Appendix 5.D
Contaminants

Appendix 5.D
Contaminants

5.D.0 Executive Summary

Contaminants have been identified as adverse stressors in the Sacramento–San Joaquin River Delta (Delta) ecosystem and have been associated with pelagic organism decline (POD) (Baxter et al. 2010; Brooks et al. 2012; Johnson et al. 2010; Glibert 2010; Glibert et al. 2011). Some of these contaminants are contaminants that have been introduced to the ecosystem, and others are naturally occurring constituents in the Delta that have been mobilized and/or concentrated by anthropogenic activities. Although contaminants in water can be directly lethal to biota at very high concentrations, contaminants usually occur at concentrations much below lethal levels, enter the food chain at lower trophic levels, and can become more concentrated higher up in the food chain. Sublethal levels in fish result in various effects, including impaired growth and reproduction, and increase in the organism's susceptibility to disease (Werner et al. 2008).

The evaluated starting operations (ESO) will not introduce new contaminants or increase the concentrations of contaminants in the Plan Area directly, with the exception of herbicides, which would be applied in limited and safe concentrations to control invasive aquatics weeds. However, the ESO includes restoration and changes in water operations that have the potential to change how contaminants already present in the Plan Area are mobilized and transported in the Plan Area. To determine whether ESO actions would influence the exposure to and effects of contaminants on covered fish species, potential mechanisms for ESO actions to result in increased concentrations and bioavailability of contaminants first were identified and evaluated. This was achieved by developing conceptual models that included all factors that influence the environmental fate and transport, mobility in an aquatic system, and bioavailability to covered fish species for each contaminant. Quantitative analyses are applied where they were useful in describing factors within the conceptual models, and if data inputs and available analytical and modeling tools were deemed sufficient to provide reliable results. As discussed in this appendix, given the complex nature of contaminant biogeochemistry, area hydrology, and behavior and physiology of covered fish species that together determine the effects of contaminants, quantitative analyses alone were not sufficient to fully examine potential effects.

The environmental contaminants evaluated in this appendix were selected based on historical and current land use along with published literature regarding water quality in the Delta and the types of contaminants that have effects on fish.

- Mercury and methylmercury
- Selenium
- Copper
- Ammonia/um
- Pesticides
    - Pyrethroids
    - Organochlorines
    - Organophosphates

Based on results of the evaluation presented in this appendix, ESO water operations are not expected to affect contaminants significantly in the Delta through either increased mobilization or transport. Two primary pathways of effects on contaminants were examined in connection with water operations connected to the potential for an increase in the proportional amount of flow from the San Joaquin River into the Delta and a reduction in flow in the Sacramento River.

The first pathway is the potential for increased loading of selenium from increased contributions of water from the San Joaquin watershed as Sacramento River inputs are diverted by north Delta intakes. Based on the evaluation of current and expected future reductions in selenium from the San Joaquin watershed, and source-water fingerprinting that indicates no increase of San Joaquin water contribution at Suisun Marsh and a only a slight increase in the south Delta, minimal effects on selenium or associated effects on covered fish species are expected.

The second issue connected to ESO water operations is the potential for decreased dilution capacity of the Sacramento River, especially for Sacramento Regional Wastewater Treatment Plant (WWTP) effluent, and more specifically for ammonia and pyrethroids. Modeling results presented in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*, indicate that reduced dilution capacity in the Sacramento River at the Sacramento WWTP will result from changes in upstream reservoir operations associated with the ESO, not from diversion of water to the Yolo Bypass or from north Delta intakes located downstream of the WWTP. Quantitative analysis presented in this appendix indicates that the Sacramento River will have sufficient dilution capacity under the ESO for both ammonia and pyrethroids to avoid adverse effects from these contaminants on the covered fish.

Restoration actions will result in some level of mobilization and increased bioavailability of methylmercury, copper, and pesticides (including organophosphate, organochlorine and pyrethroid pesticides). Given current information, it is not possible to estimate the concentrations of these constituents that will become available to covered fish species, but review of the conceptual models for each of these contaminants indicates that the effects should be limited both temporally and spatially. The most problematic of these potential effects is methylmercury. To address this issue, the Plan includes Conservation Measure (CM) 12 *Methylmercury Management*, which provides for site-specific assessment of restoration areas, integration of design measures to minimize methylmercury production, and site monitoring and reporting. The areas with the highest potential for methylmercury generation are the Yolo Bypass, and to a lesser extent, the Mokelumne-Cosumnes River. With the implementation of CM12, effects of methylmercury mobilization on covered fish at the tidal wetland restoration sites are expected to be minimized. Selenium may also become more bioavailable under certain conditions at restoration sites. *AMM27 Selenium Management* (Appendix 3.C, *Avoidance and Mitigation Measures*) is included to minimize possible selenium effects.

In general, the following conclusions can be drawn.

- ESO water operations will have few to no effects on contaminants in the Delta.
- ESO restoration will increase bioavailability of certain contaminants, especially methylmercury, but the overall effects on covered fish species are expected to be localized and of low magnitude.
- Available data suggest that species exposure to contaminants would be below sublethal and lethal levels.
- The long-term benefits of restoration will reduce exposure to existing contaminants in the environment and reduce or eliminate some sources.

A summary of conclusions from the contaminants analysis is presented in Table 5.D.0-1. The color coding in the table is based on consideration of the potential for an increase in the bioavailability of contaminants due to covered activities, presence of covered fish species/life stages, and expected potential for effects on covered fish species/life stage. Based on this analysis, none of the scenarios was rated as *High* potential for effects.

- **None—**Areas with potential for increase in contaminants due to the ESO, but susceptible life stage of covered fish species is absent (also applies if there is fish occurrence, but no contaminants).
- **Low—**Areas with potential for increase in contaminants due to ESO and susceptible life stage of covered fish species present, but evaluation shows little potential for effects.
- **Moderate—**Same as *Low*, but evaluation shows moderate potential for effects.
- **High—**Same as *Moderate*, but evaluation shows high potential for effects based on mobilization of contaminants into the foodweb and effects on covered fish species.

Table 5.D.0-1. Potential for Effects of Contaminants on Covered Fish Species from the BDCP

Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Delta smelt	Eggs	M, C	M, C	C, S, P*	C, S, P	🟩	M, S*	M*	S, P*
	Larva	M, C	M, C	C, S, P*	C, S, P	S	M, S*	M*	S, P*
	Juvenile	M, C	M, C	C, S, P*	C, S, P	S	M, S*	M*	S, P*
	Adult	M, C	M, C	C, S, P*	C, S, P	S	M, S*	M*	S, P*
Longfin smelt	Eggs	M, C	M, C	C, S, P*	C, S, P	S	M, S	🟩	🟩
	Larva	M, C	M, C	C, S, P*	C, S, P	S	M, S	M*	S, P
	Juvenile	M, C	M, C	C, S, P*	C, S, P	S	M, S	🟩	S, P
	Adult	M, C	M, C	C, S, P*	C, S, P	S	M, S	🟩	S, P
Steelhead	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Fry	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Juvenile	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P
Winter-run Chinook salmon	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Fry	M, C	M, C	C, S, P	C, S, P	🟩	🟩	🟩	🟩
	Juvenile	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M, C	M, C	C, S, P	C, S, P	S	M, S	M	
Spring-run Chinook salmon	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Fry	M, C	M, C	C, S, P	C, S, P	🟩	🟩	🟩	🟩
	Juvenile	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M, C	M, C	C, S, P	C, S, P	S	M, S	M	
Fall-/late fall–run Chinook salmon	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Fry	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P
	Juvenile	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M, C	M, C	C, S, P	C, S, P	S	M, S	M	S, P

Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Sacramento splittail	Egg/Embryo	M	🟩	C, S, P*	🟩	🟩	M, S	M	S, P
	Larvae	M	M	C, S, P*	C, S, P	🟩	M, S	M	S, P
	Juvenile	M	M	C, S, P*	C, S, P	S	M, S	M	S, P
	Adult	M	M	C, S, P*	C, S, P	S	M, S	M	S, P
White sturgeon	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Larva	M	M	C, S, P*	C, S, P	🟩	🟩	M	S, P
	Juvenile	M	M	C, S, P*	C, S, P	S	M, S	M	S, P
	Adult	M	M	C, S, P*	C, S, P	S	M, S	M	S, P
Green sturgeon	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Larva	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Juvenile	M, C	M, C	C, S, P*	C, S, P*	S*	M, S*	M*	S, P*
	Adult	M, C	M, C	C, S, P*	C, S, P*	S*	M, S*	M*	S, P*
Pacific lamprey	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Ammocoete	M, C	M, C	C, S, P*	C, S, P*	🟩	🟩	M	S, P*
	Macropthalmia	M, C	M, C	C, S, P*	C, S, P*	S*	S*	M*	S, P*
	Adult	M, C	M, C	C, S, P*	C, S, P*	S*	M, S*	M*	S, P*
River lamprey	Egg/Embryo	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Ammocoete	M, C	M, C	🟩	🟩	🟩	🟩	M	🟩
	Macropthalmia	M, C	M, C	C, S, P*	C, S, P*	S*	M, S*	M*	S, P*
	Adult	M, C	M, C	C, S, P*	C, S, P*	S*	M, S*	M*	S, P*

* Scoring partially based on low abundance of species/life stage in the area.
M = mercury, P = pesticides, S = selenium, C = copper
Categories of effect of contaminants as result of the BDCP:

🟩 None
🟨 Low
🟧 Medium
🟥 High

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Tables

Figures

Acronyms and Abbreviations

μg/g	micrograms per gram (equivalent to parts per million)
μg/L	micrograms per liter (equivalent to parts per billion (ppb))
AWQC	EPA Ambient Water Quality Criteria
AWQC-Fresh Water-Chronic	EPA Ambient Water Quality Criteria for chronic exposures
BDCP	Bay Delta Conservation Plan
cfs	cubic feet per second
CM	Conservation Measure
Cu	Copper
Cu^{1+}	cuprous ion
Cu^{2+}	cupric ion
Cu^{2+}	cupric ion
DBW	California Department of Boating and Waterways
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethene
DDT	dichlorodiphenyltrichloroethane
Delta	Sacramento–San Joaquin River Delta
DOC	dissolved organic carbon
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
DWR	California Department of Water Resources
EBC	existing biological conditions
EDCs	endocrine-disrupting compounds
EEQs	estradiol equivalents
ELT	early long-term
EPA	U.S. Environmental Protection Agency
ESO	evaluated starting operations
g/day	grams per day
HOS	high-outflow scenario
kg/year	kilograms per year
kg/yr	kilograms per year
LC50	lethal concentration, 50%
LLT	late long-term
LOS	low-outflow scenario
Mercury Basin Plan Amendments	Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Methylmercury and Total Mercury in the Sacramento–San Joaquin Delta Estuary
mg/kg	milligrams per kilogram (equivalent to parts per million)
mgd	million gallons per day
ng/L	nanograms per liter (equivalent to parts per trillion)
NH^{3+}	ammonia
NH^{4+}	ammonium ion

NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
PCBs	polychlorinated biphenyls
POD	pelagic organism decline
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
ROAs	restoration opportunity areas
Se^{2-}	selenides
Se^{4+}	selenites
Se^{6+}	selenates
State Water Board	State Water Resources Control Board
TMDL	total maximum daily load
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WWTP	Sacramento Regional Wastewater Treatment Plant

Appendix 5.D
Contaminants

5.D.1 Organization of Appendix

This appendix presents a discussion of the contaminants that are widely recognized as significant to determining the potential of the Sacramento–San Joaquin River Delta (Delta) ecosystem to support covered fish species, and how potential changes to contaminants caused by the Bay Delta Conservation Plan (BDCP) could affect covered fish species. To do this, the appendix provides a general overview of toxic constituents currently present in the Delta aquatic ecosystem, identifies and assesses changes in contaminants that could result from implementation of the BDCP, and describes how those changes could result in changes in exposure of covered fish species to contaminants. The analysis focuses only on changes in contaminants that are directly attributable to the covered activities that could affect covered fish species.

Water quality parameters, including salinity, turbidity, and temperature, are integrated with the hydrologic flow analyses and are discussed in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*. Results of the flow analysis are included in this appendix where they support analysis of contaminants. This appendix discusses only covered fish species. Ecological effects, including food chain and organisms other than covered fish species, are evaluated in Appendix 5.F, *Biological Stressors on Covered Fish*.

The approach in this contaminants analysis is to develop a complete picture of all factors that contribute to the bioavailability and effects of these contaminants on covered fish species. Qualitative conceptual models are presented that capture and describe all determining factors. The conceptual models draw from those developed by the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP), along with other relevant information sources. Quantitative analyses are used where they are useful in describing factors within the conceptual models, and if data inputs and available analytical and modeling tools are deemed sufficient to provide reliable results. As discussed in this appendix, given the complex nature of contaminant biogeochemistry, area hydrology, and behavior and physiology of covered fish species that together determine the effects of contaminants, quantitative analyses alone were not sufficient to fully examine potential effects.

The analyses in this appendix are presented in two steps. The first step identifies effects on contaminants that are directly attributable to covered activities. The second step evaluates the potential for these changes in contaminants to affect covered fish species, at what life stages, and where in the BDCP Study Area. The general approach to the analysis for each contaminant is outlined below.

1. Determine effects of covered activities on contaminants in the Delta ecosystem.
    a. Describe the environmental chemistry of each parameter, the source of the element, how it is transported in the environment, and where it tends to accumulate.
    b. Discuss covered activities that could result in changes in contaminants, at what locations and when (if there is a seasonal component).

2. Determine effects of changes in potentially toxic constituents on covered fish species.
    a. Compare the spatial/temporal occurrence of each covered fish species/life stage with changes in contaminants, identifying where changes in contaminants coincide temporally and spatially with the presence of covered fish species.
    b. Discuss how BDCP–induced changes to contaminants could affect covered fish species/life stages in the Delta.

5.D.2 Overview of Contaminants as Stressors

Stressors act on the environment by changing flow, water quality, temperature, or other attributes that determine the suitability of habitat for a species. Contaminants have been identified as adverse stressors in the Delta ecosystem and have been associated with pelagic organism decline (POD) (Baxter et al. 2010; Glibert 2010; Glibert et al. 2011). Some of these contaminants are contaminants that have been introduced to the ecosystem, and others are naturally occurring constituents in the Delta that have been mobilized and/or concentrated by anthropogenic activities. Although contaminants in water can be directly lethal to biota at very high concentrations, contaminants usually occur at concentrations much below lethal levels, enter the food chain at lower trophic levels, and can become more concentrated higher up in the food chain. Sublethal levels in fish result in various effects, including impaired growth and reproduction, and increase in the organism’s susceptibility to disease (Werner et al. 2008).

5.D.2.1 Selection of Contaminant Stressors for Analysis

Water quality characteristics and the presence of contaminants in the environment are determined by both natural conditions and land use. The primary land uses affecting contaminants in the Delta include historical mining operations in the mountains drained by Delta tributaries, agriculture in the Delta and tributaries, discharges related primarily to rural human habitation (wastewater), and discharges related to urban development (stormwater runoff, municipal wastewater, industrial wastewater). The types of contaminant issues typically associated with these land uses are presented in Table 5.D.2-1 and discussed further in the following paragraphs.

