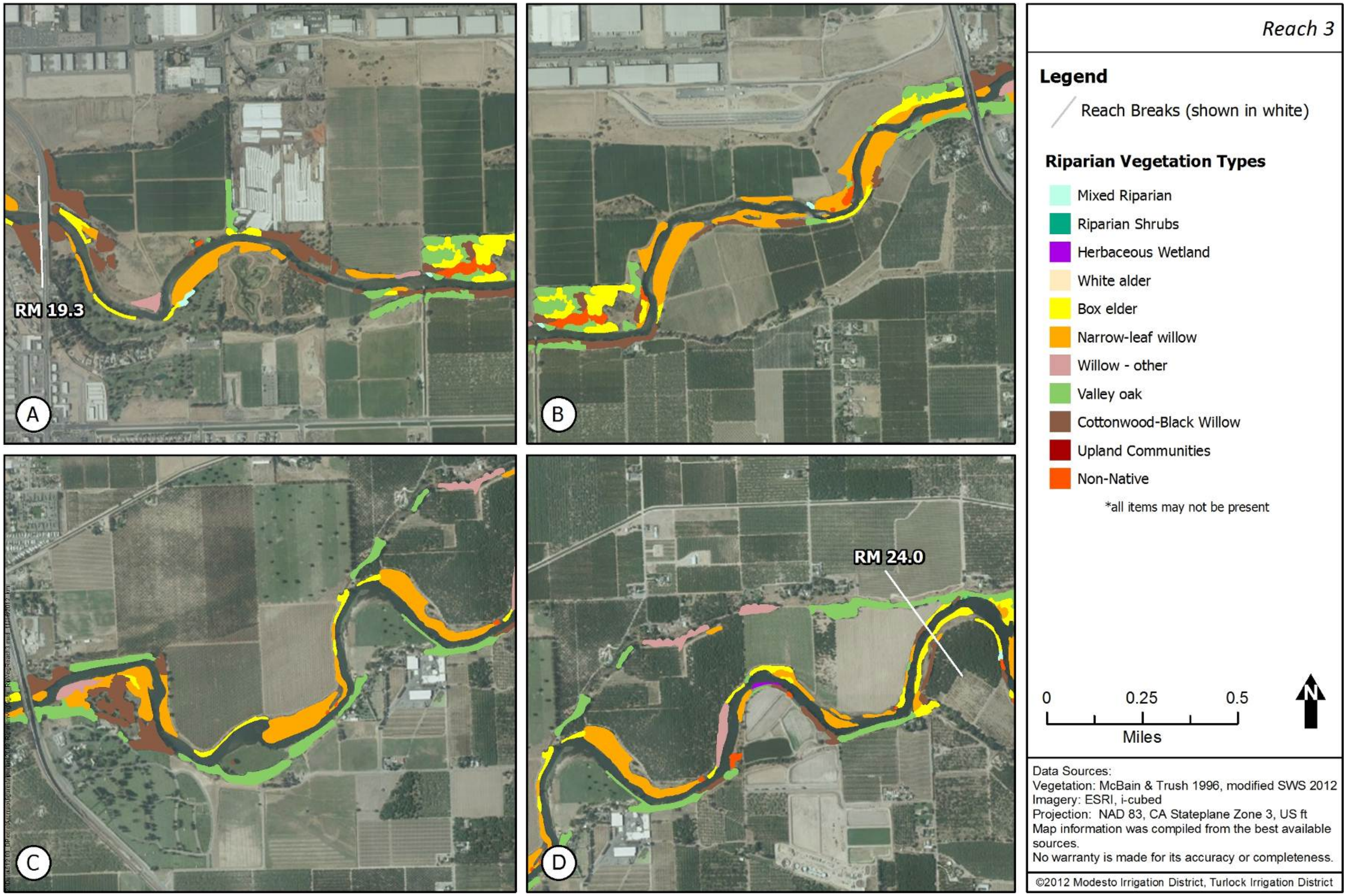


Figure B-4. Existing vegetation mapped along Reach 3 of the lower Tuolumne River.

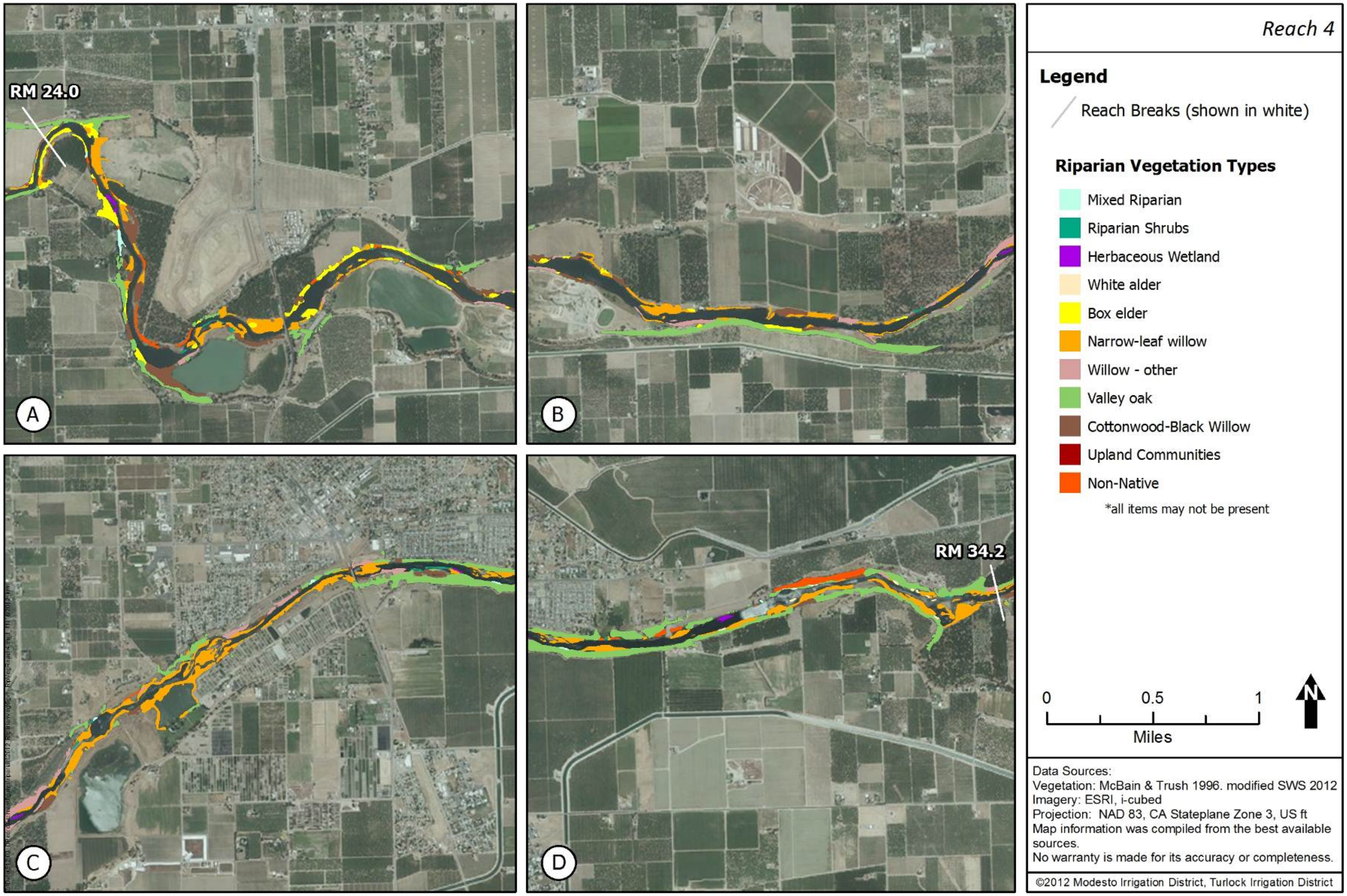
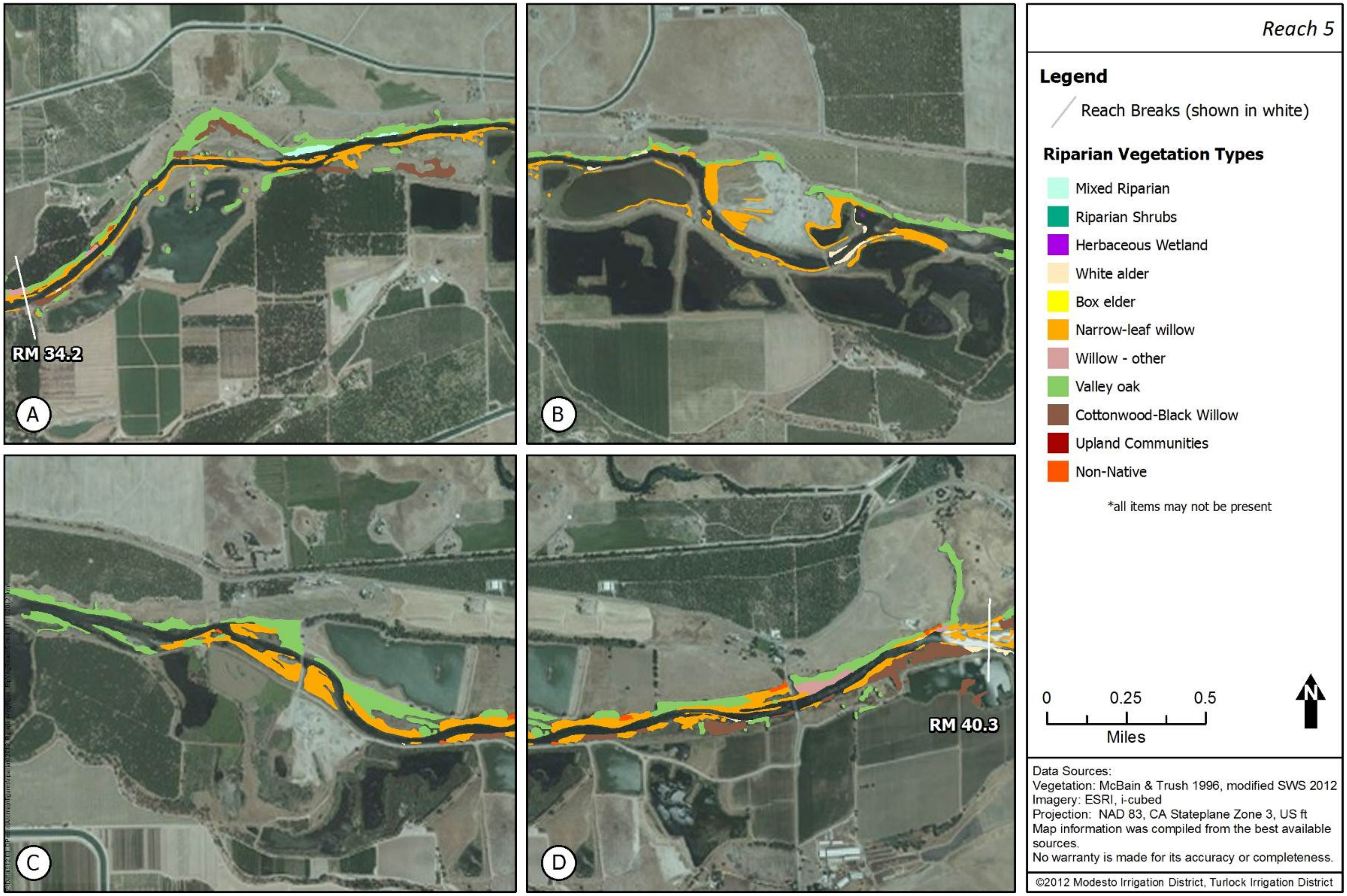
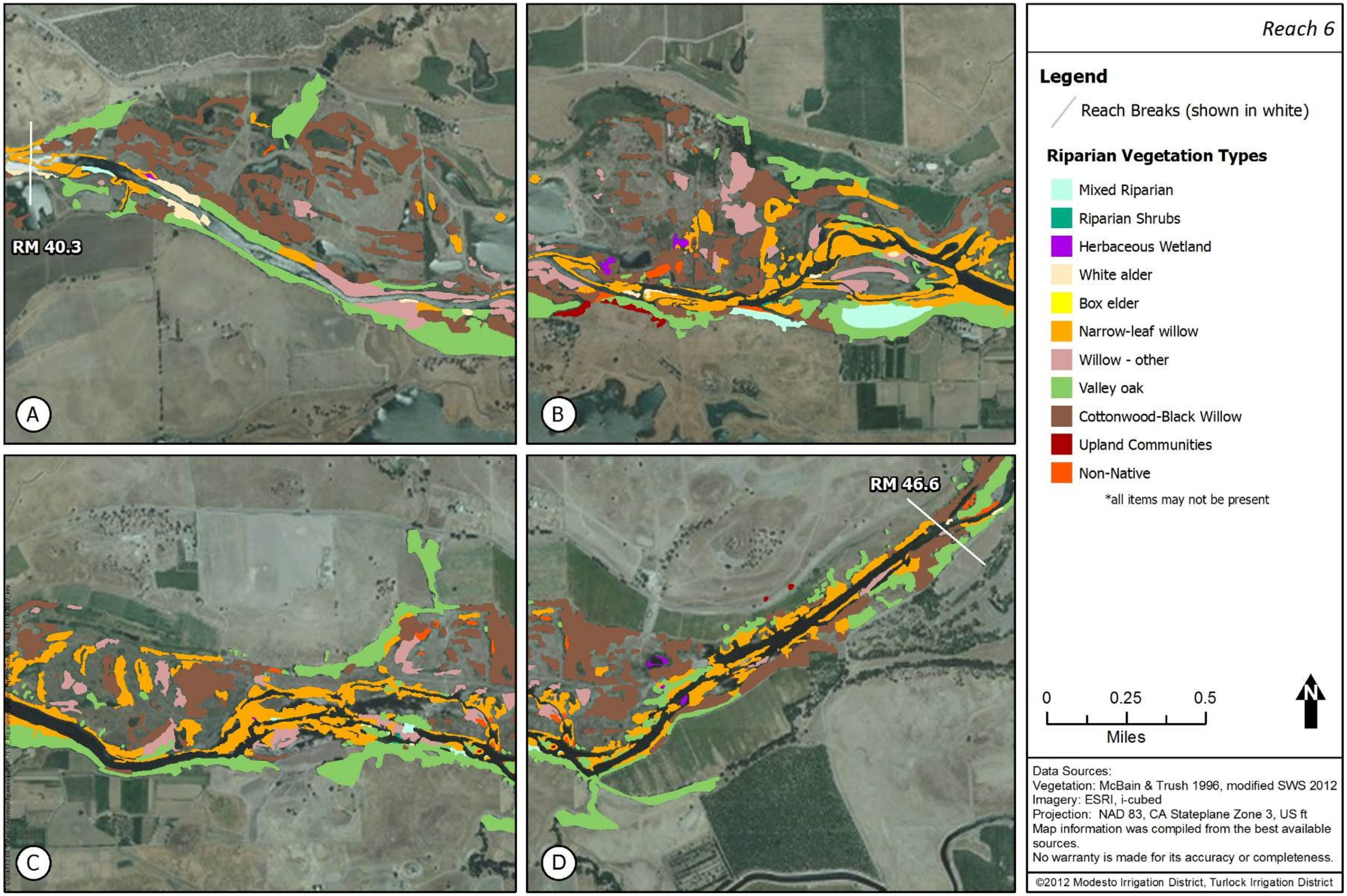