Table 5.D.2-1. Land Use and Typically Associated Contaminant Issues

Land Use	Typical Discharges/Operations	Typical Contamination Issues
Mining (historical)	Concentrated mining waste	Mercury and copper (specific to mining operations local to Delta)
Agriculture	Fertilizers	Nutrients (ammonia)
	Pesticides	Copper
	Drainage	Pesticides
		Selenium*
Rural human habitation	Wastewater discharge	Nutrients (ammonia)
Urban development	Municipal wastewater treatment plant discharge	Nutrients (ammonia), pesticides, endocrine disruptors
	Stormwater runoff	Metals, pesticides, petroleum residues (PAHs)
	Industrial waste discharges	Metals, PCBs (from historical discharges)

* Selenium from agricultural drainage is specific to locations like the Delta that have high levels of naturally occurring selenium in soils, which are concentrated in agricultural drainage.

Historical mining of mercury and gold resulted in concentrating and mobilizing certain metals that occur naturally in the mountains of the upper tributaries. Metals are present in rocks, soils, and sediments to varying degrees, dependent on the source rocks. During the mining process, naturally occurring metals were mobilized, transported via streams, and deposited in sediments of the Delta marshes, wetlands, and streambeds.

Agriculture has been the primary land use in the Delta for more than a century (Wood et al. 2010). In the Plan Area, 503,779 acres (59%) are used for agriculture (see Chapter 2, *Existing Conditions*). The pesticides, herbicides, and fertilizers applied to cultivated lands throughout the Delta are present in the soils where they were applied but also have migrated off the farmed properties via air, groundwater, runoff, and rivers and are dispersed throughout all environmental media in the Delta ecosystem. The majority of insecticides used in the Delta fall into three families—organochlorines (including dichlorodiphenyltrichloroethane [DDT]), which were used historically and now are banned, and pyrethroids and organophosphates, which are currently in use.

Rural developments associated with agricultural land use have minimal discharge of contaminants. The main types of discharges are relatively small volumes of wastewater, typically through local septic systems.

Cities and towns account for only 8% of the Plan Area (70,174 acres). The main urban centers are the cities of Sacramento and West Sacramento located on the Sacramento River, and the city of Stockton located on the San Joaquin River (Wood et al. 2010). Although urban development accounts for a small percentage of land use in the Delta, urban discharges have affected the aqueous environment. Release of contaminants to water typically associated with urban development is related to stormwater and wastewater treatment plant (WWTP) discharges.

Stormwater typically is characterized by varying levels of metals, pesticides, and hydrocarbons that can accumulate in river sediments over time. Historically, polychlorinated biphenyls (PCBs) often were associated with urban discharge, and these contaminants have been detected in fish tissues in San Francisco Bay, although there is little research on PCB levels in the Delta.

Wastewater discharges from WWTPs also are associated with urban and suburban land use. Wastewater contains high levels of nutrients, and the concentrations in effluent are dependent on the level of the treatment system. In the Delta, ammonia historically has been problematic in both the Sacramento and San Joaquin Rivers; however, planned and functioning upgrades to WWTPs have resulted or will result in reductions in ammonia (discussed later in this appendix). Both stormwater runoff and effluent from the Sacramento Regional WWTP have been shown to contain pesticides, including pyrethroids (Weston and Lydy 2010). Although this will be discussed further, it should be noted that the north Delta intakes would be downstream of the Sacramento WWTP discharge and would not affect dilution of effluent.

Endocrine-disrupting compounds (EDCs), which include many of the pesticides, are also referred to as *emerging contaminants* and also are found in urban runoff and wastewater discharges. EDCs include many different types of chemicals from a wide range of sources with widely varying chemical attributes, and their distribution in the Delta is not yet fully understood.

The environmental contaminants discussed in this appendix were selected based both on land use discussed above and on other literature that identifies primary constituents of concern to fish in the Delta. The U.S. Environmental Protection Agency (EPA) identified ammonia, selenium, pesticides, and contaminants of emerging concern (including endocrine disruptors) for more focused evaluation in *Water Quality Challenges in the San Francisco Bay/Sacramento–San Joaquin Delta Estuary* (U.S. Environmental Protection Agency 2011a). Contaminants of concern also are identified under the Clean Water Act Section 303(d) list provided in Table 5.D.2-2. Those for which total maximum daily load (TMDL) studies have been completed are listed in Table 5.D.2-3. These lists identify the same contaminants listed above plus furans, dioxins, PCBs, mercury/methylmercury, and pathogens. Dioxin, furans, and pathogens are listed only for Stockton, and *E. coli* (a pathogen) is listed for the east Delta.

Table 5.D.2-2. Clean Water Act 2010 Section 303(d) Listed Pollutants and Sources in the Plan Area

Pollutant/Stressor	Listing Region	Listed Source	Delta Location of Listing
Chlordane	Central Valley	Agriculture, Nonpoint Source	N, W
Chlorpyrifos	Central Valley	Agriculture, Urban Runoff/Storm Sewers	N, S, E, W, NW, C, Exp, Stk
DDT	Central Valley	Agriculture, Nonpoint Source	N, S, E, W, NW, C, Exp, Stk
Diazinon	Central Valley	Agriculture, Urban Runoff/Storm Sewers	N, S, E, W, NW, C, Exp, Stk
Dioxin Compounds	Central Valley	Source Unknown, Atmospheric Deposition	Stk
E. Coli	Central Valley	Source Unknown	E
Invasive Species	Central Valley	Source Unknown, Ballast Water	N, S, E, W, NW, C, Exp, Stk
Furan Compounds	Central Valley	Contaminated Sediments, Atmospheric Deposition	Stk
Group A Pesticides[a]	Central Valley	Agriculture	N, S, E, W, NW, C, Exp, Stk
Mercury	Central Valley	Resource Extraction	N, S, E, W, NW, C, Exp, Stk
Selenium	Central Valley	Agriculture	N, S, E, W, NW, C
Pathogens	Central Valley	Recreational and Tourism Activities (non-boating), Urban Runoff/Storm Sewers	Stk
PCBs	Central Valley	Source Unknown	N, Stk
Unknown Toxicity[b]	Central Valley	Source Unknown	N, S, E, W, NW, C, Exp, Stk
Electrical Conductivity	Central Valley	Agriculture	S, W, NW, Stk
Organic Enrichment/ Low Dissolved Oxygen	Central Valley	Municipal Point Sources, Urban Runoff/Storm Sewers	Stk
Sediment Toxicity	Central Valley	Agriculture	E
Total Dissolved Solids	Central Valley		S

Source: State Water Resources Control Board 2010.

DDT = dichlorodiphenyltrichloroethane, PCB = polychlorinated biphenyls.

Delta Locations: C = central, E = east, Exp = export area, N = north, NW = northwest, S = south, Stk = Stockton Deep Water Ship Channel, W = west.

[a] Group A pesticides include aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, BHC (including lindane), endosulfan, and toxaphene.

[b] Toxicity is known to occur, but the constituent(s) causing toxicity is unknown.

Table 5.D.2-3. Summary of Completed and Ongoing Total Maximum Daily Loads in the Delta

Pollutant/Stressor	Water Bodies Addressed	Total Maximum Daily Load Status
Chlorpyrifos and Diazinon	Sacramento County urban creeks	TMDL report completed—September 2004 State-federal approval—November 2004
	Sacramento and San Joaquin Rivers and Delta	TMDL report completed—June 2006 State-federal approval—October 2007
	Sacramento and Feather Rivers	TMDL report completed—May 2007 State-federal approval—August 2008
	Lower San Joaquin River	TMDL report completed—October 2005 State-federal approval—December 2006
Methylmercury	Delta	TMDL report completed—April 2010 State-federal approval—October 2011
Pathogens	Five-Mile Slough, Lower Calaveras River, Mormon Slough, Mosher Slough, Smith Canal, and Walker Slough	TMDL report completed—March 2008 State-federal approval—May 2008
Pesticides	Central Valley	Ongoing
Organochlorine Pesticides	Central Valley	Ongoing
Salt and Boron	Lower San Joaquin River	TMDL report completed—October 2005 State-federal approval—February 2007
Selenium	San Joaquin River	TMDL report completed—August 2001 State-federal approval—March 2002
Low Dissolved Oxygen	Stockton Deep Water Ship Channel	TMDL report completed—February 2005 State-federal approval—January 2007

Source: State Water Resources Control Board 2011.

The environmental contaminants evaluated in this appendix were selected based on historical and current land use along with published literature regarding water quality in the Delta and the types of contaminants that have effects on fish. The contaminants are:

- Mercury and methylmercury
- Selenium
- Copper
- Ammonia/um
- Pesticides
  - Pyrethroids
  - Organochlorines
  - Organophosphates

5.D.3 Methods

To evaluate effects on covered fish species, published data on occurrence, biogeochemical behavior, mass balances, quantitative modeling tools, and studies of impacts of specific toxic constituents on covered fish species were reviewed. There are a broad range of available studies specific to the Central Valley and Delta region, many of which are referenced in this appendix. The objective of the analysis in this appendix is to provide an overview of how these constituents could become more bioavailable to covered fish species in the Plan Area and whether there is potential for covered activities to result in effects on covered fish species.

A qualitative framework or conceptual model is presented to evaluate the potential effects of BDCP conservation measures on contaminants in the Delta environment, and the possible effects on covered fish species. The effects on covered fish species are dependent more on the increase in both bioavailability and concentration of a given contaminant than on just the increase in concentration of the contaminant in the water. Given the currently available analytical tools, available occurrence data, and the breadth of the Plan Area, a purely quantitative approach is unable to capture the environmental/ chemical factors that result in transformation of a chemical to a form that is more bioavailable and toxic in the ecosystem. Where available field data and quantitative modeling tools were deemed sufficient to capture the relevant aspects of the constituent in estimating impacts, quantitative model results are presented along with a full discussion of the conceptual model for each constituent. Where quantification would lead to results with very high margins of error and uncertainty and would not appropriately inform or define the effects on covered fish species, effects were discussed only qualitatively with the objective of determining the probability of effects on covered fish species.

For reference, the EPA Ambient Water Quality Criteria (AWQC) for chronic exposures (AWQC-Fresh Water-Chronic) are included in the discussions of each contaminant for context. The AWQC-Fresh Water-Chronic is expressed as the highest concentration of a substance in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. It should be emphasized that the role of the effects analysis is to evaluate effects on covered fish species, and not compliance with the Clean Water Act, Basin Plans, or other regulatory guidelines. However, ecological benchmarks are provided where they are useful in evaluating effects.

Presented below is a more detailed description of the components that were examined to develop the qualitative conceptual models, and the quantitative tools that were used to more fully describe the potential effects of contaminants on covered fish species. The models were developed to describe the biogeochemistry that determines how these contaminants partition in the aqueous system (to sediment, water, or biota), how they are taken into the foodweb, and the potential effects on the covered fish species.

5.D.3.1 Problem Formulation

Historical and current land use in the Delta has resulted in the release of contaminants into the environment. The effects of contaminants on the Delta ecosystem have been identified as contributing to the POD described by Baxter et al. (2010). Covered activities may serve to increase or decrease the presence and effects of the contaminants already present in the Delta and are deserving of attention in this effects analysis.

5.D.3.2 Conceptual Model

Multiple chemical-specific, environmental, and species-specific factors contribute to determining whether a constituent will cause toxic effects on biota. The general conceptual model outlined below and illustrated in Figure 5.D.3-1 is intended to provide a framework to evaluate these factors and a full description of the potential for each contaminant to affect covered fish species under the BDCP.

The textual explanations in the following sections are meant to provide definitions of factors included in the conceptual model shown in Figure 5.D.3-1 and information on how the factors work together to determine the ultimate effects on covered fish species. The conceptual model is meant to summarize and synthesize a complex system that integrates chemical-specific biogeochemistry with site-specific environmental factors and species/life stage–specific physiology.

5.D.3.2.1 Conceptual Model Components—Contaminant Biogeochemistry

The contaminants identified in the Delta environment and the fate and transport of these chemicals, along with the propensity for these chemicals to enter the food chain, are evaluated through analysis of the factors discussed below.

5.D.3.2.1.1 Fate and Transport

The conceptual model for contaminants includes a discussion of the biogeochemistry of the chemical and the fate and transport characteristics. The analysis of fate and transport involves identifying the source of the contaminant in the Delta, how the constituent is transported and accumulates in the ecosystem, and the chemical properties that cause it to partition to sediment/water/air/biota. This analysis integrates the environmental setting and hydrology to determine how and where the contaminant is transported from its source area to other parts of the Delta.

The basic chemical characteristics that determine how a contaminant is transported and partitions in the environment include solubility in water, tendency to sorb to particulates, and volatility (tendency to occur as a vapor). A contaminant with high water-solubility can migrate dissolved in rivers. Alternatively, metals and some pesticides often have low solubility in water and tend to sorb to particulates and organic carbon, so they typically are found in sediments closer to the source. Further, the chemical form of the element can change the water solubility, as is true for mercury and copper, which are further discussed below.

Chemicals can be broken down in the environment by chemical or biological processes. The rate of this degradation is measured by a chemical-specific half-life, which is the time it takes for half of the mass to break down. Chemical degradation includes photodegradation, where the contaminant is chemically broken down by sunlight. Biological degradation is usually a product of bacterial degradation of organic chemicals.

Water chemistry also affects the fate, transport, partitioning, and bioavailability of a contaminant in an aqueous system. Salinity, hardness, temperature, pH, organic carbon, and redox potential (in sediments) influence the form that a chemical will take. In many cases, certain forms of a given contaminant (species or ionic state) determine partitioning and the ultimate toxicity. For example, copper is more toxic in the cupric species (2+), than in the cuprous species (1+), and mercury is more toxic in a methylated state.

5.D.3.2.1.2 Bioavailability, Bioaccumulation

Bioavailability is a measure of the ability of a contaminant to cross the cellular membrane of an organism, to become incorporated in that organism, and to enter the food chain (Semple et al. 2004). Not all contaminants are in a form that can be taken up by an organism. Bioavailability is not only chemical-specific, but it also can be specific to the chemical form that a constituent takes. For instance, copper in the 2+ state is more bioavailable than copper in the 1+ state, making the first form much more toxic than the second. Mercury in an organic complex as methylmercury is much more bioavailable and toxic than elemental mercury or mercury complexed with an inorganic compound.

In addition to the availability of the chemical to be taken up by biota, some chemicals are magnified more through the food chain. *Bioaccumulation* often is loosely used interchangeably with the term *biomagnification.* Strictly speaking, bioaccumulation occurs at any one trophic level or in any one species (and age-class) as a pollutant is ingested inside of food items or absorbed from the environment and thereby *accumulates* to some concentration in tissues of organisms at that particular trophic level or in that particular species (and age-class). In contrast, *biomagnification* more properly refers to increases in tissue concentrations of a pollutant as it passes upward through the food chain, from prey to predator, to the topmost, mature predators. In these top predators tissue concentrations may be harmful both to the animal (especially to offspring) and to those that consume it. A common example of a pollutant bioaccumulating and biomagnifying to harmful levels is the buildup of mercury in large game fish such as tuna or striped bass. In summary, bioaccumulation happens within a specific trophic level; biomagnification occurs over multiple trophic levels. For purposes of simplicity in this analysis, however, the term *bioaccumulation* will encompass biomagnification through the food chain.

Bioaccumulation is a function of the chemical's specific characteristics and the way that the organism metabolizes the chemical—such as whether it is metabolized and excreted, or stored in fat. Contaminants that are bioavailable and lipophilic (tend to accumulate in fatty tissue of an organism and are not very water soluble) typically bioaccumulate at higher rates. If stored, the chemical can biomagnify in the food chain, for example, mercury and some pesticides.

5.D.3.2.2 Conceptual Model Components—Effects of Covered Activities on Contaminants

For the purposes of this analysis, the conservation measures are grouped as either water operations or restoration, as depicted on Figure 5.D.3-1. Conservation Measure (CM) 12 *Methylmercury Management*, which is aimed at minimizing mercury mobilization from restoration areas, will be discussed in the mercury analysis. *CM19 Urban Stormwater Treatment*, which will reduce contaminant inputs from urban stormwater, will be discussed in the analyses of stormwater-related contaminants. Herbicides will be discussed in the context of *CM13 Invasive Aquatic Vegetation Control*.

The primary concern with the BDCP habitat restoration measures regarding contaminants is the potential for mobilizing contaminants sequestered in sediments of the newly inundated floodplains and marshes. This appendix provides an overview of what contaminants are known to be present in these areas and the biogeochemical conditions that will determine whether they could be mobilized into the aquatic environment and the food chain by restoration actions.

The greatest potential for effects on contaminants related to the evaluated starting operations (ESO) water operations is the potential for changes in dilution and mixing of existing contaminants. For instance, certain contaminants, such as selenium, are known to be present in the San Joaquin watershed. A change in the proportion of San Joaquin water inputs to the Delta relative to the Sacramento River could result in diminished dilution (and increased concentrations) in the Delta of contaminants from the San Joaquin watershed. Reduction of flows in the Sacramento River downstream of north Delta intakes also may result in decreased dilution of contaminants in the Delta.

5.D.3.2.3 Conceptual Model Components—Effects of Changes in Contaminants on Covered Fish Species

The previous steps determine if and where covered activities potentially could change the amounts and bioavailability of contaminants. This step looks at how these changes could affect covered fish species. The toxic effects of a chemical are determined by how it works on a biochemical level. Some of the types of effects are listed in Figure 5.D.3-1 under *Toxic Effects*. Contaminants can target specific tissues, organs, or organ systems. For example, contaminants that affect the neurological, immune, or endocrine systems typically lead to potential effects on behavior, ability to combat disease, and reproduction, respectively. Certain contaminants tend to accumulate in particular tissues or organs, such as the fatty tissues, liver, or kidneys; those that accumulate in fatty tissues have a greater potential to bioaccumulate. These factors determine the overall effect of the contaminant on the organism, and whether it will affect reproductive, developmental, or adult life stages. Effects of a particular toxic chemical can vary between species, and also between life stages within a species. The conceptual model for this effects analysis considers all these factors.

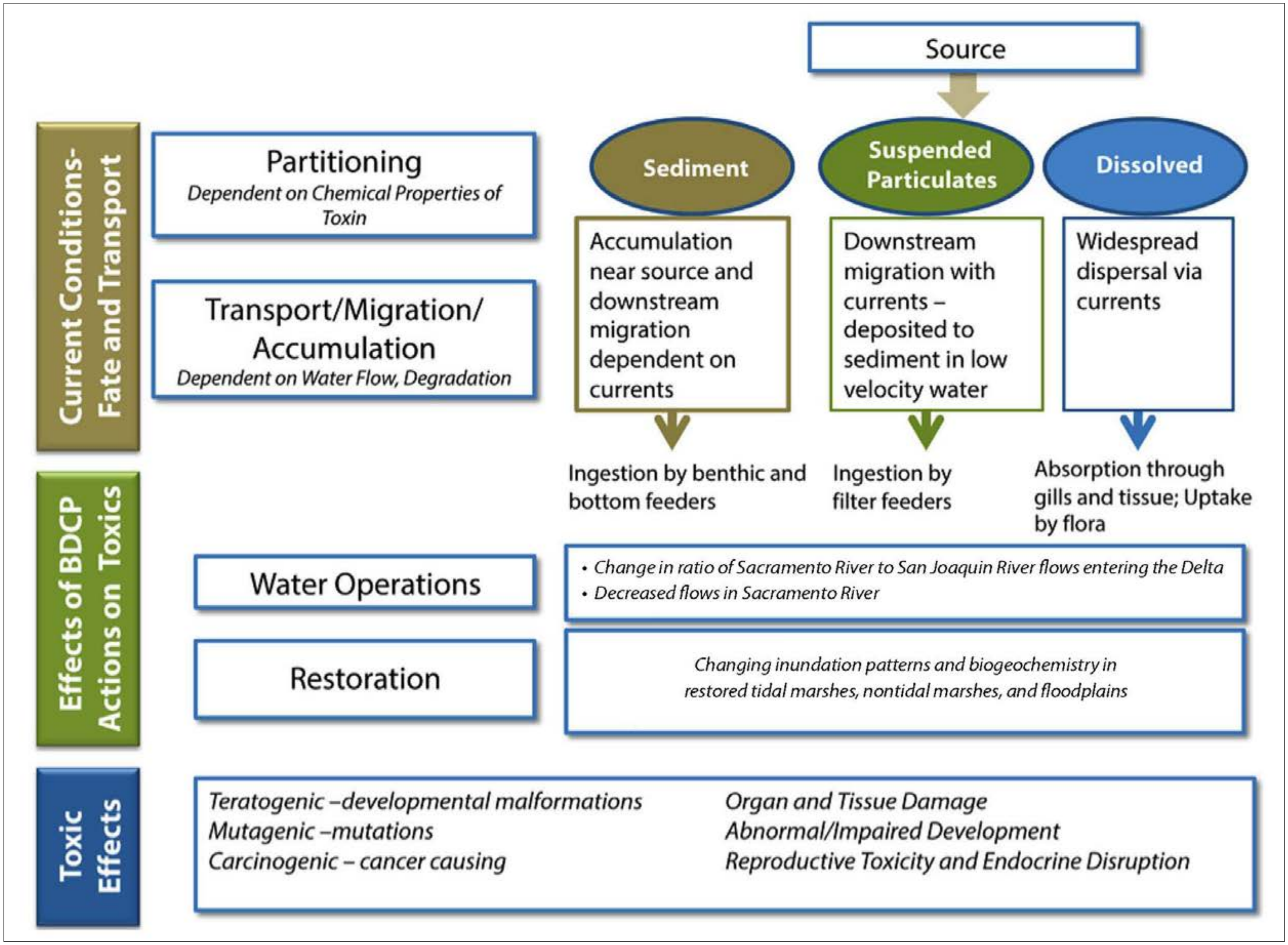


Figure 5.D.3-1. Generic Conceptual Model to Evaluate BDCP Contaminant Effects

5.D.4 Results—Effects of Covered Activities on Contaminants

5.D.4.1 Mercury

5.D.4.1.1 Mercury—Location, Environmental Fate, and Transport

Elemental mercury and mercury in the form of inorganic compounds have relatively low water solubility and tend to accumulate in soils and sediments. When mercury forms an organic complex called monomethylmercury (commonly referred to as methylmercury), it becomes more water soluble, and the toxicity and bioavailability are greatly enhanced, making it a primary concern for ecosystem effects. The toxicity of methylmercury is amplified as it biomagnifies through the foodweb. Because of the widespread presence of toxic methylmercury in the Delta, much recent research has been completed on the cycling of methylmercury through the physical environment and biota of the area.

As discussed below, the biogeochemical factors that control conversion of mercury to methylmercury are complex. In general, concentrations of the more toxic methylmercury are related to concentrations of elemental mercury, although this is not always the case. Locally, conditions may not be conducive to convert mercury to methylmercury, resulting in little correlation of mercury and methylmercury concentrations. These factors are discussed further in this section.

The mercury data available in the literature that is discussed in this section is for both total mercury and methylmercury. Concentrations of mercury and methylmercury in water are typically expressed in nanograms per liter (ng/L, which is equivalent to parts per trillion [ppt]). Concentrations in fish tissue are typically expressed in milligrams per kilogram (mg/kg; which is equivalent to parts per million [ppm]). These units will be used in the discussion below.

Mining operations in the mountains drained by Central Valley tributaries resulted in transport and widespread deposition of mercury into the water and sediments of the Delta ecosystem. Mercury, in the form of the mineral cinnabar, was mined mainly from the Coastal Range. In the Sierra Nevada and Klamath-Trinity Mountains, mercury was used for gold recovery in placer and hard-rock mining operations (Alpers and Hunerlach 2000; Alpers et al. 2005). Inorganic mercury was transported with sediment loads by creeks and rivers draining the mountains and became distributed throughout the riverbed, marsh, wetland, and floodplain sediments of the Delta, with highest concentrations in upper tributaries.

The Sacramento River is the primary transport route of mercury to the Delta and contributes about 80% of riverborne mercury inputs (Stephenson et al. 2007; Wood et al. 2010). The amounts of methylmercury, or organic mercury, will correspond roughly with these percentages. In the Sacramento River watershed, the highest concentrations of mercury are found in Cache Creek and the Yolo Bypass where Cache Creek terminates. Cache Creek, which drains a former mining area, is the largest contributor of mercury to the Delta, as it drains 2% of the area in the Central Valley and contributes 54% of the mercury (Foe et al. 2008). Methylmercury concentrations decrease significantly (by 30% to 60%) downstream of Rio Vista, where concentrations were at or below 0.05 nanograms per liter (ng/L) (Foe 2003; Wood et al. 2010).

Relative to the Sacramento River, the San Joaquin River is a relatively minor contributor of methylmercury to the Delta. Methylmercury water concentrations in some waters of the San Joaquin watershed are comparable or higher than the Sacramento River, but overall loading is minor because of the low flows. The Mokelumne-Cosumnes River is the greatest contributor of mercury in the San Joaquin watershed, but accounts for only 2.1% of the total methylmercury in the Delta, with an average concentration of 0.17 ng/L (Wood et al. 2010). Marsh Creek, which drains the Mt. Diablo mining area, contributes a small percentage (0.04%) because of its size, but it does have relatively high average concentrations of methylmercury estimated at 0.25 ng/L (Wood et al. 2010). Bear Creek and Mosher Creek, which drain a former mining area, are also high in mercury, with concentrations reported at 0.31 ng/L (Wood et al. 2010). These creeks are also small and contribute a relatively small percentage to the overall mercury budget in the Delta.

For reference, the current Criterion Continuous Concentration (AWQC-Fresh Water-Chronic) for mercury in fresh water is 770 ng/L (0.77 micrograms per liter [μg/L]). The criteria can be applied to total mercury (organic plus inorganic mercury), but they are derived from data for inorganic mercury (III) and therefore should be considered underprotective if a substantial portion of mercury occurs as methylmercury. The Delta is listed on the Clean Water Act Section 303(d) list as an impaired water body for mercury in fish tissues (State Water Resources Control Board 2010). The recommended water column concentrations calculated from the TMDLs in the Delta and in San Francisco Bay are provided in Table 5.D.4-1. The TMDL-based water column concentration for the Delta (0.06 ng/L) was approved in 2011.

Table 5.D.4-1. Mercury and Methylmercury TMDLs in the Delta and San Francisco Bay

Analyte	California Toxics Rule [a]	EPA Recommended Criteria[b]	Delta Methylmercury TMDL[c]	San Francisco Bay Mercury TMDL[d]
Mercury (ng/L)	50	770	–	25
Methylmercury (ng/L)	–	–	0.06	–

[a] Criterion for the protection of human health from total recoverable mercury in fresh water (U.S. Environmental Protection Agency 2006).

[b] Criterion for the protection of chronic exposure from total mercury to freshwater aquatic life (U.S. Environmental Protection Agency 2006).

[c] The recommended water column concentration (from TMDL) of methylmercury for the protection of fish bioaccumulation (Central Valley Regional Water Quality Control Board 2011a, 2011b).

[d] The recommended water column 4-day average (from TMDL) concentration for total mercury (U.S. Environmental Protection Agency 2006).

The chemistry of mercury in the environment is complex. Conversion of inorganic mercury to methylmercury occurs in flooded fine sediments subjected to periodic drying-out periods and is associated with anaerobic (oxygen-depleted), reducing environments (Alpers et al. 2008; Ackerman and Eagles-Smith 2010). Methylmercury production is higher in high marshes that are subjected to wet and dry periods over the highest monthly tidal cycles; production appears to be lower in low marshes not subjected to dry periods (Alpers et al. 2008). Relatively high rates of methylmercury production also have been attributed to agricultural wetlands, mainly rice fields (Windham-Myers et al. 2010). In addition to inundation regime, numerous factors determine mercury methylation rates in estuarine environments; they include vegetation, grain size, pH, redox, availability of binding constituents (iron, sulfur, organic matter), and factors influencing success of the microbes responsible for the methylation process (nutrients and dissolved oxygen) (Alpers et al. 2008; Wood et al. 2010). Figure 5.D.4-1 provides a simplified illustration of the basic factors controlling mercury methylation.

In-situ production of methylmercury in Delta sediments is an important source of this contaminant to the Delta ecosystem. Several investigators have quantified inputs of methylmercury to the Delta from sediments, with varying results (Stephenson et al. 2007; Byington 2007; Foe et al. 2008; Wood et al. 2010). Results of the CALFED Mercury Project Annual Report for 2007 (Stephenson et al. 2007) indicate that river inputs (11.5 grams per day [g/day] methylmercury) and *in-situ* production from wetland/marsh sediments (11.3 g/day methylmercury) are the leading sources of methylmercury to the Delta waters, and have roughly comparable levels of input. Wood et al. (2010) estimates that *in-situ* methylmercury production in open water and wetlands contributes approximately 36% of the overall methylmercury load to the Delta (approximately 5 g/day) but is less than riverine/tributary inputs (8 g/day). The higher estimate of methylmercury production from sediments reported by Stephenson et al. is based on periods of higher water (wet) and may be more representative of what might occur when new restoration opportunity areas (ROAs) are opened for inundation, especially when combined with the effects of sea level rise.

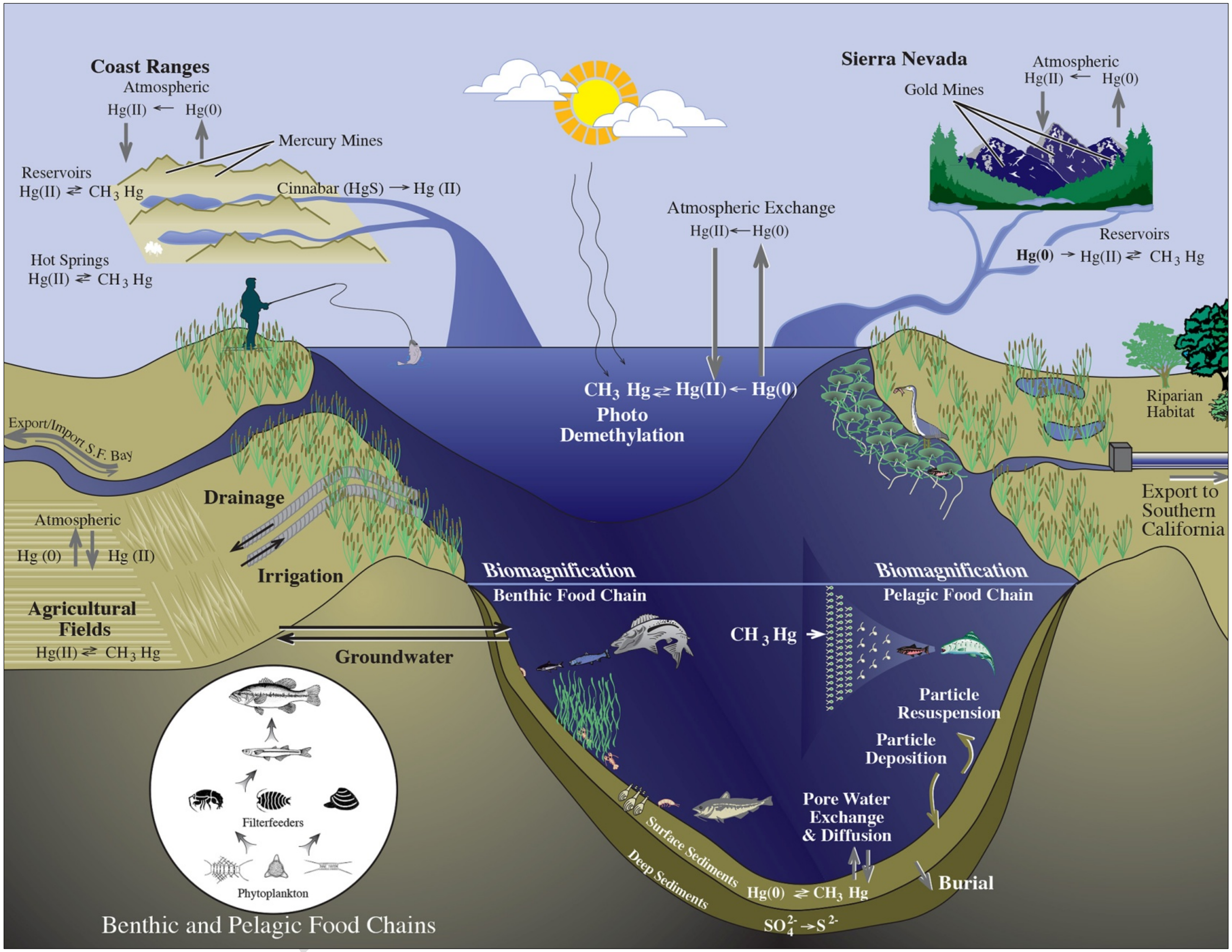
Despite all sources of methylation, the Delta remains a net sink for waterborne methylmercury, and photodegradation that results in demethylation of mercury may be an important factor in methylmercury losses from the system (Stephenson et al. 2007). However, it should be noted that demethylation transforms methylmercury into the less bioavailable inorganic mercury that tends to stick to sediments; the mercury remains in the system and can be methylated again.