Figure B-5. **Existing vegetation mapped along Reach 4 of the lower Tuolumne River.**



Data Sources:
Vegetation: McBain & Trush 1996, modified SWS 2012
Imagery: ESRI, i-cubed
Projection: NAD 83, CA Stateplane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

Figure B-6. **Existing vegetation mapped along Reach 5 of the lower Tuolumne River.**



Data Sources:
Vegetation: McBain & Trush 1996, modified SWS 2012
Imagery: ESRI, i-cubed
Projection: NAD 83, CA Stateplane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

Figure B-7. **Existing vegetation mapped along Reach 6 of the lower Tuolumne River**

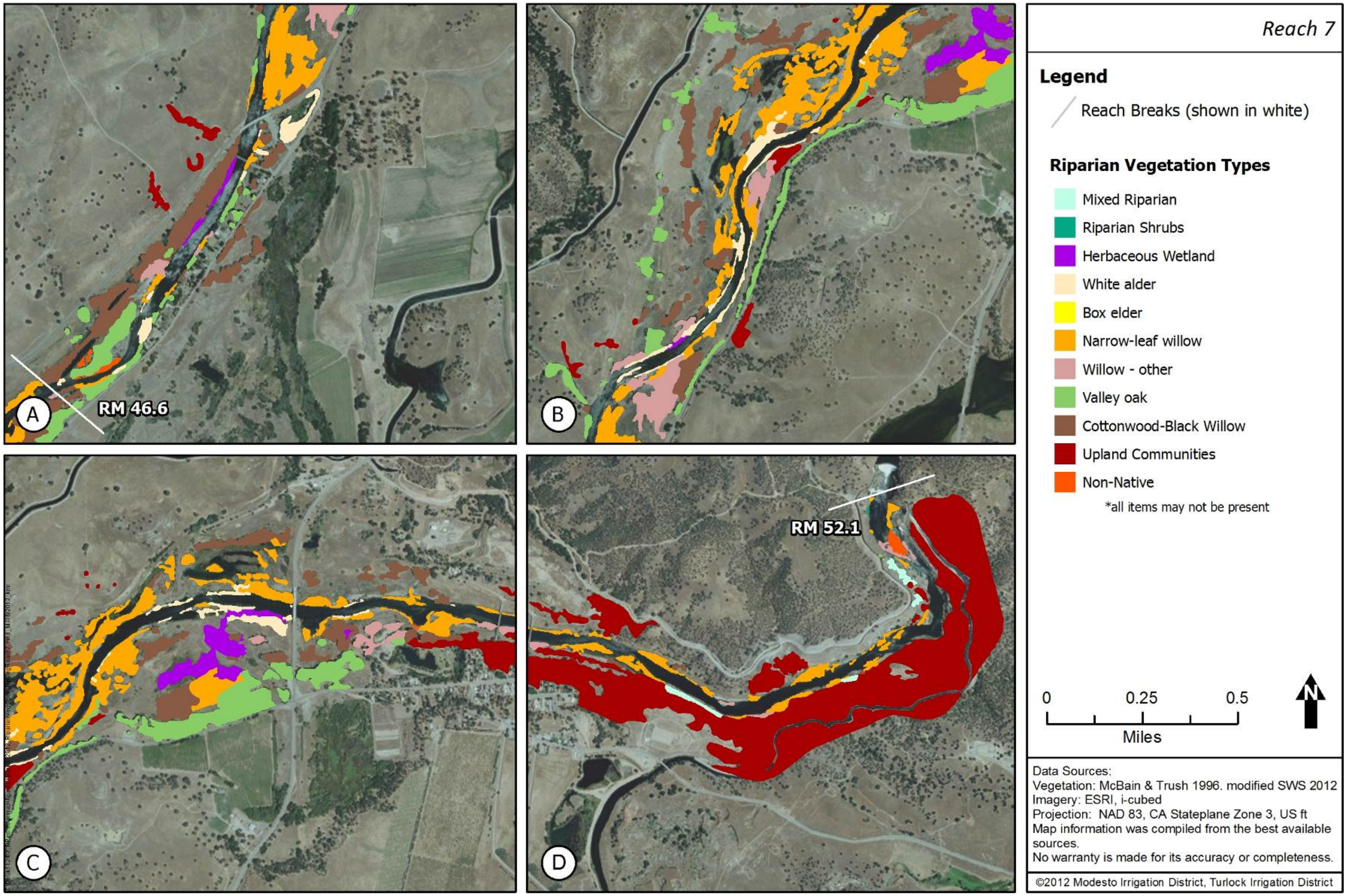


Figure B-8. **Existing vegetation mapped along Reach 7 of the lower Tuolumne River.**

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LOWER TUOLUMNE RIVER RIPARIAN INFORMATION AND SYNTHESIS

ATTACHMENT C

DESCRIPTION OF INVASIVE NON-NATIVE SPECIES IN THE LOWER TUOLUMNE RIVER

Giant Reed (*Arundo donax*)

Overall = High; Impact = severe (A); Invasiveness= Moderate (B); Distribution = Severe (A)

Giant reed is the most invasive non-native observed on the lower Tuolumne River to-date. Due to its clonal growth strategy, efficient use of resources, and high growth rate, *A. donax* is one of the most successful riparian weedy invaders in California (Rieger and Kreager 1989). Once established in an area, it grows into dense and rapidly spreading monotypic stands, spreading vegetatively via rhizomes, and is documented to aggressively out-compete other plants species through both its very high water acquisition rates and very high growth rates, suppressing growth of other neighboring plants through water and light limitation (Holt 2002, Dudley 2000). *Arundo donax* plants are uprooted and dispersed downstream during large, winter flood events characteristic of Mediterranean-type climates (Bell 1994). Portions of the rhizome or culm break off, float downstream, land on a bare, moist substrate as flood waters recede and begin growing. Fragments of the rhizome or culm as small as 0.8 in^2 have been shown to sprout under most soil types, depths and soil moisture conditions (Else 1996, Boose and Holt 1999, Wijte et al. 2005). Growing at an extremely high rate of up to 2.5 in per day under ideal conditions), giant reed quickly establishes on unvegetated or sparsely vegetated soil and grows to a height of greater than 20 ft after only a few months (Rieger and Kreager 1989, Coffman 2007). It then expands outward in area, quickly displacing indigenous shrubs, herbs and grasses, and eventually even trees. It directly competes with Fremont cottonwood and most willow species for riparian habitat (Coffman 2007).

When above ground biomass of giant reed dies back in late summer and fall, riparian areas dominated by this plant become susceptible to fire (Scott 1994). Riparian terraces invaded by giant reed adjacent to shrubland communities are most vulnerable (Coffman 2007). Indigenous riparian trees, shrubs, and other vegetation not as well-adapted to fire are burned along with giant reed and resprout much more slowly (Coffman 2007, Coffman et al. 2010). Giant reed grows back immediately to completely replace the open burned areas originally dominated by indigenous riparian vegetation (Coffman 2007). When natural riparian vegetation types are replaced by thick stands of giant reed, bird species abundance and other native wildlife have been found to decline (Bell 1994, Bell 1997, Herrera and Dudley 2003, Kisner 2004, Labinger and Greaves 2001).

Eucalyptus (*Eucalyptus globulus*)

Overall = Moderate; Impact = Moderate (B); Invasiveness= Moderate (B); Distribution = Moderate (B)

Eucalyptus has been planted in central and coastal California since the mid-1800s as both a wind break and for fuel wood (Warner 2004). It is classified as moderately invasive by Cal-IPC. Reproduction is by large seeds that remain viable for multiple years and germinate best on bare mineral soil (Bean and Russo 1986). Anecdotal reports of rapid reproduction and spread from established stands are common, but not documented in the scientific literature (Warner 2004). The leaves and bark release allelopathic chemicals, suppressing germination and growth of other plants species (Molina et al. 1991, Watson 2000). Eucalyptus stands could spread locally in upper terrace areas of the lower Tuolumne River, but is not a threat to the moister floodplain areas.

Tree of Heaven (*Ailanthus altissima*)

Overall = Moderate; Impact = Moderate (B); Invasiveness= Moderate (B); Distribution = Moderate (B)

Tree of heaven is a deciduous tree that is classified as a Cal-IPC moderate invasive. Native to China, it was introduced by Chinese immigrants during the California Gold Rush as a landscape ornamental, food plant for silk worms, and for medicinal use (DiTomaso and Healy 2007). It is a fast-growing species which spreads rapidly either vegetatively (i.e., with creeping roots), through stump sprouting, or by the copious production of seeds (one tree can produce over 300,000 seeds in a year). Seeds are samara (contained in a “winged” structure that enables the wind to carry the seed further from the parent tree) which can be dispersed by wind or downstream by water. These trees often form dense monocultures (via root sprouts or seed) which preclude native plants by both direct competition for light and water and through allelopathic chemicals leached from the tissue to the soil (De Feo et al. 2003, Heisey 1996). The rapid growth, prolific reproduction and allelopathic effects enable this species to dominate riparian areas in a short amount of time (Kowarik 1995, Hoshovsky 1999).