In the methylmercury budgets developed by Wood et al. (2010), Foe et al. (2008), Byington (2007), and Stephenson et al. (2007), photodegradation rates are higher than sediment production rates for methylmercury. Gill (2008) identified photodegradation of methylmercury as potentially the most effective mercury detoxification mechanism in the Delta.

Specific photodegradation rates vary on daily and monthly timescales, as the process is dependent on light intensity (Gill 2008). Photodegradation of methylmercury occurs in the photic zone of the water column (the depth of water within which natural light penetrates) and as such can be expected to occur in a large portion of the shallow, newly inundated ROAs. At the 1% light level, the mean depth for the photic zone in the Delta was calculated to be 2.6 meters, with measured depths ranging from 1.9 meters to 3.6 meters (Gill 2008; Byington 2007). Gill and Byington also conclude that photodegradation may be most active in the top half-meter of the water column in the Delta.

Mediated by sunlight, photodegradation occurs at higher levels in the dry season than in the wet season, with minimum photodegradation rates occurring December through February and maximum degradation rates occurring in May and June (Byington 2007). Research by Byington indicates that photodegradation of methylmercury in marshes and tules in the Delta is severely diminished by reduced light penetration resulting from the presence of high dissolved organic carbon (DOC), turbidity, and aquatic vegetation.

Atmospheric deposition also may contribute to the mercury load; however, estimated daily loads are an order of magnitude lower than most other sources to the Delta and constitute approximately 1% of the entire methylmercury load contributed from external and in-Delta sources (Wood et al. 2010). In addition, atmospheric contributions are not anticipated to be altered by BDCP. Therefore, atmospheric deposition can be considered an insignificant source from the perspective of assessing BDCP effects.



Source: California Department of Fish and Game and California Bay Delta Authority 2008.

Figure 5.D.4-1. Methylmercury Cycling

5.D.4.1.2 Mercury—Effects of Covered Activities

Quantitative modeling was performed to estimate the effects of ESO water operations on mercury and methylmercury in the aquatic system and on fish.

Modeling was based on DSM2 output that estimated changes in water flows under preliminary proposed actions. Results were considered in the context of a qualitative discussion to fully capture some of the factors that were not quantified, including mercury methylation in ROAs and biogeochemical factors that affect concentrations, environmental partitioning, degradation, and bioavailability.

5.D.4.1.2.1 Water Operations

Modeling Methods

Modeling methods are fully described in Attachment 5D.A, *Bioaccumulation Model Development for Mercury Concentrations in Fish*, and a brief overview is provided here. DSM2 was used to estimate the water concentrations that would occur in the late long-term (LLT) under conditions without the BDCP (EBC2_LLT), and under three BDCP scenarios: evaluated starting operations (ESO_LLT), a low-outflow scenario (LOS_LLT), and a high-outflow scenario (HOS_LLT). The analytical conditions of these scenarios and the baseline scenarios are described in Table 5.D.4-2.

Table 5.D.4-2. Analytical Conditions of the Modeled Scenarios

Condition		Description
Existing Biological Conditions	EBC1	Current operations, based on the USFWS (2008) and NMFS (2009) BiOps, excluding management of outflows to achieve the Fall X2 provisions of the USFWS (2008) BiOp.
	EBC2	Current operations based on the USFWS (2008) and NMFS (2009) BiOps, including management of outflows to achieve the Fall X2 provisions of the USFWS (2008) BiOp.
Projected Future Conditions without the BDCP	EBC2_ELT	EBC2 projected into year 15 (2025) accounting for climate change conditions expected at that time.
	EBC2_LLT	EBC2 projected into year 50 (2060) accounting for climate changes conditions expected at that time.
Projected Future Conditions with the BDCP[a]	ESO_ELT	Evaluated starting operations in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	ESO_LLT	Evaluated starting operations in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
	HOS_ELT	High-outflow operations (high-outflow outcomes of decision tree for management of spring and fall outflow) in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	HOS_LLT	High-outflow operations (high-outflow outcomes of decision tree for management of spring and fall outflow) in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
	LOS_ELT	Low-outflow operations (low-outflow outcomes of decision tree for management of spring and fall outflow) in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	LOS_ELT	Low-outflow operations (low-outflow outcomes of decision tree for management of spring and fall outflow) in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.

[a] The decision-tree process, described in Section 3.4.1.4.4, *Decisions Trees*, provides a mechanism for selection of one of four potential operational outcomes for *CM1 Water Facilities and Operation*: evaluated starting operations, high outflow scenario, low outflow scenario.

Sample data listed in Table 5.D.4-3 were used to characterize mercury and methylmercury concentrations in source waters. DSM2 then was used to model the mixing of these source waters, and the resultant mercury and methylmercury concentrations in water.

Using the DSM2 water results, two models were used to estimate the resultant concentrations of mercury in fish tissue under these scenarios. A regression model was developed to link concentrations of mercury in largemouth bass tissue samples (1999 to 2000 data) to a modeled methylmercury concentration at that location for Water Year 2000. The regression model allows the prediction of future, altered average fish tissue mercury concentrations under the ESO water operations. For this modeling effort, largemouth bass was used as the example fish. Although this is not a covered fish species, there are sufficient data to develop relationships between water and fish concentrations, and largemouth bass is a high-level consumer relative to the covered fish species and would show effects from bioaccumulation. The second model used was the model developed by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) to relate the fish tissue TMDL to water concentrations.

Table 5.D.4-3. Historical Methylmercury Concentrations in the Five Delta Source Waters for the Period 2000–2008

	Source Water[a]									
	Sacramento River		San Joaquin River		San Francisco Bay		East Side Tributaries		Agriculture in the Delta	
Data Parameters	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
Mean[b] (ng/L)	0.10	0.03	0.15	0.03	0.032	–	0.22	0.08	0.25	–
Minimum (ng/L)	0.05	0.03	0.09	0.01	–	–	0.02	0.02	–	–
Maximum (ng/L)	0.24	0.03	0.26	0.08	–	–	0.32	0.41	–	–
75th Percentile (ng/L)	0.12	0.03	0.18	0.06	–	–	0.20	0.15	–	–
99th Percentile (ng/L)	0.23	0.03	0.26	0.08	–	–	0.31	0.39	–	–
Data Source	Central Valley Water Board 2008		Bay Delta and Tributaries Project 2010; Central Valley Water Board 2008		San Francisco Estuary Institute 2010	–	Central Valley Water Board 2008		Central Valley Water Board 2008	–
				USGS 2010				USGS 2010		
Station(s)	Sacramento River at Freeport		San Joaquin River at Vernalis		Martinez		Mokelumne and Calaveras Rivers		Mid-Delta locations, median	
Date Range	2000–2003	2000	2000–2001; 2003–2004	2000–2002	2007	–	2000–2001; 2003–2004	2000; 2002	2008	–
ND Replaced with RL	Not Applicable		Not Applicable	Yes	–		Yes		Not Applicable	
Data Omitted	None		None		–		None		None	
No. of Data Points	36	1	49	25	–	–	27	9	–	–

Sources: Bay Delta and Tributaries Project 2010; Central Valley Regional Water Quality Control Board 2008; San Francisco Estuary Institute 2010; U.S. Geological Survey 2010.

[a] The total recoverable concentration of the analyte for each source water is presented in first column and the dissolved concentration of the analyte is presented in the second column.

[b] Means are geometric means.

ng/L = nanograms per liter.

Modeling Results—Water Operations

Modeling based on DSM2 showed small, insignificant changes in total mercury levels in water and fish tissues due to BDCP water operations, as shown in Table 5.D.4-4, Table 5.D.4-5, and Table 5.D.4-6. Model results for mercury in water are shown in Table 5.D.4-4. Changes in mercury concentrations in water from EBC2_LLT (future conditions without the BDCP) compared with the BDCP scenarios ranged from a decrease in mercury of 0.8 ng/L to an increase of 0.5 ng/L, relative to the benchmark of 25 ng/L.

Model results for methylmercury in water are presented in Table 5.D.4-5. Under current conditions, methylmercury concentrations in water exceed TMDL target values (0.06 ng/L), and model results do not indicate that the BDCP water operations will change this condition. Changes in methylmercury concentrations in water from EBC2_LLT to the BDCP scenarios ranged from a decrease in mercury of 0.012 ng/L to an increase of 0.01 ng/L, relative to the benchmark of 0.06 ng/L.

Currently, mercury concentrations in fish tissues exceed Delta TMDL guidance targets, which are set for human health rather than effects on fish, and the BDCP is not expected to substantially alter this condition through water operations. Modeled concentrations (based on the regression model) of total mercury in fish are presented in Table 5.D.4-6. The change in mercury concentration in fish estimated from model results for EBC2_LLT compared to the BDCP scenarios ranges from a decrease of 0.02 mg/kg to an increase of 0.04 mg/kg, relative to a benchmark of 0.24 mg/kg. Modeled concentrations of total mercury in fish, based on the Central Valley Water Board TMDL model, are presented in

Table 5.D.4-7. The change in mercury concentration from EBC2_LLT to the BDCP scenarios ranges from a decrease of 0.04 mg/kg to an increase of 0.09 mg/kg. Overall, the Central Valley Water Board TMDL model resulted in higher fish tissue concentrations than the regression model results, but the trends between specific locations were similar. Concentrations estimated from both fish tissue models and the water model indicate lower mercury concentrations in drought conditions, and of the locations, Buckley Cove has the highest concentrations.

Table 5.D.4-4. Modeled Total Mercury Concentrations in Water for the Late Long-Term—DSM2

Location	Period[a]	Modeled Concentrations of Mercury (nanograms per liter)			
		EBC2_LLT	LOS_LLT	ESO_LLT	HOS_LLT
Delta Interior					
Mokelumne River (South Fork) at Staten Island	All	5.1	5.3	5.3	5.3
	Drought	4.6	4.7	4.8	4.8
San Joaquin River at Buckley Cove	All	7.5	7.5	7.5	7.6
	Drought	7.3	7.5	7.5	7.5
Franks Tract	All	4.9	5.2	5.3	5.3
	Drought	4.5	4.6	4.6	4.7
Old River at Rock Slough	All	5.1	5.4	5.5	5.6
	Drought	4.6	4.8	4.8	4.9
Western Delta					
Sacramento River at Emmaton	All	4.5	4.5	4.5	4.5
	Drought	4.5	4.5	4.5	4.5
San Joaquin River at Antioch	All	5	5.2	5.2	5.2
	Drought	4.9	4.9	4.9	5
Sacramento River at Mallard Island	All	5.6	5.8	5.7	5.7
	Drought	5.9	5.9	5.9	5.9

[a] *All* (water years 1975–1991) represents the 16-year period modeled using DSM2. *Drought* represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Table 5.D.4-5. Modeled Total Methylmercury Concentrations in Water for the Late Long-Term—DSM2

Location	Period[b]	Modeled Concentrations- of Methylmercury (nanograms per liter)			
		EBC2_LLT	LOS_LLT	ESO_LLT	HOS_LLT
Delta Interior					
Mokelumne River (South Fork) at Staten Island	All	0.13	0.14	0.14	0.14
	Drought	0.12	0.13	0.13	0.13
San Joaquin River at Buckley Cove	All	0.16	0.16	0.16	0.16
	Drought	0.17	0.16	0.16	0.16
Franks Tract	All	0.12	0.12	0.13	0.13
	Drought	0.11	0.11	0.12	0.12
Old River at Rock Slough	All	0.12	0.13	0.13	0.13
	Drought	0.12	0.12	0.12	0.12
Western delta					
Sacramento River at Emmaton	All	0.10	0.10	0.10	0.10
	Drought	0.10	0.10	0.10	0.10
San Joaquin River at Antioch	All	0.10	0.11	0.11	0.11
	Drought	0.09	0.10	0.10	0.10
Sacramento River at Mallard Island	All	0.08	0.08	0.09	0.09
	Drought	0.07	0.07	0.07	0.07

[a] The recommended water column TMDL concentration of methylmercury for the protection of fish bioaccumulation = 0.06 ng/L (Central Valley Regional Water Quality Control Board 2008). All concentrations exceed this concentration.

[b] All (water years 1975–1991) represents the 16-year period modeled using DSM2. Drought represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Table 5.D.4-6. Modeled Mercury Concentrations in Largemouth Bass Fillets for the Late Long-Term—DSM2 (Regression-based Model)

Location	Period *	Modeled Concentrations of Mercury (milligrams per kilogram wet weight)			
		EBC2_LLT	LOS_LLT	ESO_LLT	HOS_LLT
Delta Interior					
Mokelumne River (South Fork) at Staten Island	All	0.51	0.55	0.55	0.55
	Drought	0.45	0.48	0.48	0.48
San Joaquin River at Buckley Cove	All	0.65	0.63	0.63	0.63
	Drought	0.66	0.64	0.64	0.64
Franks Tract	All	0.44	0.46	0.47	0.48
	Drought	0.41	0.42	0.43	0.43
Old River at Rock Slough	All	0.46	0.48	0.49	0.5
	Drought	0.43	0.44	0.45	0.46
Western Delta					
Sacramento River at Emmaton	All	0.38	0.38	0.38	0.38
	Drought	0.37	0.37	0.37	0.37
San Joaquin River at Antioch	All	0.38	0.39	0.4	0.4
	Drought	0.34	0.34	0.35	0.35
Sacramento River at Mallard Island	All	0.29	0.29	0.3	0.3
	Drought	0.25	0.25	0.25	0.25

Notes:

Fish tissue concentrations were evaluated in relation to the Delta methylmercury TMDL tissue target of 0.24 mg mercury/kg wet-weight of largemouth bass fillets (muscle tissue) for fish normalized to a standard 350 mm total length (Central Valley Regional Water Quality Control Board 2008). All tissue concentrations exceed this target.

* *All* (water years 1975–1991) represents the 16-year period modeled using DSM2. *Drought* represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Table 5.D.4-7. Modeled Mercury Concentrations in Largemouth Bass Fillets for the Late Long-Term—Central Valley Water Board TMDL Model (CVWQB TMDL Model)

Location	Period*	Modeled Concentrations of Mercury (milligram per kilogram wet weight)			
		EBC2_LLT	LOS_LLT	ESO_LLT	HOS_LLT
Mokelumne River (South Fork) at Staten Island	All	0.75	0.83	0.83	0.83
	Drought	0.64	0.69	0.69	0.69
San Joaquin River at Buckley Cove	All	1.05	1.01	1.01	1.01
	Drought	1.09	1.04	1.04	1.04
Franks Tract	All	0.61	0.66	0.67	0.68
	Drought	0.55	0.58	0.59	0.59
Old River at Rock Slough	All	0.65	0.70	0.72	0.74
	Drought	0.60	0.62	0.64	0.65
Sacramento River at Emmaton	All	0.49	0.50	0.50	0.50
	Drought	0.48	0.47	0.48	0.48
SJR at Antioch	All	0.49	0.52	0.53	0.54
	Drought	0.42	0.43	0.44	0.44
Sacramento River at Mallard Island	All	0.35	0.34	0.36	0.36
	Drought	0.28	0.28	0.28	0.28

* *All* (water years 1975–1991) represents the 16-year period modeled using DSM2. *Drought* represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Uncertainty Analysis

Several sources of uncertainty are associated with the modeled estimations. There is uncertainty associated with components of the model build-up, including using an average source-water concentration and uncertainties associated with DSM2 results. Although the bioaccumulation models produced differing estimates of concentrations, they are most useful to provide a comparison of scenarios and to evaluate changes due to the BDCP. Results should be considered along with, and are consistent with, the qualitative discussion in this analysis.

Also, the models capture effects due to BDCP water operations, but do not estimate the potential for methylation in existing or newly created environments (e.g., ROAs). The detailed, site-specific information needed to construct such a model, with acceptable margins of error, is lacking but may be developed as part of specific, future evaluations of actions (see discussion above concerning key processes controlling mercury fate, transport, and risk determination). Agricultural and existing wetlands may be very different in production of methylmercury and uptake into various trophic levels and are not easily generalized or modeled (Windham-Myers et al. 2010).

5.D.4.1.2.2 Restoration

As discussed above, *in-situ* conversion of mercury to methylmercury occurs at highest rates in intermittently flooded marshes and floodplains, as well as intermittently flooded agricultural areas. BDCP restoration actions will expand intermittently wetted areas by converting managed marshes, diked wetlands, agricultural areas, and other upland areas to tidal, open-water, and floodplain habitats (see Chapter 3, *Conservation Strategy*, for details of restoration), resulting in new areas with the potential to increase methylmercury in the aquatic system.

Under *CM12 Methylmercury Management*, the Implementation Office will minimize conditions that promote production of methylmercury in restored areas and its subsequent introduction to the foodweb, and to covered fish species in particular. CM12 will be developed and implemented in coordination with the California Department of Water Resources (DWR) Mercury Monitoring and Evaluation Section, which is working on DWR's compliance with the requirements of the *Sacramento–San Joaquin Delta Methylmercury Total Maximum Daily Load* (Central Valley Regional Water Quality Control Board 2011a) and *Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Methylmercury and Total Mercury in the Sacramento–San Joaquin Delta Estuary* (Mercury Basin Plan Amendments) (Central Valley Regional Water Quality Control Board 2011b). Under Phase I of the TMDL, the DWR Mercury Monitoring and Evaluation Section is planning control studies to research and identify effective measures to mitigate methylmercury generation and mobilization in connection with restored wetlands. The results of these Phase I control studies will be integrated into BDCP restoration planning to mitigate effects of methylmercury.

Following is a discussion of current distribution of methylmercury and the potential effects of the BDCP on methylmercury generation and mobilization, absent *CM12 Methylmercury Management*. Implementation of CM12 will result in minimization of these effects, as discussed above.

Wood et al. (2010) estimated rates of methylmercury generation for intertidal and floodplain areas (0.0369 g/acre/year) and for open-water production (0.01476 g/acre/year). However, methylmercury generation rates ultimately are dependent on the concentrations of mercury in the soils and, often more importantly, the specific biogeochemistry of the system. For this effects analysis, the margin of error on applying these estimated production rates across a wide geographic area with varying hydrology and concentrations of sequestered mercury was deemed to be too large to produce a reliable estimate of methylmercury generation at the scale of the ROAs.

The Sacramento River watershed, and specifically the Yolo Bypass, is the primary source of mercury in the Delta. The highest concentrations of mercury and methylmercury are in the Cache Creek area and the Yolo Bypass. The amount of methylmercury produced in the Yolo Bypass has been estimated to represent 40% of the total methylmercury production for the entire Sacramento watershed (Foe et al. 2008). Water discharging from the Yolo Bypass at Prospect Slough has a reported average annual methylmercury concentration of 0.27 ng/L, compared with the 0.06 ng/L TMDL (set for human health from bioaccumulation effects in fish).

The highest levels of methylmercury generation, mobilization, and bioavailability are expected in the Yolo Bypass during periods of seasonal flooding. When the bypass is not flooded, little to no methylmercury is produced (Wood et al. 2010). Under the BDCP, Yolo Bypass will be subjected to more frequent and wider areas of inundation, resulting in an overall increase in methylmercury production and mobilization during seasonal flood conditions. The concentrations of methylmercury in water exiting the Yolo Bypass will depend on many variables. Recent studies in the Yolo Wildlife Management Area showed that methylmercury increased with increased residence time (Windham-Myers et al. 2010). This same study also noted that the residence time in Cache Settling Basin, seasonality, and agricultural practices all factor into methylmercury production and cycling through the system in the Yolo Bypass. Marvin-DiPasquale et al. (2009) also identified a wide range of site-specific factors that determine methylmercury production, as well as variability in distribution and speciation of mercury in wetlands in the Yolo Bypass. Foe et al. 2008) developed an empirical relationship between net methylmercury production in the Yolo Bypass and outflow (methylmercury production = 0.0042*(flow)$^{0.782}$), but given the varied factors controlling methylmercury cycling, this calculation will not provide an estimate of methylmercury production in the Yolo Bypass that can be relied on with any certainty.

The covered activities for the Yolo Bypass have the potential to increase the loading, concentrations, and bioavailability of methylmercury in the aquatic system in the Yolo Bypass. Currently, the methylmercury in water discharging from the Yolo Bypass to the Sacramento River is 0.27 ng/L (annual average) (Foe et al. 2008). This concentration likely will increase under the BDCP, but will be mitigated to some extent by CM12, as discussed below. The current and future concentrations of methylmercury will exceed the TMDL (set for human health from bioaccumulation effects in fish) concentration of 0.06 ng/L water. Also, decreased flows in the Sacramento River due to ESO upstream water operations may reduce the dilution capacity of the Sacramento River and result in increased concentrations of methylmercury in the river.

As part of CM12, measures will be implemented to mitigate the production of methylmercury in ROAs. These measures may include construction and grading that minimize exposure of mercury-containing soils to the water column, design to support photodegradation, and pre-design field studies to identify depositional areas where mercury accumulation is most likely and characterization and/or design that avoids these areas. CM12 provides for consideration of new information as it develops that could effectively minimize methylmercury production and mobilization. Also, the Delta TMDL for methylmercury was adopted recently (Central Valley Regional Water Quality Control Board 2011a, 2011b) and will be integrated into the BDCP through CM12 (discussed below) and adaptive management.

Photodegradation may be an important factor in reducing the amount of methylmercury mobilized from restoration projects. Recent research has indicated that photodegradation of methylmercury in shallow waters can demethylate an amount of methylmercury similar to that produced in sediments of the Delta system (Byington 2007). Photodegradation has high potential to demethylate a percentage of the methylmercury produced in newly restored areas, with the rates partially dependent on the turbidity of the water column and the resultant depth of the photic zone. However, demethylation by photodegradation still leaves the less toxic inorganic mercury in the system. More research into the fate of mercury following photodegradation is needed. *CM12 Methylmercury Management* includes provisions for implementing restoration project design to enhance photodegradation.

As discussed throughout this section, the biogeochemistry and fate and transport of mercury and methylmercury are very complex. Restoration will involve inundation of areas where mercury has been sequestered in soils, and if methylation occurs, the methylmercury will be mobilized into the aquatic system. Once in the aquatic system, the methylmercury can be transported with water flow, taken up by biota, volatilized, demethylated, and returned to sediment (but not necessarily at the original restoration site).

5.D.4.1.2.3 Mercury Summary

Modeling of BDCP water operations effects showed little changes in methylmercury concentrations in water or fish tissue, although methylmercury concentrations in both media would continue to exceed criteria under the BDCP. However, restoration actions are likely to result in increased production, mobilization, and bioavailability of methylmercury in the aquatic system.

Methylmercury likely would be generated by inundation of restoration areas, with highest concentrations expected in the Yolo Bypass, Cosumnes and Mokelumne Rivers, and at other ROAs closest to these source areas.

CM12 Methylmercury Management will help to minimize the increased mobilization of methylmercury at restoration areas. It describes pre-design characterization, design elements, and best management practices to mitigate methylation of mercury, and requires monitoring and reporting of observed methylmercury levels. The effectiveness of CM12 will be enhanced by integration with results of the Methylmercury TMDL Control Study Programs, which will provide results of methylmercury management and control measures that can be applied to restoration planning and design.

5.D.4.2 Selenium

5.D.4.2.1 Selenium—Location, Environmental Fate, and Transport

Selenium is a naturally occurring micronutrient that can have significant ecological effects at elevated concentrations. Selenium has been identified as an important contaminant in the Delta, especially in the San Joaquin watershed where irrigation practices mobilize naturally occurring selenium from the soils. In the Delta watershed, selenium is most enriched in marine sedimentary rocks of the Coast Ranges on the western side of the San Joaquin Valley (Presser and Piper 1998). Irrigation of soils derived from the marine rocks leaches the selenium, and the subsequent practice by farmers to drain excess shallow groundwater from the root zone to protect their crops results in elevated concentrations of selenium in groundwater and receiving rivers (McCarthy and Grober 2001).

For reference, the current AWQC-Fresh Water-Chronic for selenium in fresh water is 5.0 µg/L and is expressed as the total recoverable selenium in the water column. In the Grassland waterways and Salt Slough, a more protective chronic value of 2 µg/L applies, in consideration of sensitive listed species. The lentic conditions of water in the marshes were also a factor in setting these site-specific objectives. Available criteria, standards, and objectives for selenium are presented in Table 5.D.4-8.

Table 5.D.4-8. Applicable Federal Criteria, State Standards/Objectives, and Other Relevant Effect Thresholds for Selenium in Surface Water

	Region 5 Basin Plan[a]	Region 2 Basin Plan[b]	CTR[c]	Drinking Water MCL[d]	EPA Recommended Criteria[e]	Other Relevant Thresholds[f]
Selenium (μg/L)	5/12	5/20	5/20	50	5/variable	2

[a] Objectives apply to the lower San Joaquin River from the mouth of the Merced River to Vernalis as 5 μg/L (4-day average) and 12 μg/L (maximum concentration) total selenium concentration (Central Valley Regional Water Quality Control Board 2009).

[b] Selenium criteria were promulgated as total recoverable concentrations for all San Francisco Bay/Delta waters in the National Toxics Rule (NTR) (U.S. Environmental Protection Agency 1992; San Francisco Bay Regional Water Quality Control Board 2007).

[c] Standard is Criterion Continuous Concentration as 5 μg/L total recoverable selenium; California Toxics Rule (CTR) deferred to the NTR for San Francisco Bay/Delta waters and San Joaquin River (U.S. Environmental Protection Agency 2000).

[d] Maximum Contaminant Level. In addition, the Office of Environmental Health Hazard Assessment (2010) has recommended a Public Health Goal of 30 μg/L.

[e] Criteria for protection of freshwater aquatic life are 5 μg/L (continuous concentration, 4-day average) total recoverable selenium and they vary for the Criterion Maximum Concentration (CMC) (24-hour average) (U.S. Environmental Protection Agency 2012). The CMC = 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively.

[f] Concentration as total recoverable selenium identified as a Level of Concern for the Grassland Bypass Project (Beckon et al. 2008).

It should be noted that in addition to the adopted water quality objectives shown here, at the national level, EPA plans to propose Clean Water Act Section 304(a) selenium guidance criteria for aquatic life for freshwater chronic values only, and will distinguish between flowing and standing waters (U.S. Environmental Protection Agency 2011a). These guidance criteria will form the basis for adopting protective water quality standards expressed as tissue concentration of selenium in fish egg or ovary and a corresponding water column concentration, where tissue concentration data are not available. Concentrations in tissue, such as bird eggs or fish tissue, better indicate actual exposure and, in combination with foodweb information, provide a basis for deriving site-specific numeric water column values. The revised national guidance criteria will be supplemented by regional efforts. EPA Region 9, in conjunction with the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and National Marine Fisheries Service (NMFS) and pursuant to its obligations under the Endangered Species Act, is developing criteria to protect threatened and endangered wildlife species, aquatic-dependent species, and aquatic life in California. The first phase of this effort addresses San Francisco Bay and the Delta. It uses data on affected species and relies on the Presser-Luoma (2010) ecosystem-based model, a model that accounts for foodweb processes and site-specific conditions. This phase will be followed by a second phase for statewide criteria (including the San Joaquin River and its tributaries).

Selenium is highly bioaccumulative and can cause chronic toxicity (especially impaired reproduction) in fish and aquatic birds (Presser and Luoma 2010; Ohlendorf 2003; San Francisco Bay Regional Water Quality Control Board 2009). Developmental effects on fish from selenium are well-documented; locally, significant ecosystem effects were described in the early 1980s from water management practices that discharged groundwater containing selenium to the Kesterson Reservoir in the San Joaquin Valley, California. The fate and transport section below provides an overview of selenium sources in the Delta, and the biogeochemical processes that result in increased bioavailability of selenium in an aqueous system. The discussion focuses on the San Joaquin watershed and how selenium could be mobilized by covered activities.

The main controllable sources of selenium in the Bay-Delta estuary are agricultural drainage (generated by irrigation of seleniferous soils in the western side of the San Joaquin basin) and discharges from North Bay refineries (in processing selenium-rich crude oil). Both the San Joaquin River and North Bay selenium loads have declined in the last 15 years in response to, first, a control program in the San Joaquin Grassland area, and, second, National Pollutant Discharge Elimination System (NPDES) permit requirements established for refineries in the late 1990s. The annual loads of selenium (mostly as selenate) entering the Bay-Delta estuary from the San Joaquin and Sacramento Rivers vary by water year (that is, by flow), but dissolved selenium loadings averaged 2,380 kilograms per year (kg/year) from the San Joaquin and 1,630 kg/year from the Sacramento in the 1990–2007 period. The Sacramento River selenium concentration, however, is essentially at background levels (.06 +/-.02 μg/L), without evidence of significant controllable sources (U.S. Environmental Protection Agency 2011a).

The San Joaquin watershed, and specifically the Grassland section of the watershed, historically has been identified as a source of selenium to the Delta. However, mitigation measures have been put into place to manage selenium discharges to meet regulatory requirements. According to the *Grassland Bypass Project Report 2006–2007*, selenium loads already had been reduced by 75% in 2007 relative to 1996 levels (McGahan 2010:Chapter 2). Concentrations of selenium in Salt Slough reportedly met the monthly mean goal of 2 μg/L (U.S. Environmental Protection Agency 2011b). Selenium concentrations measured in the San Joaquin River were consistently below 5 μg/L (McGahan 2010:Chapter 2),). As selenium discharge from the Grassland Bypass Project continues to decrease as the 5 μg/L goal is approached, concentrations in the San Joaquin River also can be expected to decrease.