Edible Fig (*Ficus carica*)

Overall = Moderate; Impact = Moderate (B); Invasiveness= Severe (A); Distribution = Moderate (B)

Edible fig was brought to California as a food crop and ornamental tree and remains an important crop in the state (Randall 2004, Furguson et al. 1990). It is a medium sized broad-leaved tree often found on levees or floodplains. Edible fig can become established in undisturbed riparian areas, but several lands managers suggest that flood disturbance might promote establishment (Randall 2004). Edible fig was observed to spread rapidly at the Cosumnes River Preserve (Randall 2004), but documentation on spread rates is lacking. Reproduction occurs by both seed two to three times a year, through root sprouts, and from branch fragments (Michailides et al. 1996, Furguson et al. 1990, Kjelberg et al. 1987). Seeds can be transported by birds that consume the fruit, and branch fragments, which are easily broken off, can be transferred downstream to new locations (Randall 2004).

STUDY REPORT W&AR-19

LOWER TUOLUMNE RIVER RIPARIAN INFORMATION AND SYNTHESIS

ATTACHMENT D

FEMA FLOOD AREAS ALONG THE LOWER TUOLUMNE

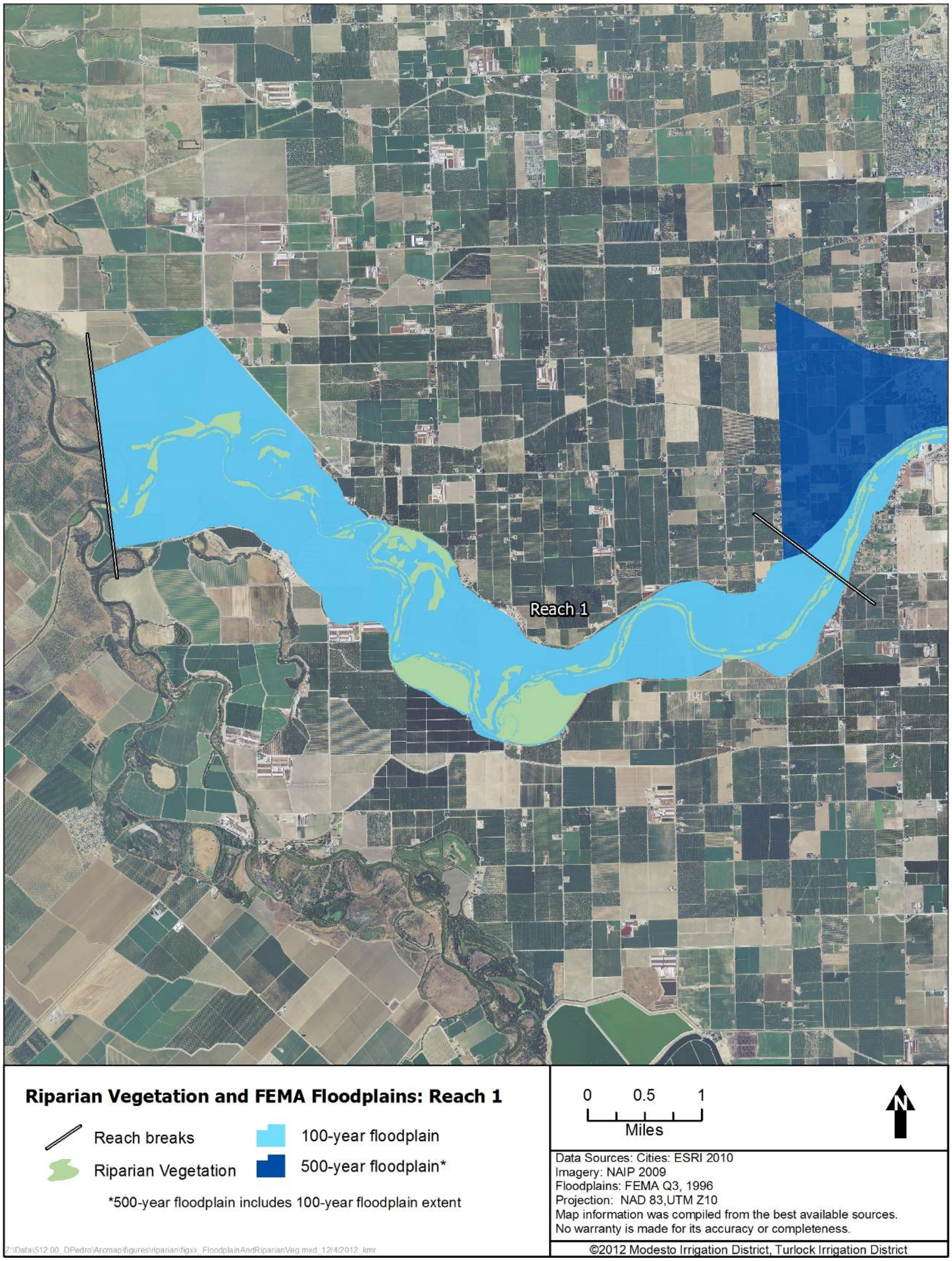


Figure D-1. **Riparian vegetation and FEMA floodplains along Reach 1 of the lower Tuolumne River.**

Figure D-2. **Riparian vegetation and FEMA floodplains along Reach 2 of the lower Tuolumne River.**

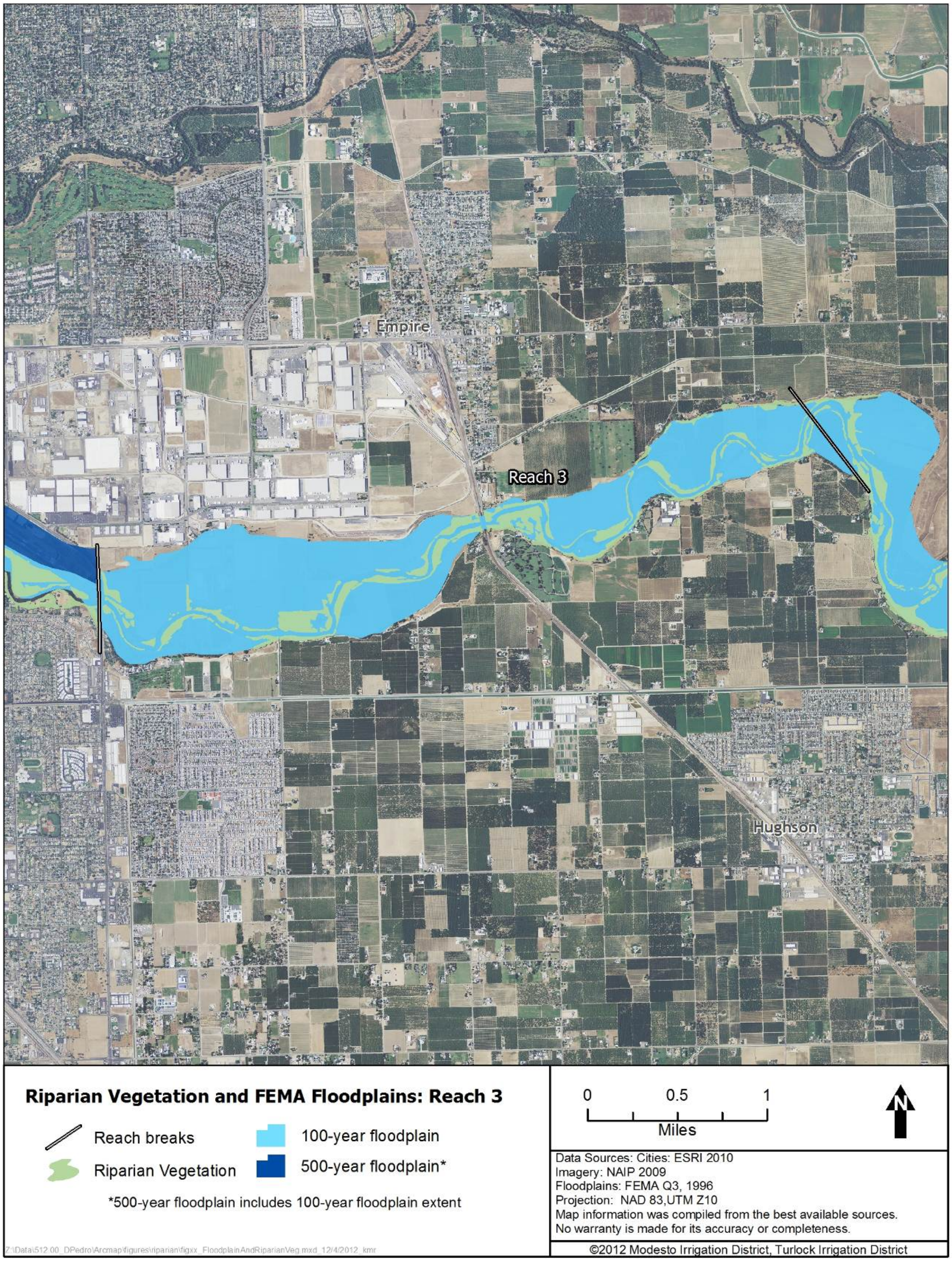
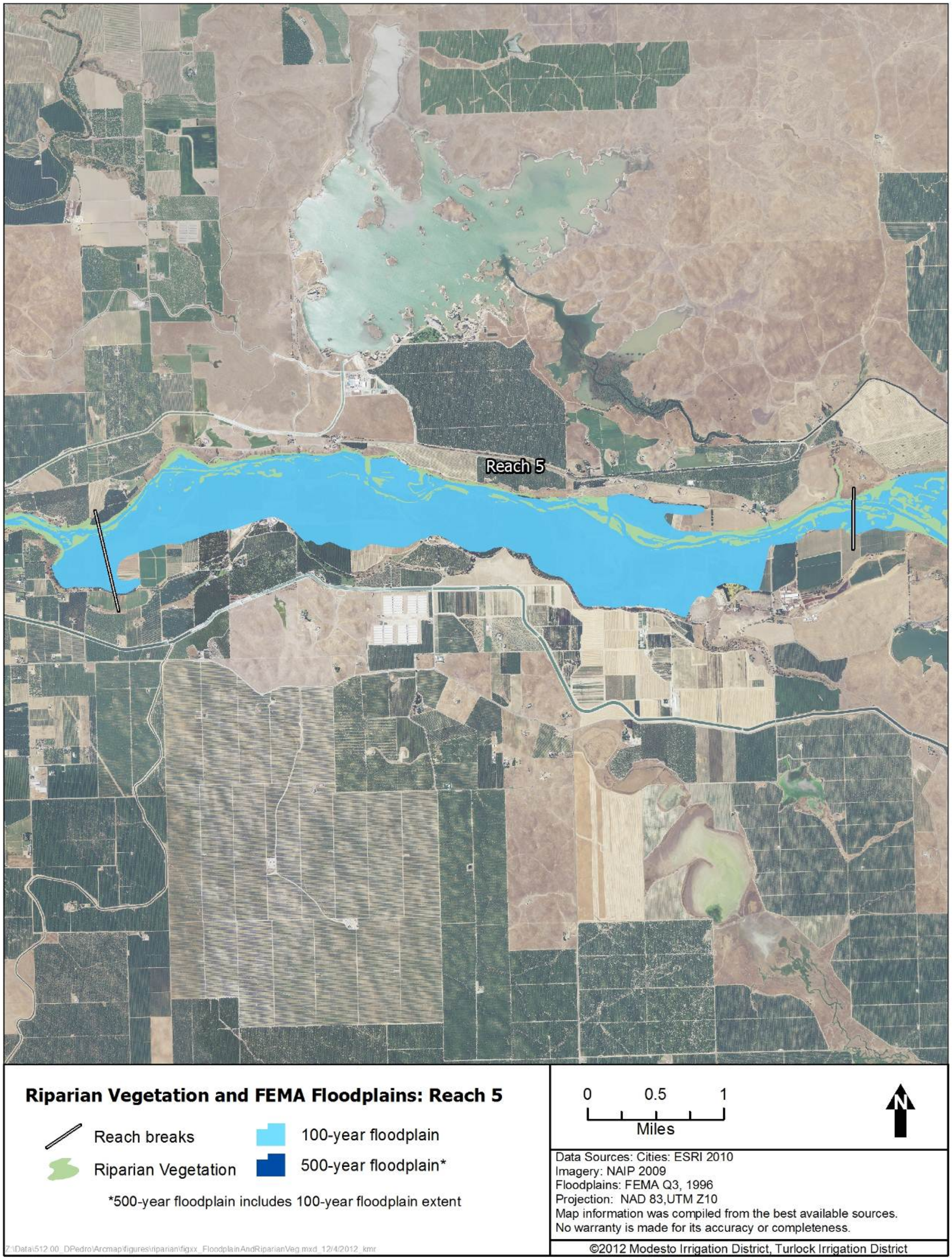


Figure D-3. Riparian vegetation and FEMA floodplains along Reach 3 of the lower Tuolumne River.