Under the Grassland Bypass Project, selenium discharges to Mud Slough (in the San Joaquin watershed) must be substantially reduced by December 31, 2019. Further, the Central Valley Regional Water Quality Control Board (2010b) recently approved an amendment to the basin plan in light of this project. The amendment requires that agricultural drainage be halted after December 31, 2019, unless water quality objectives are met in Mud Slough (north) and the San Joaquin River between Mud Slough (north) and the mouth of the Merced River. Also, if the State Water Resources Control Board (State Water Board) finds that timely and adequate mitigation is not being implemented, it can prohibit discharge any time before December 31, 2019. As a result, a substantial reduction in selenium inputs (unrelated to the BDCP) to the San Joaquin River by 2019 would be expected to result in lower selenium inputs to the Delta from the San Joaquin River.

Elevated selenium concentrations also have been identified in Suisun Bay. Although particulate concentrations of selenium (the most bioavailable) in this region are considered low, typically between 0.5 and 1.5 micrograms per gram (μg/g), the bivalve overbite clam (*Potamocorbula amurensis*) contains elevated levels of selenium that range from 5 to 20 μg/g (Stewart et al. 2004). Given the fact that *Potamocorbula* may occur in abundances of up to 50,000 per square meter, this area can be considered a sink for selenium because 95% of the biota in some areas are made up of this clam.

Selenium can occur in four oxidation stages as selenates (Se^{6+}), selenites (Se^{4+}), selenides (Se^{2-}), and elemental selenium. The oxidized state, selenates (Se^{6+}), is soluble and the predominant species in alkaline surface waters and oxidizing soil conditions. Selenates are readily reduced to selenites (Se^{4+}) and selenides (Se^{2-}), which are more bioavailable than selenate. Further reduction to elemental selenium can result in an insoluble precipitate, which is not bioavailable.

Although selenium is soluble in an oxidized state, the majority typically becomes reduced and partitions into the sediment/particulate phases in an aqueous system; these reduced sediment/particulate phases are the most bioavailable (Presser and Luoma 2010). Selenium in soils is taken up by plant roots and microbes and enters the food chain through uptake by lower organisms. A portion of the selenium also is recycled into sediments as biological detritus. Lemly and Smith (1987) indicate that up to 90% of the total selenium in an aquatic system may be in the upper few centimeters of sediment and overlying detritus (Lemly 1998).

Oxidized forms of selenium (selenates and selenites) may reduce further to precipitate as elemental selenium or complex with particulates. Selenate reduces to elemental selenium through dissimilatory reduction through reactions with bacteria. These reactions reduce selenium from surface waters, resulting in an increase in selenium concentrations in sediment over time. In wetlands in particular, the organic-rich stagnant waters create a chemically reducing environment in which dissolved selenate is able to convert to selenite or elemental selenium (Werner et al. 2008). The longer the residence time of surface waters, the higher the particulate concentration resulting in higher selenium concentrations in wetlands and shallows (Presser and Luoma 2006, 2010). Aquatic systems in shallow, slow-moving water with low flushing rates are thought to accumulate selenium most efficiently (Presser and Luoma 2006; Lemly 1998). However, the ratio of selenium in particulates (which is more bioavailable) to selenium in the water column is a complex relationship that can vary across different hydrologic regimes and seasons (Presser and Luoma 2010).

Because bioaccumulation can be an important component of selenium toxicity, water column selenium concentrations are not reliable indicators of risk to biota (Presser and Luoma 2010). Selenium enters the food chain at a low trophic level and, under certain conditions, is magnified up the food chain. Lower trophic organisms can bioaccumulate hundreds of times the waterborne concentration of selenium, especially where a food chain is based on sessile filter feeders. However, research has demonstrated that bioaccumulation is less important when the food chain is based on plankton rather than on sessile filter feeders, because plankton excrete most of the selenium they consume (Stewart et al. 2004). This is an important factor that mitigates bioaccumulation in some of the covered fish species, and is more fully discussed in later sections of this appendix.

5.D.4.2.2 Selenium—Effects of Covered Activities

Because the San Joaquin River historically has been a major contributor of selenium to the Delta system, there is concern that the increased contribution to the Delta from the San Joaquin River relative to the Sacramento River as a result of ESO operations would result in an increase in selenium transport and bioaccumulation in the Delta.

Quantitative modeling was performed to estimate the effects of ESO water operations on selenium in the aquatic system and on covered fish species. Modeling was based on DSM2 output that estimated changes in water flows under the preliminary proposed actions, and estimated selenium concentrations in source waters that discharge into the Delta. Results were considered in the context of a qualitative discussion to fully capture some of the factors that were not quantified.

The ESO represents a potential outcome of the decision tree as described in Chapter 3. There are potential variations on these outcomes related to other potential outcomes of the decision tree.

Review of CALSIM modeling and the conceptual models for contaminants described above indicates that the ESO likely captures the potential effect of contaminants from the BDCP.

5.D.4.2.2.1 Water Operations

Modeling Methods

Quantitative models were used to estimate the concentrations of selenium in the water column and expected resultant concentrations of selenium in fish tissue. Modeling methods for estimating selenium concentrations in water and in fish tissue are described in Attachment 5D.B, *Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets*, and Attachment 5D.C, *Addendum to Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets (Attachment 5D.B)*. The modeling is based on water and fish tissue sample data and DSM2 model results, and provides an analysis of the effects of ESO water operations on selenium concentrations.

The output from the DSM2 model (expressed as percent inflow from different sources) was used in combination with the available measured waterborne selenium concentrations to model concentrations of selenium at locations throughout the Delta; the sources of these data are provided in Table 5.D.4-9. These modeled waterborne selenium concentrations were used in the relationship model to estimate bioaccumulation of selenium in whole-body fish. Selenium concentrations in fish fillets then were estimated from those in whole-body fish.

Selenium concentrations in whole-body fish were calculated using ecosystem-scale models developed by Presser and Luoma (2010). The models were developed using biogeochemical and physiological factors from laboratory and field studies; information on loading, speciation, and transformation to particulate material; bioavailability; bioaccumulation in invertebrates; and trophic transfer to predators. Important components of the methods included (1) empirically determined environmental partitioning factors between water and particulate material that quantify the effects of dissolved speciation and phase transformation; (2) concentrations of selenium in living and nonliving particulates at the base of the foodweb that determine selenium bioavailability to invertebrates; and (3) selenium biodynamic foodweb transfer factors that quantify the physiological potential for bioaccumulation from particulate matter to consumer organisms and prey to their predators.

Bioaccumulation in two fish species was modeled. Largemouth bass was used as the example fish, primarily because it is the only species for which fish tissue data were available from representative locations throughout the Delta (including wet and dry years), so fish tissue and water data could be used to develop relationships between water and fish concentrations. Also, because largemouth bass is a voracious consumer, and a high-level consumer relative to the covered fish species, it will show effects of bioaccumulation, and is a reasonable surrogate for covered species such as salmon. The largemouth bass model approach is fully described in Attachment 5D.B. Because the greatest probability for selenium accumulation in fish was identified for benthic-feeding sturgeon in the west Delta (Suisun Bay), bioaccumulation in sturgeon at two west Delta location was also modeled; the modeling approach is fully described in Attachment 5D.C.

Table 5.D.4-9. Historical Selenium Concentrations in the Five Delta Source Waters for the Period 1996–2010

Source Water	Sacramento River[a]	San Joaquin River[b]	San Francisco Bay[a]	East Side Tributaries[c]	Agriculture in the Delta[a]
Mean (µg/L)[d]	0.32	0.84	0.09	0.1	0.11
Minimum (µg/L)	0.04	0.40	0.03	0.1	0.11
Maximum (µg/L)	1.00	2.80	0.45	0.1	0.11
75th percentile (µg/L)	1.00	1.20	0.11	0.1	0.11
99th percentile (µg/L)	1.00	2.60	0.41	0.1	0.11
Data Source	U.S. Geological Survey 2010	Surface Water Ambient Monitoring Program Website 2009	San Francisco Estuary Institute 2010	None	Lucas and Stewart 2007
Station(s)	Sacramento River at Freeport	San Joaquin River at Vernalis (Airport Way)	Central-West; San Joaquin River near Mallard Is. (BG30)	None	Mildred Island, Center
Date Range	1996–2001, 2007–2010	1999–2007	2000–2008	None	2000, 2003–2004
ND Replaced with RL	Yes	Yes	Yes	Not applicable	No
Data Omitted	None	Pending Data	None	Not applicable	No
No. of Data Points	62	453	11	None	1

Sources: U.S. Geological Survey 2010; Surface Water Ambient Monitoring Program 2009; San Francisco Estuary Institute 2010; Lucas and Stewart 2007.

[a] Dissolved selenium concentration.

[b] Not specified whether total or dissolved selenium.

[c] Dissolved selenium concentration in Mokelumne, Calaveras, and Cosumnes Rivers is assumed to be 0.1 µg/L because of lack of available data and lack of sources that would be expected to result in concentrations greater than 0.1 µg/L.

[d] Means are geometric means.

5.D.4.2.2.2 Modeling Results—Selenium

Selenium concentrations in the water column under future conditions with and without the BDCP are listed in Table 5.D.4-10 and Table 5.D.4-11. These tables also provide estimates for drought years only, when there is potential for greater effects. Generally, concentrations for the late long-term were slightly lower for the BDCP scenarios than for conditions without the BDCP (EBC2_LLT). The resultant water concentrations of selenium are an order of magnitude less than 2 µg/L, which is considered protective of fish species and is the lowest identified benchmark for selenium in water (see Table 5.D.4-10 and Table 5.D.4-11 in comparison to Table 5.D.4-9).

Table 5.D.4-10. Modeled Selenium Concentrations in Water for the Late Long-Term

Location	Period[b]	Modeled Concentrations[a] of Selenium (micrograms per liter)			
		EBC2_LLT	LOS_LLT	ESO_LLT	HOS_LLT
Mokelumne River (SF) at Staten Island	All	0.26	0.25	0.25	0.25
	Drought	0.29	0.28	0.28	0.28
San Joaquin River at Buckley Cove	All	0.69	0.74	0.74	0.74
	Drought	0.62	0.71	0.71	0.71
Franks Tract	All	0.36	0.40	0.41	0.41
	Drought	0.31	0.32	0.33	0.33
Old River at Rock Slough	All	0.39	0.42	0.44	0.45
	Drought	0.32	0.33	0.34	0.35
Sacramento River at Emmaton	All	0.32	0.32	0.33	0.33
	Drought	0.30	0.30	0.30	0.30
San Joaquin River at Antioch	All	0.31	0.33	0.34	0.34
	Drought	0.27	0.28	0.28	0.28
Sacramento River at Mallard Island	All	0.25	0.26	0.27	0.27
	Drought	0.21	0.21	0.22	0.22

[a] Results compared to lowest of relevant thresholds—Level of Concern for the Grassland Bypass Project = microgram(s) per liter (Beckon et al. 2008.) There are no exceedances.

[b] *All* (water years 1975–1991) represents the 16-year period modeled using DSM2. *Drought* represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Estimated selenium concentrations in largemouth bass and sturgeon tissues for the late long-term with and without the BDCP are presented below.

For largemouth bass (Table 5.D.4-11), selenium concentrations under the BDCP scenarios are generally comparable to those under future conditions without the BDCP (EBC2_LLT). None of the fish tissue concentrations exceeded the Advisory Tissue Level (Office of Environmental Health Hazard Assessment 2008) of 2.5 mg/kg, and most concentrations were an order of magnitude less than this level. Modeled selenium concentrations under all scenarios were below the level of concern commonly used for whole-body fish (lower-end range) (Beckon et al. 2008) of 4 mg/kg, except in the San Joaquin River at the Buckley Cove location. The concentration for whole-body fish at this location was 4.50 mg/kg for EBC2_LLT and between 5.12 and 5.14 mg/kg for the BDCP scenarios. If a lower benchmark is used, such as the 2 mg/kg benchmark suggested by USFWS (Beckon pers. comm.) for coldwater fish, there would be more exceedances of the benchmark under all scenarios (Table 5.D.4-11). It should be noted, however, that such a low benchmark would be approximately equivalent to the upper end of background concentrations for coldwater fish (U.S. Department of the Interior 1998).

Table 5.D.4-11. Modeled Selenium Concentrations in Fish Fillets and Whole-Body Fish for the Late Long-Term (milligrams per kilogram dry weight)

		Fish Fillets[b]				Whole Body			
Location	Period[a]	EBC2_ LLT	LOS_ LLT	ESO_ LLT	HOS_ LLT	EBC2_ LLT	LOS_ LLT	ESO_ LLT	HOS_ LLT
Mokelumne River (South Fork) at Staten Island	All	0.35	0.33	0.33	0.33	1.18	1.12	1.12	1.12
	Drought	0.7	0.68	0.68	0.68	2.07	2.01	2.01	2.01
San Joaquin River at Buckley Cove	All	1.11	1.2	1.2	1.2	3.1	3.32	3.32	3.33
	Drought	1.67	1.92	1.92	1.92	4.5	5.12	5.13	5.14
Franks Tract	All	0.52	0.6	0.6	0.61	1.6	1.77	1.82	1.84
	Drought	0.77	0.82	0.82	0.83	2.24	2.3	2.35	2.38
Old River at Rock Slough	All	0.57	0.66	0.66	0.68	1.74	1.89	1.96	2
	Drought	0.8	0.86	0.86	0.88	2.3	2.38	2.46	2.5
Sacramento River at Emmaton	All	0.45	0.46	0.46	0.46	1.42	1.45	1.46	1.46
	Drought	0.74	0.75	0.75	0.76	2.15	2.18	2.19	2.2
San Joaquin River at Antioch	All	0.44	0.49	0.49	0.49	1.39	1.49	1.52	1.53
	Drought	0.66	0.69	0.69	0.7	1.97	2	2.04	2.05
Sacramento River at Mallard Island	All	0.34	0.36	0.36	0.36	1.14	1.17	1.2	1.2
	Drought	0.49	0.51	0.51	0.51	1.54	1.54	1.57	1.57

[a] *All* (water years 1975–1991) represents the 16-year period modeled using DSM2. *Drought* represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

[b] Fish Fillet results compared to Advisory Tissue Level = 2.5 mg/kg. (Office of Environmental Health Hazard Assessment 2008.) Exceedances are shaded and in italics—there are no exceedances.

Results compared to level of concern for whole-body fish (lower end range) = 4 mg/kg. (Beckon et al. 2008).

Modeled selenium concentrations for sturgeon at two west Delta locations are presented in Table 5.D.4-12. At both locations and under all scenarios, concentrations are lowest during “all” conditions compared to “drought” conditions. For the San Joaquin River at Antioch, modeled selenium concentrations for sturgeon ranged from 12.3 mg/kg dry weight during “all” conditions to a high of 20.0 mg/kg dry weight during “drought” conditions. Of these, EBC2_LLT had the lowest selenium concentrations in whole-body sturgeon for both “all” and “drought” conditions. Similarly, for the Sacramento River at Mallard Island, EB2_LLT had the lowest concentrations (9.92 mg/kg dry weight for “all” conditions and 15.0 mg/kg dry weight for “drought” conditions). ESO_LLT and HOS_LLT had the highest concentrations, with 10.7 mg/kg dry weight for "all" conditions and 15.8 mg/kg dry weight for "drought" conditions.

Table 5.D.4-12. Modeled Annual Average Selenium Concentrations in Sturgeon—West Delta

		Modeled Concentrations of Selenium (milligrams per kilogram dry weight)			
Location	Period [a]	EBC2_LLT	LOS_LLT	ESO_LLT	HOS_LLT
San Joaquin River at Antioch	All	12.3	13.1	13.5	13.5
	Drought	19.3	20	20	20
Sacramento River at Mallard Island	All	9.92	10.3	10.7	10.7
	Drought	15	15	15.8	15.8

[a] *All* (water years 1975–1991) represents the 16-year period modeled using DSM2. *Drought* represents a 5 consecutive year (water years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Presser and Luoma (2013) present low and high benchmark values for whole-body fish tissue that they developed from the available toxicity data. The low benchmark is 5 mg/kg dry weight and the high value is 8 mg/kg dry weight. Modeled selenium concentrations in whole-body sturgeon exceeded these benchmarks under every scenario and for both "all" and "drought" conditions at both west Delta locations. However, as shown in Table 5.D.4-12, the differences among scenarios within location and water-year type ("all" or "drought") are relatively small, so the differences in their biological significance with respect to impacts on sturgeon from BDCP scenarios are likewise likely to be small. For example, the largest difference among scenarios (San Joaquin River at Antioch under "all" conditions) is just 1.2 mg/kg and the differences between LOS_LLT and EBC2_LLT are all less than 1 mg/kg.

Uncertainty Analysis

Although green sturgeon spend much of their lives in the ocean, coming into the estuary or rivers mainly to spawn, white sturgeon typically spend most of their lives in the estuary. However, they are known to move in response to salinity changes, and do migrate up the Sacramento River to spawn, and thus do not spend their entire lives in one localized area (Moyle 2002). Given that the modeled estimates of selenium bioaccumulation in sturgeon at the two westernmost Delta locations represent long-term, worst-case conditions for a fish spending most of its life in this vicinity, it is likely that actual selenium levels in sturgeon would be highly variable. This is due to the variety in prey concentrations experienced by a sturgeon that moves from one part of the estuary to another and up into the Sacramento River to spawn, the variety in diets between individuals, and the range in trophic transfer factors (0.6 to 1.7) of sturgeon from San Francisco Bay (Presser and Luoma 2013). The scenario modeled represents long-term, worst-case conditions.

Also, discharges of selenium to the Delta will continue to decrease in accordance with regulatory requirements , specifically for the North San Francisco Bay Refineries, and agricultural discharges in the San Joaquin Valley.

Given the variability of concentrations expected at the individual level, decreasing concentrations in source waters to the Delta and Suisun Bay expected as described above, and the uncertainties in the water concentration modeling and subsequent bioaccumulation modeling presented above, it is unlikely that the increases in whole-body selenium for sturgeon modeled would be measurable in the environment, and there is also uncertainty about the biological significance of these increases, given the uncertainty of the actual threshold for biological effects in sturgeon.

5.D.4.2.2.3 Changes in Proportion of San Joaquin Water in the Delta

Because the San Joaquin watershed historically has been a major source of selenium to the Delta, there is a concern that water operations, and specifically reduced flows in the Sacramento River, under the BDCP could result in an increased proportion of San Joaquin water in the Delta, and with it increased selenium concentrations. DSM2 modeling results for selenium concentrations in water under BDCP scenarios are presented in Attachment 5D.B, *Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets*. The following analysis is provided as additional information on potential changes in the proportion of San Joaquin River water inputs to the Delta.

DSM2 model results for the BDCP were used to track source water in the Delta. As discussed previously, the ESO scenarios are considered to generally represent BDCP flow conditions under the decision tree described in Chapter 3, Section 3.4.1.4.4, *Decision Trees*. Results showing the difference in annual average contribution from the San Joaquin River in the south Delta and Suisun Bay for years 1976 to 1991 are presented in Table 5.D.4-13. South Delta was chosen because of its proximity to the San Joaquin River. Suisun Bay was selected, because elevated levels of selenium have been detected, mainly in biota, in the area. However, the historical source of selenium to Suisun Bay is more likely oil refineries in North Bay where elevated selenium concentrations have been an issue, but are currently being mitigated through discharge restrictions (Presser and Luoma 2010). Thus, loading of selenium to the Plan Area has been, and continues to be, significantly reduced.

Table 5.D.4-13. Increase in Annual Average Percentage of San Joaquin River Contribution to Water Flow at South Delta and Suisun Bay under BDCP Conditions

	South Delta		Suisun Bay	
Year	EBC2_ELT to ESO_ELT	EBC2_LLT to ESO_LLT	EBC2_ELT to ESO_ELT	EBC2_LLT to ESO_LLT
1976	16	17	1	1
1977	3	4	0	0
1978	12	16	3	2
1979	10	16	2	1
1980	12	11	3	2
1981	11	14	1	1
1982	13	15	3	2
1983	21	17	8	6
1984	21	24	6	6
1985	13	15	1	1
1986	13	13	2	1
1987	13	15	1	1
1988	8	7	0	0
1989	5	7	0	0
1990	5	5	0	0
1991	4	1	0	0

The relative flow contribution to the south Delta flow from the San Joaquin River would increase under the BDCP relative to conditions without the BDCP in both the early and late long-term. The results presented in Table 5.D.4-13 show the largest increase in San Joaquin River relative inputs in 1984 when the ESO would result in a 24% increase in proportion of water in the south Delta coming from the San Joaquin River. This increase will not likely result in differences in contaminant concentrations given the low overall percentage of San Joaquin discharge relative to the Sacramento River; this was verified by modeling results presented above and in Table 5.D.4-10.

Covered activities will have little to no effect on the proportion of San Joaquin water that flows to Suisun Marsh. In Suisun Bay, the proportion of San Joaquin River water would increase by less than 10% for all years and would not increase at all in five of the 16 water years evaluated.

5.D.4.2.3 Restoration

In addition to the effects described above from BDCP water operations, selenium concentrations in water and covered fish tissues may be affected by mobilization of selenium in restoration areas. Because the bioavailability of selenium increases in an aquatic system, inundation of ROAs could mobilize selenium sequestered in sediments and increase exposure of covered fish species. The rate at which selenium will become mobilized as part of restoration will depend on the amount of selenium stored in the sediments, the length of inundation (residence time), and whether sufficient time allows the selenium to cycle through the aquatic system and into the food chain. Given that the San Joaquin River historically has delivered selenium to the Delta, the South Delta ROA has potential for mobilization of selenium.

Suisun Bay is also of concern. In this area, water concentrations are not as critical as the bioaccumulation of selenium by invasive clams (*Potamocorbula*), which are a food source for some benthic-feeding species. An increase of residence time in areas with dense clam populations and benthic-feeding covered fish species could result in increased selenium bioaccumulation in the food chain of benthic-feeding fish (i.e., sturgeon) in Suisun Bay. Residence time is directly related to outflow in Suisun Bay. CALSIM modeling results indicate that outflow and residence time in Suisun Bay will not change substantially under the BDCP. Comparison of the monthly mean residence time (averaged over years 1992 through 2003) indicates that residence time in Suisun Bay may change from a decrease of 13 days to an increase of 5 days.

In the long term, selenium inputs to the Delta should decrease as the proportion of cultivated lands decreases as a result of land use changes, including restoration to marsh habitat by the BDCP; selenium no longer would be concentrated by irrigation and leaching of these formerly farmed areas. This is especially true of the south Delta, where selenium in near-surface soils could be mobilized, but additional concentration from irrigation will cease. In contrast to the benefit of stopping application of pesticides to restored farmland, the benefit associated with selenium likely will be low, as selenium actually is leached out of the soils by agricultural use, not applied. Additionally, point sources of selenium in North San Francisco Bay (i.e., refineries) that contribute selenium to Suisun Bay are expected to be reduced through a TMDL under development by the San Francisco Bay Water Board\.

5.D.4.2.3.1 Selenium Summary

Quantitative modeling of selenium concentrations suggests that the BDCP water operations generally would have little to no substantial effect on selenium in water (Table 5.D.4-10) and fish tissues (Table 5.D.4-11 and Table 5.D.4-12). Estimation of possible fish tissue selenium concentrations in a representative species, largemouth bass, throughout the Delta indicated the only exceedances of commonly used benchmarks were at Buckley Cove on the San Joaquin River during drought conditions; benchmarks were exceeded under EBC2_LLT and BDCP scenarios. It is not surprising that the highest concentrations of selenium were estimated for the San Joaquin River, because this is the recognized primary source of selenium to the Delta. Future required reductions in selenium sources in the San Joaquin watershed should result in lower concentrations than those estimated by the model. If a lower benchmark is used, such as the 2 mg/kg whole-body fish suggested by USFWS (Beckon pers. comm.) for coldwater species, there would be more exceedances under all scenarios (Table 5.D.4-11). In only two instances, the lower benchmark was exceeded under the BDCP scenarios but not under EBC2_LLT: the San Joaquin at Antioch (EBC2_LLT was 1.97 mg/kg, and the BDCP scenarios were over 2 mg/kg) and the Old River at Rock Slough (EBC2_LLT was 1.74 mg/kg and HOS_LLT was 2 mg/kg). As noted above, however, such a low benchmark would be approximately equivalent to the upper end of background concentrations for coldwater fish (U.S. Department of the Interior 1998).

Based on the biogeochemistry and food chain–specific bioaccumulation patterns of selenium, a benthic-feeding sturgeon in the vicinity of Suisun Bay in the west Delta would have the most potential for bioaccumulation. Tissue concentrations for sturgeon in this area were also modeled. Results indicated higher concentrations for sturgeon than for largemouth bass, but showed little difference across modeled scenarios and between existing and BDCP water operations. As discussed in previous sections, given these results, along with the life history of the sturgeon and the continuing reduction of selenium loading to the Delta, and specifically the West Delta, substantial effects are not anticipated under the BDCP relative to existing conditions.

Source-water fingerprinting analysis indicates that preliminary proposed water operations will not result in a significant increased proportion of San Joaquin water at Suisun Bay. Proportions of San Joaquin water in the south Delta could increase by as much as 24%. Given the expected decrease in selenium contributions from the San Joaquin River and modeling results indicating that selenium concentrations will not exceed criteria in the south Delta, no effects on selenium concentrations as a result of ESO water operations are identified.

Selenium currently sequestered in soils could be mobilized and become more bioavailable as a result of inundation of restoration areas. Because the magnitude of this mobilization of selenium would depend on the type of food sources (filter feeders vs. plankton), significant changes in residence time, and pre-existing concentrations of selenium in the specific area, covered fish species effects would need to be determined on a site-specific basis. Given the decrease in loading of selenium to the Delta (from regulation of both Grasslands in the San Joaquin River basin and oil refineries near Suisun Bay) and that the selenium would be mobilized into the food chain under a narrow set of conditions, the overall effects within the Plan Area are likely low. The potential is highest for increased mobilization of selenium in and near the San Joaquin River and the South Delta ROAs, where selenium concentrations in soils are expected to be highest, and potentially in Suisun Bay where filter feeders are the food source for benthic-feeding covered fish species.

AMM27 Selenium Management (Appendix 3.C, *Avoidance and Mitigation Measures*) is intended to minimize the potential for increased bioavailability of selenium from restoration activities. AMM27 provides for site-specific evaluation of restoration sites for selenium mobilization potential, including development of site-specific assessment and monitoring plans and incorporation of design features to minimize selenium bioaccumulation, where necessary.

5.D.4.3 Copper

5.D.4.3.1 Copper—Location, Environmental Fate, and Transport

Copper (Cu) is a naturally occurring element that is present in water, air, and many soils in the environment. It is an essential trace element required by many plants and animals at low concentrations but can be toxic at elevated concentrations. In a nonaqueous environment, copper tends to adhere to soils and is relatively immobile. In an aqueous system, copper is considered one of the more mobile heavy metals. It partitions between sediment and particulates, and as particulates, it is taken up by low trophic levels or complexes with organics or inorganics in the water column. Typically it will occur in one of two oxidation states, cuprous ion (Cu^{1+}) or cupric ion (Cu^{2+}) (U.S. Environmental Protection Agency 2009b). Toxicity is much higher for the Cu^{2+} ion, than for the Cu^{1+} ion or the copper that is organically complexed (Buck et al. 2007; Sunda and Guillard 1976).

Although copper is not listed in the 303(d) list in the Delta, it is of concern mainly because of its widespread use in pesticides. In the Delta, anthropogenic sources of copper include pesticides/herbicides, mine drainage, brake pads, and anti-foulants (such as paint used on boat bottoms) (U.S. Environmental Protection Agency 2009b). Because agriculture is the dominant land use in the Delta, use of pesticides/herbicides is a dominant source of copper to the environment.

Mine drainage also has been a historical source of copper to the Delta. The Iron Mountain Mines Superfund Site, a former mine that released acid mine drainage to the Sacramento River upstream of Keswick Dam, has been a significant source of copper and other metal contamination. However, the

Superfund Site is undergoing remediation that has decreased discharge of copper into the rivers, and a TMDL has been implemented (Central Valley Regional Water Quality Control Board 2002). Following remediation, copper inputs from this mine should continue to decrease.

The current AWQC-Fresh Water-Chronic for copper in fresh water is derived on a site-specific basis requiring the input of 10 separate site-specific parameters to calculate the criteria—temperature, pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. Because these parameters vary depending on location, it is not possible to calculate a general AWQC-Fresh Water-Chronic for copper.

Overall, levels of copper in the Delta ecosystem do not appear to be significantly elevated. Copper concentrations in the Sacramento River have been reported to be consistently low, with some seasonal fluctuation (Connon et al. 2010). Based on collection of 549 water samples collected during critically dry, normal, and wet years from 15 Delta stations, metals concentrations did not exceed AWQC and did not show toxicity (Central Valley Regional Water Quality Control Board 1998).

Bruns et al. (1998) conducted water sampling between 1993 and 1995, compared both dissolved and total copper results against EPA AWQC and other criteria, and reported concentrations below criteria from almost all locations, including the Sacramento River. Because the criteria are dependent on sample-specific water quality measurements (including hardness), the criteria varied between sampling episodes. Significantly higher copper levels (at least an order of magnitude higher than all other results) that exceeded criteria were reported for Prospect Slough at the head of the Yolo Bypass.

In general, the copper data sets discussed above indicate low levels of copper (less than 2 μg/L) throughout the Delta waterways and elevated concentrations in agricultural drainage sloughs, and in tributaries at the head of the Yolo Bypass.

5.D.4.3.2 Copper—Effects of Covered Activities

5.D.4.3.2.1 Water Operations

ESO water operations will result in decreased flow in the Sacramento River under certain conditions. However, because copper concentrations are consistently low throughout the Sacramento River (less than 2 μg/L) and copper concentrations in the Sacramento River watershed have been tied to flow rates, appreciable impact on copper concentrations is not expected.

5.D.4.3.2.2 Restoration

Restoration of cultivated lands under the BDCP will have two outcomes relative to copper: copper contained in soils may become more bioavailable, and copper in pesticides that would have been applied to the cultivated land will be subtracted from the total Delta copper loads.