Figure D-4. **Riparian vegetation and FEMA floodplains along Reach 4 of the lower Tuolumne River.**



Data Sources: Cities: ESRI 2010
Imagery: NAIP 2009
Floodplains: FEMA Q3, 1996
Projection: NAD 83,UTM Z10
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

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Figure D-5. Riparian vegetation and FEMA floodplains along Reach 5 of the lower Tuolumne River.

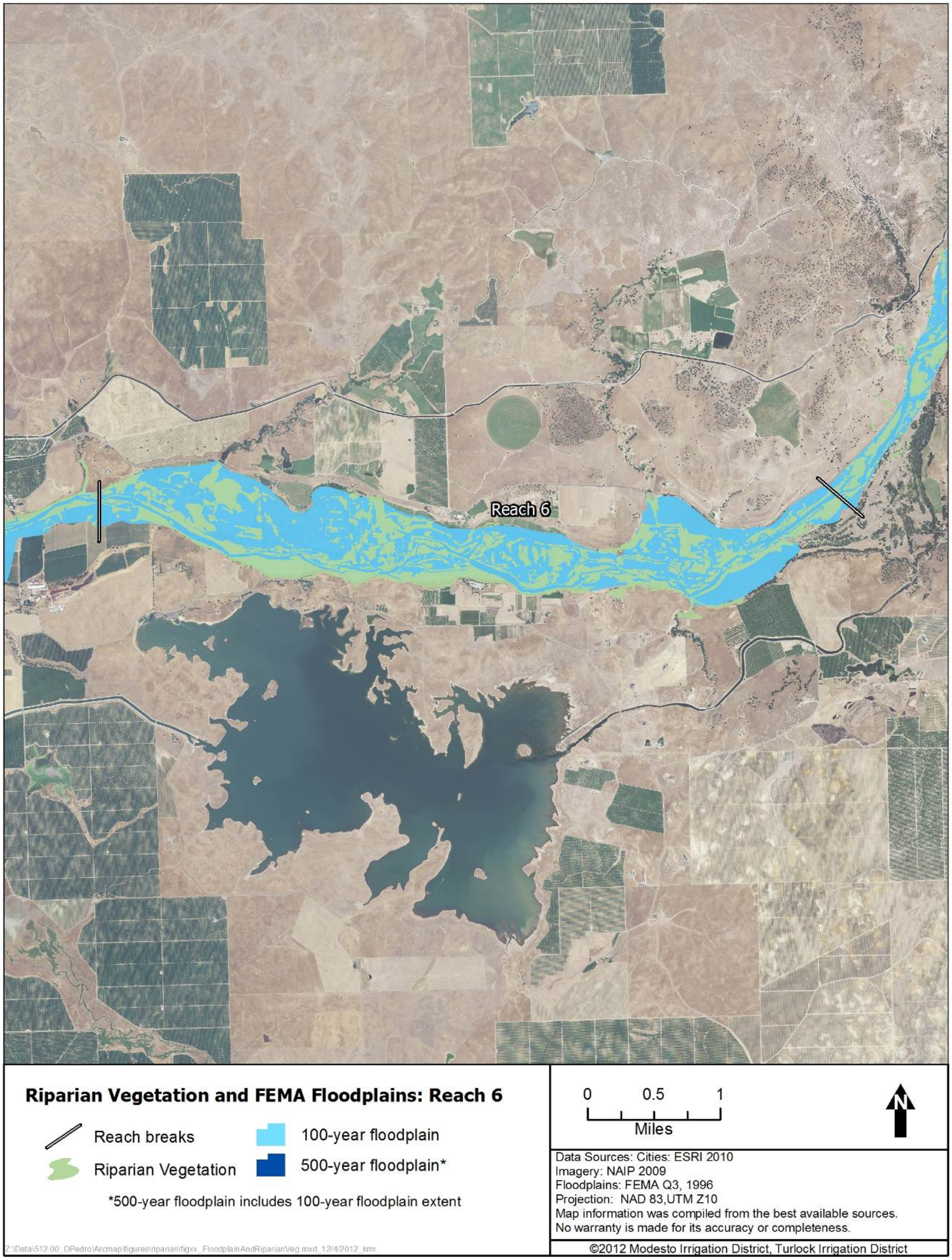

Figure D-6. Riparian vegetation and FEMA floodplains along Reach 6 of the lower Tuolumne River.

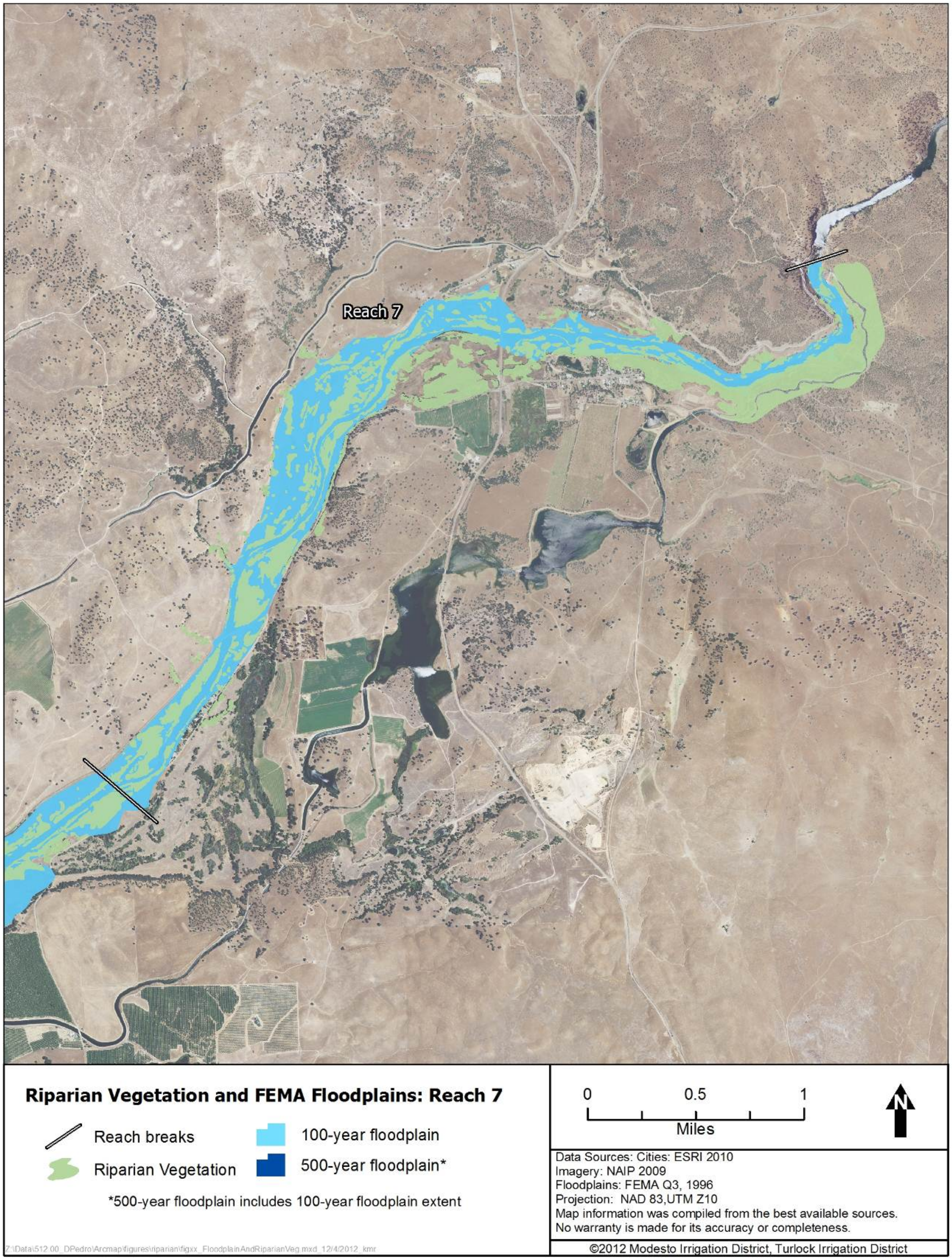

Figure D-7. **Riparian vegetation and FEMA floodplains along Reach 7 of the lower Tuolumne River.**

ONCORHYNCHUS MYKISS SCALE COLLECTION AND AGE DETERMINATION
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299

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

Prepared by:
Stillwater Sciences

December 2013

Oncorhynchus mykiss Scale Collection and Age Determination 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
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
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
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
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
ISR	Initial Study Report
ITA	Indian Trust Assets
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
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
ppb	parts per billion
ppm	parts per million
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
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
TLSRA	Turlock Lake State Recreation Area
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	microSeimens per centimeter

1.0 INTRODUCTION

1.1 Background

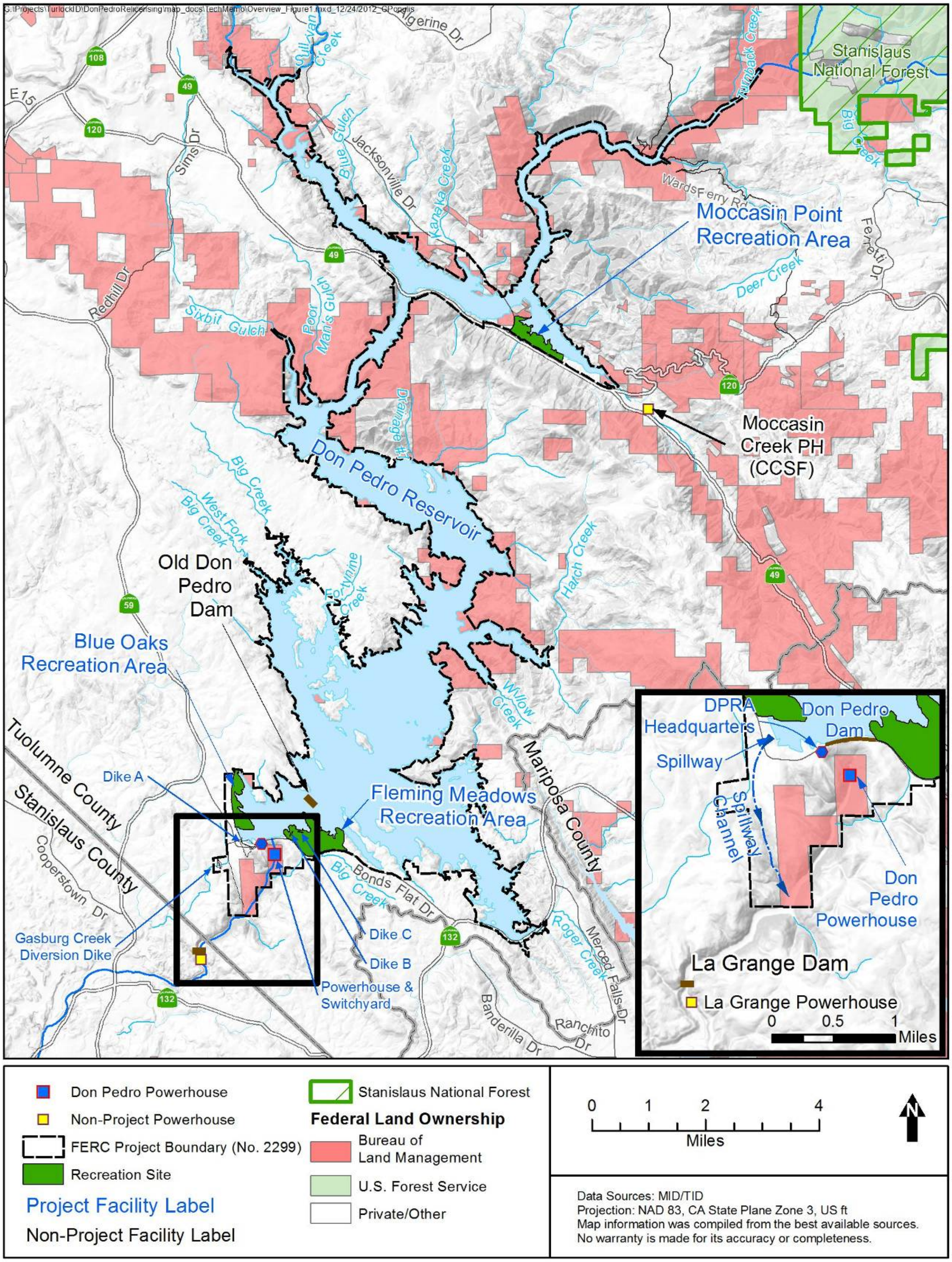
Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir has a 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). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

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. The “water bank” within Don Pedro Reservoir provides significant benefits for CCSF’s 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 RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at an elevation corresponding to the 845 ft contour (31 FPC 510 [1964]). 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) 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.



Data Sources: MID/TID
Projection: NAD 83, CA State Plane Zone 3, US ft
Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.

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 *O. mykiss* Scale Collection and Age Determination Study (W&AR-20) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. On January 17, 2013, the Districts filed the Initial Study Report for the Don Pedro Project. The U.S. Department of the Interior, Fish and Wildlife Service (USFWS) filed comments on the Initial Study Report on March 11, 2013; the Districts replied to study comments on April 9, 2013. The USFWS comment referred to use of the W&AR-20 data in the *W&AR-10: O. mykiss Population Study Report*; data used in the model are fully described in the W&AR-10 study report. In order to clarify data analyzed in this study, the Districts edited the *W&AR-20 O. mykiss Scale Collection and Age Determination Study Report* to correct an error regarding the Zimmerman et al. (2009) *O. mykiss* age classes. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

The continued operation of the Don Pedro Project may contribute to cumulative effects to the salmonid fish habitat in the lower Tuolumne River, including the quantity and quality of physical habitat available for *O. mykiss*, potentially affecting populations in the lower Tuolumne River.

As part of the *Oncorhynchus mykiss Population Study* (W&AR-10), the Districts will incorporate fish age and growth analyses into the development of population models, relying primarily on length-frequency analysis (e.g., MacDonald and Pitcher 1979) of *O. mykiss* observed during snorkel surveys of the past several years (e.g., TID/MID 2011). At the request of relicensing participants, the Districts also agreed to collect scales from *O. mykiss* in the lower Tuolumne River downstream of La Grange Dam to refine the age composition and growth estimates as detailed in the W&AR-20 Study Plan. The results of this exercise (age-at-length relationship based on scale analysis) will provide more comprehensive *O. mykiss* length data to develop a representative population age structure as part of the interrelated *O. mykiss Population Study* (TID/MID 2011).

Consistent with the Districts agreement to undertake this study, FERC in its December 22, 2011 Study Plan Determination directed the Districts to file a study plan for FERC approval after consultation with relicensing participants, within 60 days of the SPD. On February 28, 2012, the Districts filed their study plan. FERC subsequently approved the study plan as proposed by the Districts on July 25, 2012. FERC recommended that the Districts collect *O. mykiss* data, including scales, to verify their age and growth, but only if the Districts were able to obtain authorization from NMFS to collect scales from *O. mykiss* in the lower Tuolumne River. The Districts were able to conduct this study by operating under FISHBIO’s existing Endangered Species Act (ESA) section 10(a)(1)(a) permit that allowed take of up to 80 *O. mykiss*. The Districts carried out the Scale Collection and Age Determination Study consistent with the FERC-approved study plan.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study is to use scales to estimate the age-at-length relationship of *O. mykiss* in the lower Tuolumne River. Objectives in meeting this goal include:

- Collecting, preserving, and analyzing *O. mykiss* scales to estimate ages of individual fish, and
- Developing an age-at-length relationship for the Tuolumne River *O. mykiss* population.

3.0 STUDY AREA

The study area included the Tuolumne River from the La Grange Dam (RM 52) downstream to Robert’s Ferry Bridge (RM 39.5). *O. mykiss* were collected by angling in the reach that extended from La Grange Dam to Turlock Lake State Recreation Area (TLSRA) at RM 42. In addition, a single sample was collected from the rotary screw trap (RST) survey near Waterford (RM 30).

4.0 METHODOLOGY

4.1 Sample Collection

The study plan proposed that "length data and scale samples will be obtained from up to 75 fish using 15 individuals per 100 mm size-group (i.e., 50–150 mm, 150–250 mm, 250–350 mm, 350–450 mm, and 450–550 mm) encountered during sampling." Six *O. mykiss* sampling efforts were conducted by angling from February 13 through April 9, 2012. One *O. mykiss* was also obtained from ongoing RST monitoring at Waterford during June 2012 (Table 4.1-1). *O. mykiss* were collected from pool and riffle-tail habitats by angling as required by FISHBIO's ESA Section 10(a)(1)(a) permit. Fish were collected from the 50–150 mm, 150–250 mm, 250–350 mm, 350–450 mm, and 450–550 mm size groups encountered during sampling. However, only two fish (one from the Waterford rotary screw trap) were collected from the 50-150 mm size class, likely due to this cohort being generally too small to take a hook and bait. No fish were captured from the 450–550 mm size group, probably due to the inherent difficulty in catching old fish that are few in number and have experience with hooks. In addition, continuing to try and collect fish to fill in the 50–150 and 450–550 mm size groups would have required capturing large numbers of *O. mykiss* in the already filled 150–250 mm, 250–350 mm, 350–450 mm categories. That could have potentially resulted in injury, and possibly mortality, to a significant number of fish, so the sampling was halted.

The survey crew recorded the date, location (GPS coordinates), and habitat type at each sampling location. Upon capture, each fish was photographed and transferred to a measurement cradle for positive identification. Data recorded for each fish included fork length (FL, mm), total length (TL, mm), sex (if possible), and any marks that would aid in determining hatchery versus wild origin (e.g., adipose fin clip).

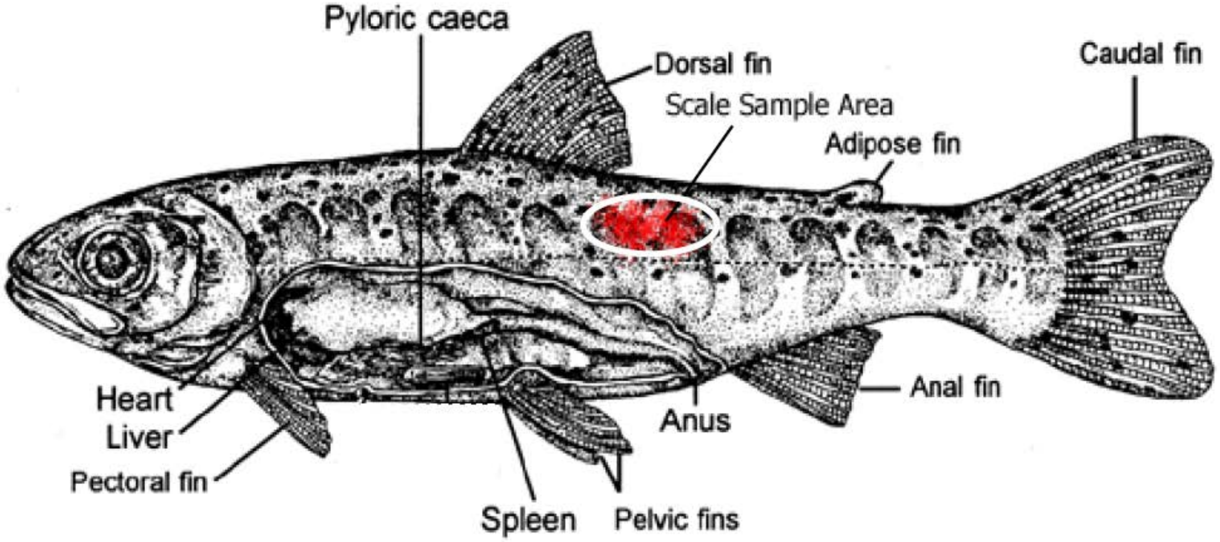
Table 4.1-1. *O. mykiss* scale sampling dates and locations, Tuolumne River, 2012.

Sample Event	Sample Period	Method	Location
1	February 13	Angling	La Grange Powerhouse to Basso Bridge
2	February 16	Angling	Basso Bridge to TLSRA[1]
3	March 12	Angling	Basso Bridge to TLSRA[1]
4	April 3	Angling	Basso Bridge to TLSRA[1]
5	April 4	Angling	La Grange Dam to Basso Bridge
6	April 9	Angling	Basso Bridge to TLSRA[1]
7	June 2	Trap	Waterford rotary screw trap

[1] Turlock Lake State Recreation Area

In accordance with the study plan, scale sampling was limited to *O. mykiss* greater than 50 mm FL. Removing scales from fish smaller than 50 mm may increase the risk of injury. Scales were removed from the region between the posterior end of the dorsal fin and the lateral line on the left side, roughly two scale rows above the lateral line (Figure 4.1-1) (RIC 1997, Stokesbury et al. 2001). Prior to scale removal, mucous and debris were cleaned from the sampling location for ease in scale processing (Schneider et al. 2000). Scales were removed by scraping a dull knife from the anterior to posterior of the sample area (RIC 1997). Approximately 10 scales were removed per fish, with the fish released immediately following sampling. Knives were cleaned with ethanol between each fish sampled to prevent cross-contamination.

Scales from each fish were placed in individual “Rite in the Rain” envelopes clearly labeled with species, site location, total and fork length, date, condition, and any other applicable information. Envelopes were pressed flat to reduce scale curling and increase analytical accuracy.



This illustration is based on a fish specimen of 150 mm fork length.

Figure 4.1-1. Fish schematic showing area (oval) where scale samples were taken from fish (modified from Columbia Basin Fish and Wildlife Authority 1999).

4.2 *O. mykiss* Age Analysis

Scales were prepared for analysis by qualified staff according to standard procedures described by Drummond (1966). Scales were transferred from envelopes onto glass slides. The best scales were arranged towards the top of the slide, with all scales oriented the same direction. Care was taken to insure that all scales were laid flat, not curled. A second glass slide was then placed on top and both slides were taped together. Each slide was labeled with the sample identification number and date.

Slides containing scales were examined under a microscope at 25x magnification, and digital images were generated and enhanced for each scale examined using AmScope Corporation’s ToupView®Version 3.2 software to improve contrast and make scale annuli more apparent. In general, age was estimated based on the number of annuli on the three best scales from each sample; however, some samples lacked three readable scales, such as in cases where scales had been regenerated (regenerated scales were excluded from the aging analysis). In those instances, fish age was based on the best available one or two scales. Annuli were identified at a 20 degree angle from the anterior-posterior scale axis. The age of fish was determined by counting the number of annuli between the scale focus and the outer margin, as described in DeVries and Frie (1996) and results were recorded in a Microsoft Excel® spreadsheet.

4.3 Growth Determination

Individual fish growth was estimated based on the distance between the scale focus and each annulus along the scales' longest posterior axis. Measurements were made to the nearest micrometer using a calibrated scale for 25x magnification power. Individual fish lengths at previous ages were back-calculated using the Fraser-Lee method, as described in DeVries and Frie (1996).

$$L_i = \left(\frac{L_c - a}{S_c}\right) S_i + a$$

Where:

L_i = back-calculated length of the fish when the *i*th increment was formed,
L_c = Fork length of the fish at capture,
S_c = scale radius at capture,
S_i = scale radius at the *i*th increment, and
α = intercept parameter (fish size at time of scale focus development).

A relatively accurate intercept parameter (α) could not be obtained from this study's dataset due to the relatively small overall sample size ($n = 47$), low numbers of samples in the smallest and largest size classes, and capture method bias (primarily angling); it was therefore necessary to review available literature to obtain a representative intercept parameter. The intercept parameter ($\alpha = 36.65$) used in this study was obtained from 1,956 rainbow trout (resident *O. mykiss*) collected during electrofishing efforts in the years 1994, 1996, and 1997 on the Sacramento River upstream of Lake Shasta (Glowacki 2003).

5.0 RESULTS

5.1 *O. mykiss* Age-at-length

The Districts were able to collect 53 *O. mykiss* for sampling (See Attachment A). Scale samples were obtained from 48 *O. mykiss* collected during the study of which 47 were suitable for analysis (the non-suitable sample contained only regenerated scales). No scales were taken from five fish because sufficient numbers of fish in their size class had already been collected.

Angling was the more successful of the two sampling methods permitted to collect *O. mykiss*, (angling and RST). However, angling is biased toward larger, older age classes. Susceptibility to angling decreases with smaller, typically younger fish. Only two samples were obtained from *O. mykiss* younger than age 2+: (1) an age-1+ fish collected by angling, and (2) an age-0+ fish captured in the Waterford RST; therefore, no size range could be determined for these age classes (Table 5.1-1). No fish from the 450–550 mm size group were captured. Overall, the size of captured fish ranged from 78 mm FL (age 0+) to 450 mm FL (age 4+) and included fish from five age classes (age 0 to age 4) (Table 5.1-1, Figure 5.1-1, Attachment A).

Table 5.1-1. Age and size ranges of *O. mykiss* in the lower Tuolumne River between RM 52 and 30.

Age	Number Sampled	Fork Length Range (mm)
0+	1	78
1+	1	150
2+	16	194–270
3+	17	267–370
4+	12	365–450

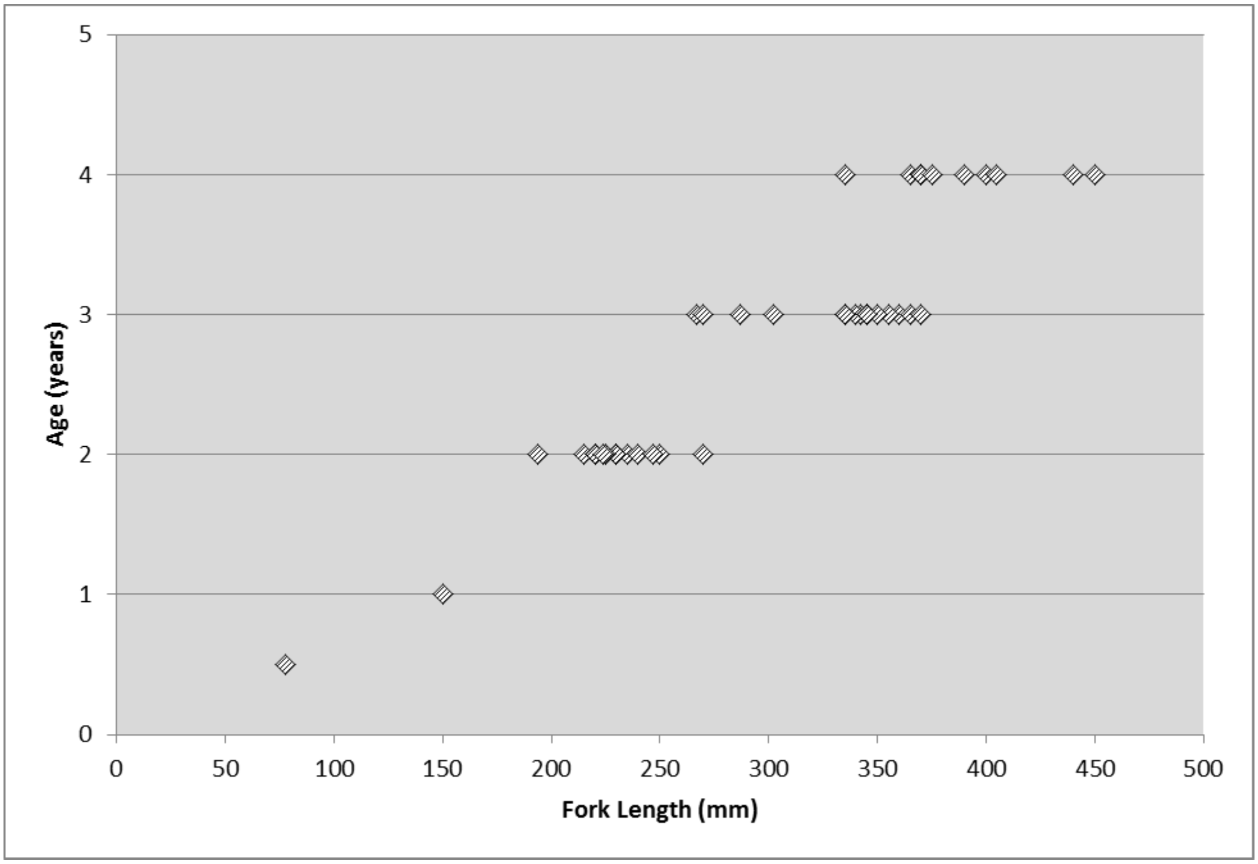


Figure 5.1-1. ***O. mykiss*** **age-at-length relationship for the lower Tuolumne River between RM 52 and 30.**

5.2 Growth Rates

The results of the scale analysis show a strong positive relationship between fish length and scale size (Figure 5.2-1). This relationship allowed for back-calculating fish size from scale data.

Growth rates for *O. mykiss* captured in this study were calculated using the Fraser-Lee method, as described in DeVries and Frie (1996). The growth rates presented in Table 5.2-1 below are based on the back-calculated lengths of individual fish when their annuli were formed (See Attachment A for raw data). Frequency distributions of back-calculated incremental growth between annuli are presented in Table 5.2-2 and Figure 5.2-2. Back-calculated lengths at annuli formation are typically less than the lengths at time of capture (i.e., when the scale was collected) due to the growth of fish between the time of most recent annulus formation and time of scale sampling.

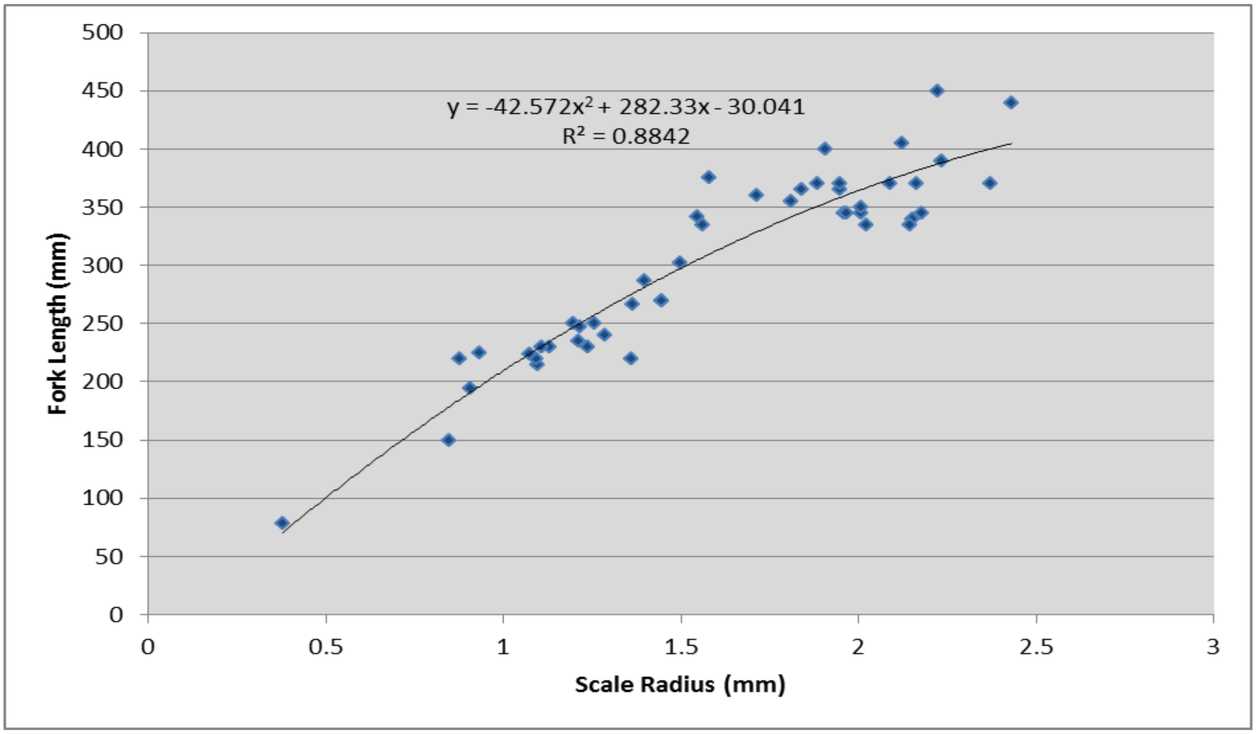


Figure 5.2-1. Relationship between scale radius and fork length for *O. mykiss* collected in this study.

Table 5.2-1. Minimum, maximum, and average back-calculated fork length at annuli and growth rates to annuli for *O. mykiss* in the lower Tuolumne River.

Age	Back-calculated Fork Length (mm) at Annuli		Annual Growth Rate (mm) to Annuli	
	Range	Average	Range	Average
1	87–127	109	51–90	73
2	147–212	182	51–92	72
3	217–291	257	49–94	74
4	298–382	331	61–98	78

Table 5.2-2. Back-calculated incremental growth rates between annuli of *O. mykiss* in the lower Tuolumne River.

Annual Growth Range (mm)	Number of Fish at Annuli Age			
	Age-1	Age-2	Age-3	Age-4
49–60	6	9	6	0
61–70	11	10	4	2
71–80	19	14	9	6
81–90	10	11	6	2
91–100	0	1	4	2

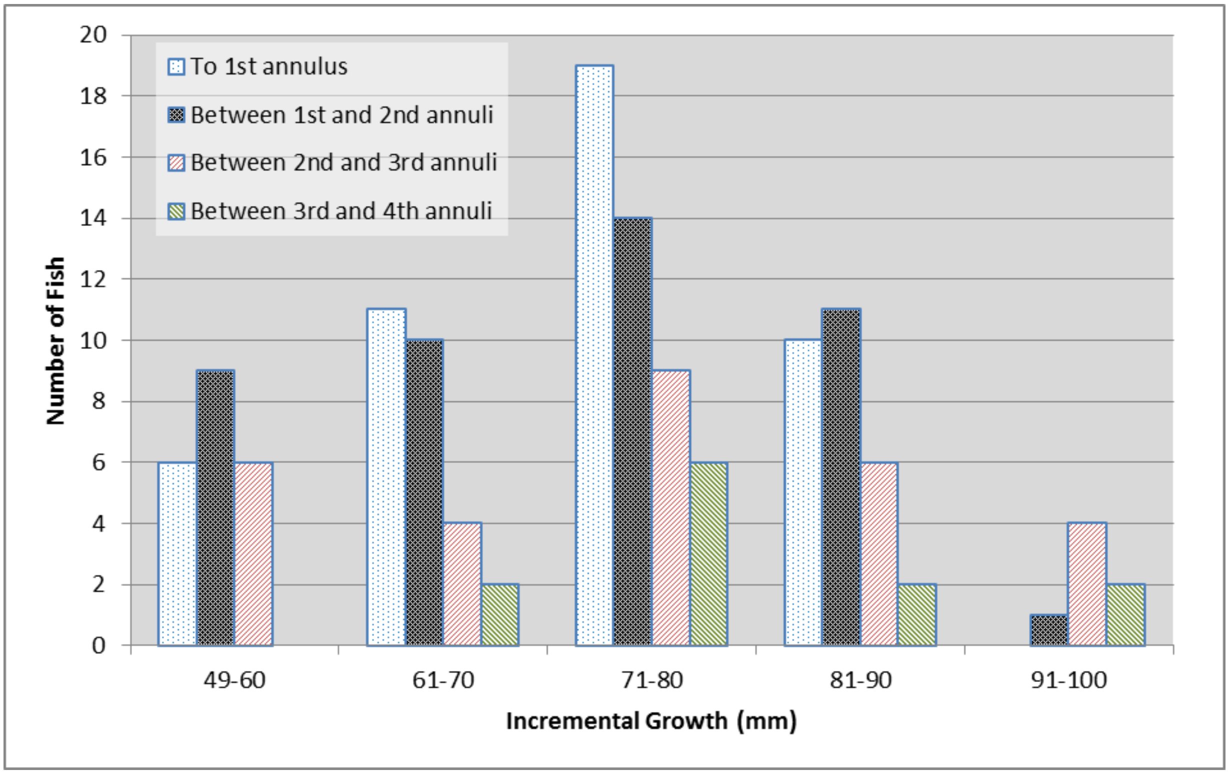


Figure 5.2-2. Incremental growth rate between annuli of *O. mykiss* collected in this study.

6.0 DISCUSSION AND FINDINGS

In general, age-at-length datasets often show substantial overlap between cohorts, which is typical in fish populations, while mean age-at-length increases each year. This is due to differences in individual growth rates which may be related to fish density, food resource abundance, water temperature, suspended sediment, disease, environmental stress, territorial competition, or other factors (Harvey et al. 2006, Bjornn and Reiser 1991, Newcombe and Jensen 1996).

A separate age-at-length data set for *O. mykiss* in the Tuolumne River was developed by Zimmerman et al. (2009). These authors analyzed otoliths from 151 fish collected between 1996 and 2008 in an attempt to determine the maternal origin and migratory history of *O. mykiss* found in Central Valley rivers. However, Zimmerman et al. (2009) combined all fish four years old and older into the single four year old age class (Figure 6.0-1). This combining of the oldest age classes limited the study's comparability with the W&AR-20 age and length data to only those fish three years old and younger.

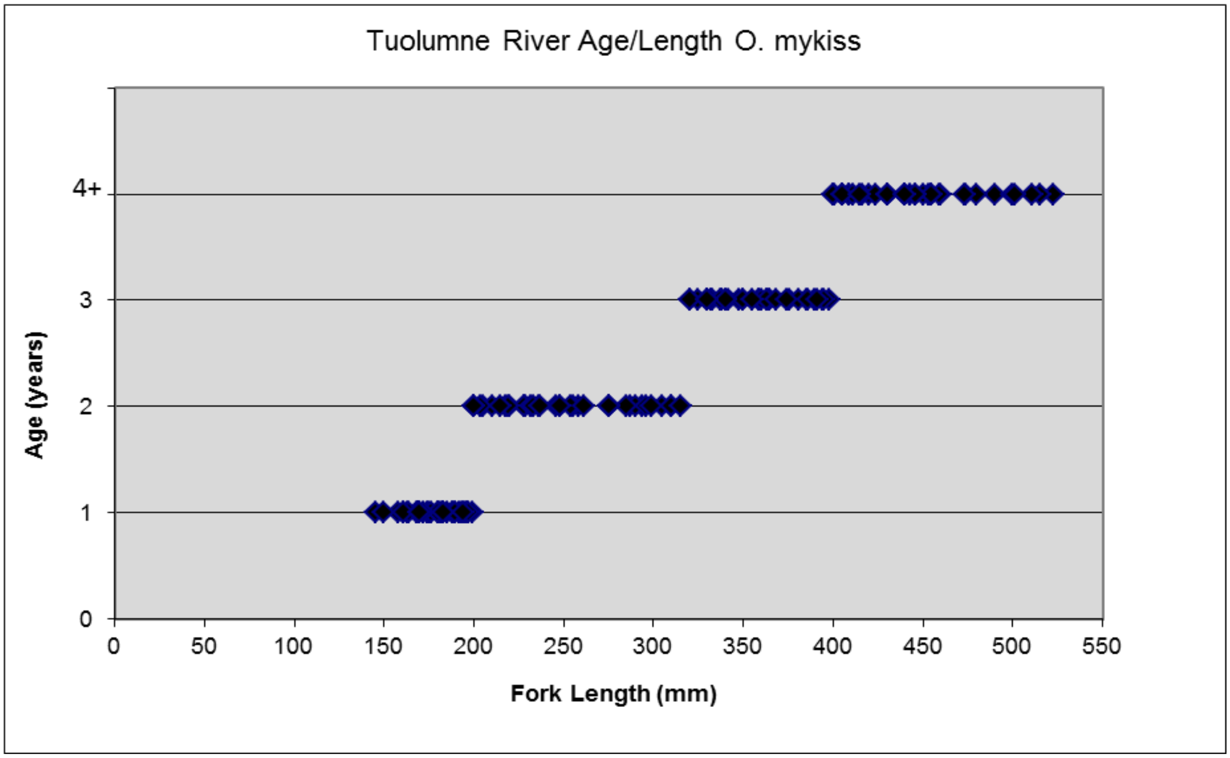


Figure 6.0-1. Age-at-length data from Zimmerman et al.'s (2009) analysis of Tuolumne River *O. mykiss* otoliths. Note the four-year age class includes all fish four years old and older.

The one-to-three year old fish analyzed in this study (W&AR-20) were generally of a smaller size than those collected by Zimmerman et al. (2009) (Table 6.0-1 and Figure 6.0.2). This may be due to differences in the time of sample collection; the fish in this study were collected during the winter and early spring when annuli would be forming and only early season growth occurred, while Zimmerman et al. (2009) samples were collected between October and May when substantial growth would have followed annulus formation. For example, a two-year old fish captured in March (just after annulus formation) would be smaller than if that same two-year old fish were captured in October to January, following a growing season that extended through the spring summer, and fall.

Dissimilarities in collection methods between this study and Zimmerman et al. (2009) resulted in differences in sample sizes and fish lengths. This study primarily used angling (one RST capture) as a collection method, resulting in a smaller sample size. This is because many fish in the 50-150 mm size class are generally too small to take a hook and bait. No fish were captured from the 450-550 mm size group, probably due to the inherent difficulty in catching old fish that are few in number and have experience with hooks. Zimmerman et al. (2009), on the other hand, was able to employ rotary screw traps, angling, electrofishing, beach seining, and carcass surveys that allowed a larger number and broader range of sizes to be collected.

Due to permitting restrictions, the W&AR-20 sample size was too small to represent the full range of fish lengths at given ages. Therefore, the Zimmerman et al. (2009) and this study's age and fork length data were combined to develop an age-at-length relationship that was based on a larger dataset (Table 6.0-2 and Figure 6.0-2).

Table 6.0-1. Size ranges of fish in this study (W&AR-20) compared to those reported by Zimmerman et al. (2009).

Age	Study W&AR-20			Zimmerman et al. (2009)		
	Minimum FL (mm)	Maximum FL (mm)	No. of Fish	Minimum FL (mm)	Maximum FL (mm)	No. of Fish
0	78	78	1	--	--	0
1	150	150	1	145	199	37
2	194	270	16	200	315	37
3	267	370	17	320	395	37
4	365	450	12	-	-	-

Note: Age four fish from Zimmerman et al. (2009) were not included in this table due to that study combining all age four and older fish into the single age four category.

Table 6.0-2. Combined Zimmerman et al. (2009) and W&AR-20 age and size ranges of *O. mykiss*.

Age	Number Sampled	Fork Length Range (mm)
0	1	78
1	38	145–199
2	53	194–315
3	54	267–395
4	12*	365–450

*Includes only W&AR-20 age four fish.

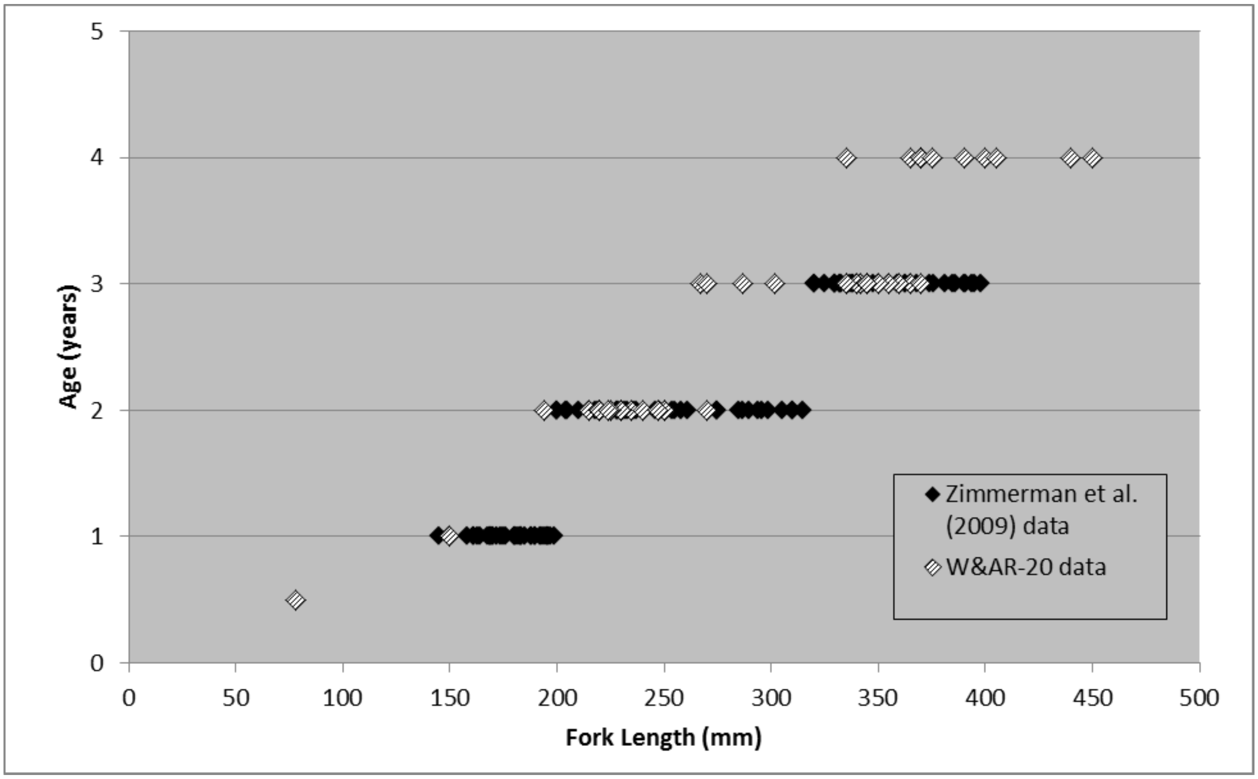


Figure 6.0-2. Combined age-at-length relationship from *O. mykiss* otoliths and scales in Zimmerman et al. (2009) ages 1–3 fish and this study.

Annual growth appeared consistent and comparable for each of the four years and each of the three age groups of *O. mykiss* collected for this study. Growth exhibited during the first and second years was very similar for all three age groups that dominated the sample (i.e., age 2, age 3 and age 4) (Figure 6.0-3). The mean observed growth during the first year varied less than 3 mm, ranging from 70 mm for age 2 fish (in 2010) to 73 mm for age 3 fish (in 2009). Similarly, mean growth during the second year varied about 2 mm among the three age groups, ranging from 72 mm for age 3 fish in 2010 to 74 mm for age 2 fish in 2011. Annual growth observed for each age group present during 2009 through 2011 was also very similar (Figures 6.0-3 and 6.0-4). Mean annual growth ranged from 74 mm (age 2) to 78 mm (age 4) in 2011, 69 mm (age 4) to 72 mm (age 3) in 2010 and was the same for both the age 3 and age 4 groups in 2009. Growth varied very little among years as well. The combined mean growth for all age groups present ranged from 70 mm in 2010 to 76 mm in 2011.

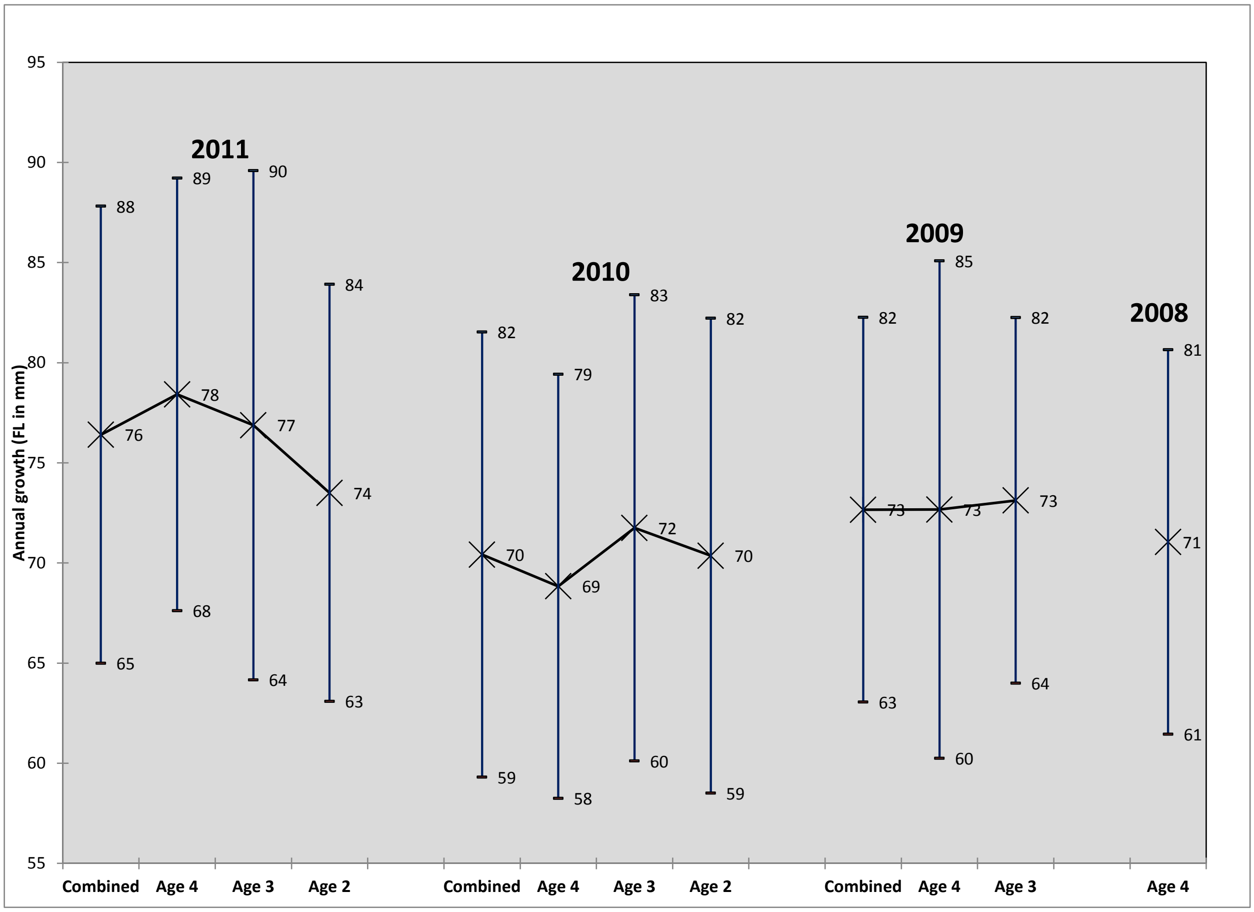


Figure 6.0-3. Mean and standard deviation growth exhibited by cohort-year (i.e., the year in which the fish was hatched) and by age for the three age groups of *O. mykiss* sampled from the lower Tuolumne River for this study in 2012.

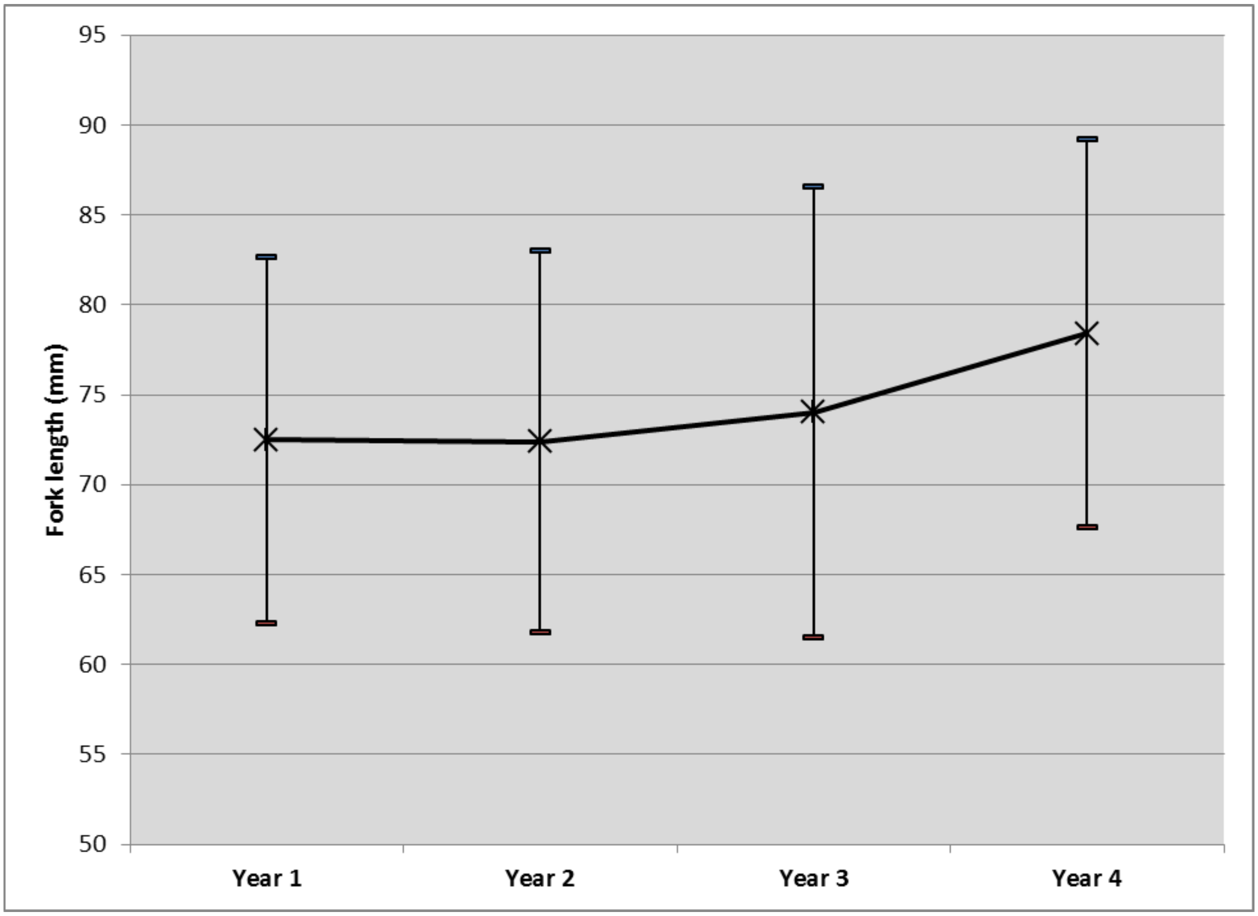


Figure 6.0-4. Estimated growth by age for four age groups of *O. mykiss* collected for this study in the lower Tuolumne River.

7.0 STUDY VARIANCES AND MODIFICATIONS

Consistent with permit requirements, the Districts proposed in their Study Plan that up to 75 fish would be collected. The Districts were able to collect 53 fish using approved sampling methods, of which 48 were sampled. No scales were taken from five fish because sufficient numbers of fish in their size class had already been collected. Permit requirements that limited the collection methods to angling and RST resulted in fewer samples per size group and limited the number of fish collected in the smallest and largest size classes.

The objectives for this study were met; scale data were used to estimate ages of individual fish, and an age-length relationship for the Tuolumne River *O. mykiss* population was developed. In addition, incremental annual growth rates for each age class were developed. The data from this study, and the information from from Zimmerman et al (2009), are sufficient as input for developing a representative population age structure as part of the interrelated *O. mykiss Population Study* (TID/MID 2011).

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STUDY REPORT W&AR-20

ONCORHYNCHUS MYKISS SCALE COLLECTION AND AGE DETERMINATION

ATTACHMENT A

SCALE SAMPLE COLLECTION, AGE, AND GROWTH DATA

W&AR-20 Scale Age and Growth Data																
Sample #	Sex (M/F)	Age	Length at capture (FL)	radius of scale (mm)	radius from nucleas to 1st annuli (mm)	radius from nucleas to 2nd annuli (mm)	radius from nucleas to 3rd annuli (mm)	radius from nucleas to 4rth annuli (mm)	length at 1st annuli (mm)	length at 2nd annuli (mm)	length at 3rd annuli (mm)	length at 4th annuli (mm)	1st yr growth (mm)	2nd yr growth (mm)	3rd yr growth (mm)	4rt yr growth (mm)
1	unk	2	250	1.2542316	0.4198873	0.899964			108	190			108	82		
2	unk	3	342	1.5463918	0.3632222	0.816351	1.2694797		108	198	287		108	89	89	
3	F	4	370	2.3705227	0.495193	0.9997602	1.5715656	2.0888396	106	177	258	330	106	71	80	73
4	M	4	365	1.9467634	0.44234	0.9901702	1.4157276	1.7765524	111	204	275	336	111	92	72	61
5	M	4	400	1.904819	0.4627188	0.830736	1.1567969	1.5511868	125	195	257	333	125	70	62	75
6	F	4	390	2.2332774	0.4051786	0.7839847	1.2467034	1.8652601	101	161	234	332	101	60	73	98
7	M	3	370	2.0895828	0.4878926	0.8296092	1.2194318	1.7421482	114	169	231	315	114	55	62	83
8	M	4	440	2.4310717	0.456725	0.9170463	1.2718772	1.7705586	112	189	248	330	112	76	59	83
9	unk	2	230	1.2379286	0.5089187	1.0270079			116	197			116	81		
10	unk	2	270	1.4466075	0.5492328	1.0483457			125	206			125	81		
11	unk	2	235	1.2114601	0.5244306	0.9826421			123	198			123	75		
12	F	3	335	2.0206665	0.4878926	1.0093503	1.3414049	1.7669624	109	186	235	298	109	77	49	63
13	unk	3	345	2.0079118	0.4937305	1.0628386	1.6561856		112	200	291		112	87	91	
14	unk	2	215	1.0964157	0.4680173	0.9431072			113	190			113	77		
15	F	3	340	2.1525054	0.4165308	0.7956126	1.461532		95	149	243		95	53	94	
16	M	3	360	1.7142172	0.4512467	0.8193119	1.3004196		122	191	282		122	69	91	
17	unk	2	194	0.9050587	0.3236634	0.6353392			93	147			93	54		
18	F	4	370	2.1637497	0.4155598	0.8031647	1.3545912	1.8700551	101	160	245	325	101	60	85	79
19	unk	2	220	0.8772596	0.4021218	0.7790578			121	199			121	79		
20	unk	2	240	1.2853632	0.3708583	0.8209902			95	167			95	71		
21	F	3	345	1.9575641	0.4639175	0.9721889	1.5715656		110	190	284		110	80	94	
22	M	4	365	1.841393	0.3996883	0.8400863	1.2965716		108	186	268		108	79	81	
23	F	3	370	1.885531	0.4591225	0.8151522	1.1364181		118	181	238		118	63	57	
24	unk	2	220	1.091321	0.4599856	0.7607049			114	164			114	51		
25	F	3	335	2.1457684	0.553824	0.991369	1.5248142		114	174	249		114	61	74	
26	F	3	355	1.8104891	0.4039799	0.7624071	1.1771757		108	171	244		108	63	73	
27	F	4	370	1.9488492	0.3883961	0.7722848	1.1850156	1.647087	103	169	239	318	103	66	71	79
28	F	4	375	1.58076	0.4017861	0.6792136	0.9546871	1.2979381	123	182	241	314	123	59	59	73
29	F	4	405	2.121194	0.44234	0.9158475	1.3665788	1.8269	113	196	274	354	113	82	78	80
30	unk	2	230	1.1304244	0.3104771	0.7120595			90	158			90	69		
31	M	na	445													
32	unk	2	230	1.1088468	0.2912971	0.6629106			87	152			87	65		
33	unk	1	150	0.8475186	0.4483337				97				97			
34	unk	4	450	2.2236874	0.4866938	0.9458164	1.3521937	1.8568689	127	212	288	382	127	85	76	94
35	unk	2	220	1.360585	0.47111	1.0668904			100	180			100	80		
36	F	3	345	2.1781347	0.4279549	0.9745864	1.4924479		97	175	248		97	77	73	
37	M	3	350	2.006713	0.468713	0.985375	1.517622		110	191	274		110	81	83	
38	unk	2	225	0.9314313	0.3296572	0.6473268			103	168			103	64		
39	unk	2	250	1.1963558	0.3847998	0.8846799			105	194			105	89		
40	unk	3	267	1.3641813	0.3836011	0.7228482	1.0680892		101	159	217		101	57	58	
41	unk	2	247	1.2167346	0.3943898	0.8379286			105	182			105	77		
42	unk	2	224	1.074083	0.450731	0.907456			115	195			115	80		
43	unk	3	302	1.497243	0.425557	0.888276	1.364181		112	194	278		112	82	84	
44	unk	3	270	1.444498	0.522656	0.890674	1.238312		121	181	237		121	59	56	
45	unk	3	287	1.3989451	0.3883961	0.7420283	1.1268281		106	169	238		106	63	69	
46	unk	3	335	1.5616159	0.4099736	0.8343323	1.2757372		115	196	280		115	81	84	
47	unk	3	345	1.9669264	0.5248981	0.9923999	1.4367058		119	192	262		119	73	70	
48	unk	0.5	78	0.3776073												
									1+	2+	3+	4+				
								Min	87	147	217	298	87	51	49	61
								Max	127	212	291	382	127	92	94	98
								Average	109	182	257	331	109	72	74	78