In general, the copper data sets discussed above indicate low levels of copper (less than 2 μg/L) throughout the Delta waterways, and elevated concentrations in agricultural drainage sloughs and near mines. Although data were not identified, it is assumed the agricultural soils will contain some level of copper given its affinity for soils in a terrestrial environment. A study of copper mobilization and bioavailability following multiple floodings of copper-enriched agricultural soils in the Everglades (Hoang et al. 2009) presents some relevant findings: (1) the amount of copper mobilized into the aquatic system depended on the concentrations in the soils, DOC, alkalinity, and soil characteristics; (2) copper concentrations in soils did not change much after multiple (four) floodings; (3) total dissolved copper in the water column did not decrease after several flooding events; and (4) the proportion of the more toxic cupric ion (Cu^{2+}) increased with the number of flooding episodes and decreasing DOC.

These findings suggest that formerly agricultural ROAs, which are likely to have elevated levels of copper in soils, will result in some level of increased copper in the aquatic system over an undetermined time period. Currently, information on the concentrations of copper in soils of specific ROAs is insufficient to estimate the increase in concentrations.

Restoration of cultivated land to marshes and floodplains will result in decreased application of copper-containing pesticides and decreased copper loading to the Delta. This net benefit at least partially will counter the copper introduced to the aquatic system through mobilization during inundation.

5.D.4.4 Ammonia/um

5.D.4.4.1 Ammonia/um—Location, Environmental Fate, and Transport

Ammonia is present in water in two forms: as un-ionized ammonia (NH^{3+}), also sometimes referred to as free ammonia, and as a positively charged ammonium ion (NH^{4+}). These two forms are collectively referred to as total ammonia or ammonia plus ammonium. Generally, environmental un-ionized ammonia is more toxic to fish, and ammonium is taken up by plants and algae as a nutrient and can drive algae blooms and growth of invasive species (Jabusch 2011).

The primary source of total ammonia in the Delta is effluent discharged from WWTPs, and the primary contributing treatment facility is the Sacramento Regional WWTP (Jassby 2008). The Sacramento plant is the source of the largest wastewater effluent discharge to the Delta (Jassby 2008), contributing an average of 141 million gallons per day (mgd) and accounting for 1 to 2% of the river water volume (Foe et al. 2010). The facility also has been the largest source of total ammonia discharge to the Delta, making up 90% of the Sacramento River ammonia load (Jassby 2008). The Stockton Regional Wastewater Control Facility historically had been an important source of the ammonia load to the Delta via the San Joaquin River. This is no longer the case, as the Stockton facility has upgraded its treatment systems in recent years to include technology to remove ammonia and ammonium from effluent before discharge to the river (City of Stockton 2011).

For ammonia, there is a current EPA AWQC dated 1999, and an updated draft AWQC dated 2009 that has not yet been finalized (Table 5.D.4-14). Both the current (1999) and draft (U.S. Environmental Protection Agency 2009a) AWQC for total ammonia as nitrogen are dependent on site-specific temperature and pH. The draft AWQC is also dependent on the presence or absence of unionid mussels. AWQC for ammonia (total as N) for both the current criteria and the draft criteria are listed in Table 5.D.4-14. For ease of comparison, only AWQC at a temperature of 25°C and pH of 8 are listed.

Table 5.D.4-14. Ambient Water Quality Criteria for Ammonia

	Draft 2009 Ammonia Criteria (at pH 8 and 25°C)	Current 1999 Ammonia Criteria (at pH 8 and 25°C)
Acute	2.9 mg N/L mussels present	5.6 mg N/L salmon present
	5.0 mg N/L mussels absent	
Chronic	0.26 mg N/L mussels present	1.2 mg N/L fish early life stages present
	1.8 mg N/L mussels absent	

Source: <http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/pollutants/ammonia/factsheet2.cfm>.

Some studies have indicated ecosystem effects of ammonium at low concentrations below the AWQC levels. A recent study indicated that biota can be affected at concentrations as low as 0.38 mg/L of total ammonia nitrogen, based on a study of Delta copepods by Teh et al. (2011). Ammonium loading from WWTPs may inhibit primary productivity (Wilkerson et al. 2006; Dugdale et al. 2007; Glibert et al. 2011; Parker et al. 2012). A shift in algal species structure also has been linked to an excess of ammonium in a system (Baxter et al. 2010; Glibert 2010). Research is ongoing to better understand the potential ecosystem effects of ammonium and the levels at which these occur (Baxter et al. 2010).

However, discharges of ammonium to the Delta from WWTPs have been, and continue to be, significantly reduced. As described in Chapter 4, the Sacramento Regional WWTP upgrades are expected to reduce ammonia/um loading into the Sacramento River. While this is not a result of BDCP, it is a related regional action that has the potential to affect the outcome of BDCP effects on covered fish species. In this case, reduced ammonia/um loading from Sacramento Regional WWTP would further reduce the potential for the BDCP to result in increased transport or accumulation in the Plan Area.

The current NPDES permit (Central Valley Regional Water Quality Control Board 2010a) for the Sacramento WWTP contains both new and interim standards for ammonia. The current NPDES permit also prohibits discharge to the Sacramento River when there is less than a 14:1 (river:effluent) flow ratio over a rolling 1-hour period in the Sacramento River. In addition, to comply with new standards (Table 5.D.4-15), the Sacramento plant will need to install new systems to reduce ammonia concentrations in effluent. The deadline for compliance with new effluent limits has been extended through a court ordered stay until May 2021, or once the new systems are in place, whichever occurs first. The State Water Board upheld the permit conditions upon appeal by the Sacramento Regional Sanitation District. The Sanitation District is now appealing the permit conditions to the California Superior Court.

Table 5.D.4-15. Sacramento Wastewater Treatment Facility Effluent—National Pollution Discharge Elimination System Permit Limits

	Units	Sacramento Effective 2010 (Interim) Average Monthly	Sacramento Effective 2020 (New) Average Monthly
Ammonia, total as N	mg/L	33	1.5 (April to October) 2.4 (November to March)
	lb	49,400	2,720
Design flow	mgd	181	181

Source: California State Water Resources Board 2012; Central Valley Regional Water Quality Control Board 2010a.

The Sacramento Regional County Sanitation District (2011) reported the following ammonia concentrations in effluent from the Sacramento WWTP for the Year 2010: average 24 mg/L (parts per million [ppm]); minimum 19 mg/L; and maximum 39 mg/L. Along with influent and effluent testing, the new 2010 NPDES permit requires that the Sacramento River (effluent-receiving water) be tested for ammonia, along with other parameters.

Ammonia concentrations in the Sacramento River were evaluated by researchers during a monitoring program conducted in 2009 and 2010 (Foe et al. 2010). Water samples were collected on a monthly basis from 21 locations throughout the Delta, with a focus on tracking concentrations of ammonia downstream of the Sacramento WWTP. None of the ammonia data collected for 344 samples over 1 year exceeded the EPA chronic criterion for early life stages of fish present in the Delta (Foe et al. 2010). Results of this study indicated elevated ammonia levels immediately downstream of the Sacramento WWTP; results are presented below.

- Ammonia concentrations were higher downstream (highest average 0.46 mg/L) of the Sacramento WWTP than upstream (average 0.04 mg/L).
- The highest ammonia concentrations were detected at Hood, 7 miles downstream of the WWTP.
- Downstream of Hood, total ammonia concentrations dropped continuously to an average of 0.08 mg/L at Threemile Slough, 20 miles downstream of the WWTP.

5.D.4.4.2 Ammonia/um—Effects of Covered Activities

5.D.4.4.2.1 Water Operations

Given the possible link established between ammonia from WWTPs and the POD (Dugdale et al. 2007; Wilkerson et al. 2006; Glibert 2010; Glibert et al. 2011), decreased dilution capacity of the Sacramento River and potential resultant increases in ammonia concentrations are of concern. Recent data (Foe et al. 2010) indicate that concentrations of ammonia downstream of the WWTP outfall do not currently exceed EPA AWQC. These conditions are maintained with a current allowed ammonia concentration in WWTP effluent of 33 mg/L (and measured maximum concentration of 39 mg/L). By 2021, effluent must be below 1.5 and 2.4 mg/L ammonia on a seasonal basis, an 18-fold decrease in ammonia concentrations. It would take a similar decrease in Sacramento River flows to achieve the current conditions, and few to no effects are expected from covered activities on ammonia/um. This conclusion is supported by the following quantitative analysis.

To evaluate resultant ammonia concentrations in the Sacramento River, the average reported concentration of ammonia in Sacramento WWTP effluent (24 mg/L) was used to calculate the Sacramento River flow required to meet AWQC. As shown in Table 5.D.4-16, the minimum flow in the Sacramento River needed to dilute effluent and meet the current AWQC of 1.2 mg/L in the Sacramento River would be 5,794 cubic feet per second (cfs).

Table 5.D.4-16. Sacramento River Flow Required to Dilute Sacramento Wastewater Treatment Plant Effluent

Average Effluent Ammonia Concentration	24 mg/L
Design flow	181 million gallons per day (mgd) (7,930.087 L/sec)
Ammonia load	190,322.1 mg/sec
River—Threshold not to exceed	1.2 mg/L
River—Upstream concentration	0.04 mg/L
River—Threshold not to exceed	1.16 mg/L
Threshold flow to exceed (river)	164,070.8 L/sec (5,794 cfs)

The CALSIM model output was analyzed to evaluate the percentage of time the minimum flow rate of 5,794 cfs would not be met relative to baseline case conditions over the 82-year model run period. This threshold represents the flows where the Sacramento River flows at Freeport would fall below the required flow to dilute effluent. Results are presented in Table 5.D.4-17 and Table 5.D.4-18. Table 5.D.4-17 shows the difference between two baseline conditions (EBC1 and EBC2) and the high-outflow scenario (HOS). Table 5.D.4-18 shows the difference between two baseline conditions (EBC1 and EBC2) and the low-outflow scenario (LOS).

Generally, the effects of HOS and LOS over the 82-year model run would be a decrease or roughly the same percentage of time that lows in the Sacramento River at Freeport that would be insufficient to meet AWQC for ammonia. However, under both HOS and LOS, November would experience more instances of flows that would be insufficient. The scenario is conservative in that Sacramento Regional County Sanitation is under order to significantly decrease concentrations in ammonia in Sacramento WWTP effluent. Comparison with AWQC, although it is an accepted standard, may be less conservative, as recent research has shown inhibition of lower trophic levels and negative impacts on the ecosystem from ammonia at concentrations an order of magnitude lower than the AWQC.

In conclusion, changes in dilution capacity of the Sacramento River under the BDCP would result from changes in upstream reservoir operations and are not expected to be significant. Diversion of water to the Yolo Bypass is not expected to affect dilution capacity, as this will occur only during high river flows. The north Delta intake would be downstream of Freeport and will not affect dilution of Sacramento WWTP discharges.

Table 5.D.4-17. Percent Increase in the Number of Months That BDCP HOS Flows Are below Threshold (5,794 cfs) for Adequate Dilution of Sacramento WWTP Effluent to <1.2 mg/L Ammonia

	Increase over EBC1		Increase over EBC2		Increase over EBC2_ELT	Increase over EBC2_LLT
Month	HOS_ELT	HOS_LLT	HOS_ELT	HOS_LLT	HOS_ELT	HOS_LLT
January	0%	1%	-2%	-1%	-1%	0%
February	0%	0%	0%	0%	0%	0%
March	-1%	1%	0%	2%	-1%	0%
April	-1%	0%	-2%	-1%	-1%	0%
May	-6%	-6%	0%	0%	-2%	-4%
June	0%	2%	1%	4%	2%	0%
July	-6%	-5%	-5%	-4%	-5%	-4%
August	-5%	-9%	-1%	-5%	-1%	-4%
September	-24%	-15%	-20%	-10%	-12%	5%
October	6%	6%	17%	17%	22%	5%
November	-11%	-7%	-6%	-2%	-6%	1%
December	-2%	-6%	-1%	-5%	0%	0%

Table 5.D.4-18. Percent Increase in the Number of Months That BDCP LOS Flows Are below Threshold (5,794 cfs) for Adequate Dilution of Sacramento WWTP Effluent to <1.2 mg/L Ammonia

	Increase over EBC1		Increase over EBC2		Increase over EBC2_ELT	Increase over EBC2_LLT
Month	LOS_ELT	LOS_LLT	LOS_ELT	LOS_LLT	LOS_ELT	LOS_LLT
January	0%	1%	-2%	-1%	-1%	0%
February	0%	0%	0%	0%	0%	0%
March	0%	0%	1%	1%	0%	-1%
April	2%	0%	1%	-1%	2%	0%
May	-1%	-4%	5%	2%	2%	-1%
June	0%	2%	1%	4%	2%	0%
July	-5%	-2%	-4%	-1%	-4%	-1%
August	-7%	-6%	-4%	-2%	-4%	-1%
September	-10%	-11%	-5%	-6%	2%	9%
October	2%	7%	13%	18%	18%	6%
November	-7%	-12%	-2%	-7%	-2%	-4%
December	1%	-2%	2%	-1%	4%	4%

5.D.4.4.2.2 Restoration

Restoration conservation measures are not expected to significantly affect distribution or levels of ammonia/um in the Delta. Nitrogen is associated with fertilizers, which are used heavily throughout the Delta. However, WWTPs have been identified as the primary sources of ammonia, contributing

90% of the ammonia load to the Sacramento River. Thus, restoration of cultivated lands to marsh and floodplain is not expected to significantly affect ammonia concentrations.

5.D.4.5 Pyrethroids

5.D.4.5.1 Pyrethroids—Location, Environmental Fate, and Transport

Pyrethroids are a group of synthetic chemicals currently used as insecticides in urban and agricultural areas. More than 1,000 synthetic pyrethroids have been developed (Agency for Toxic Substances and Disease Registry 2003), but only 25 are registered for use in California (Spurlock and Lee 2008). Pyrethroids are powerful neurotoxins, have immunosuppressive effects, and can inhibit essential enzymes such as ATPases (Werner and Orem 2008). Pyrethroids can cause acute toxicity at concentrations as low as 1 µg/L in fish (Werner and Orem 2008), and at lower levels between 2 and 5 ng/L (0.002 and 0.005 µg/L) in invertebrates. When various types of pyrethroid compounds are present together in an aqueous environment, the toxicity can be additive with increased toxic effects (Weston and Lydy 2010).

Overall pyrethroid use in the Delta has nearly quadrupled from 1990 to 2006 from approximately 27,000 kilograms per year (kg/yr) to more than 101,000 kg/yr in 2006 (Bureau of Reclamation 2008) with five pyrethroids (lambda-cyhalothrin, permethrin, esfenvalerate, cypermethrin, and cyfluthrin) among the top agricultural insecticides in California (by acres treated) (Werner and Orem 2008). Pyrethroids are found in agricultural runoff, urban stormwater runoff, and in public WWTP effluent.

Significant sources of pyrethroids coming into the Delta from cultivated land include summer irrigation return flows from treated areas, winter stormwater runoff from orchards as a result of the common practice of applying pyrethroids during the winter season, and draining of excess surface water from rice fields during cultivation (Oros and Werner 2005). In addition to agricultural sources, recent studies have shown that WWTPs and urban runoff are important sources of pyrethroids to the Delta system (Weston and Lydy 2010). Pyrethroids have been detected at concentrations lethal to amphipods in urban runoff and effluent from the Stockton, Vacaville, and Sacramento WWTPs (Weston and Lydy 2010). However, receiving waters (San Joaquin River, American River, and Sacramento River) had fewer detections of pyrethroids at sublethal concentrations. Concentrations were higher in Vacaville creeks receiving effluent.

Pyrethroids have low water solubility; they do not readily volatilize and have a tendency to bond to particulates, settle out into the sediment, and not be transported far from the source. Once pyrethroids enter the Delta, they are easily adsorbed to suspended particles, organic material, soil, and sediments (Oros and Werner 2005). Because of the low-solubility nature of pyrethroids, it is estimated that 94% of pyrethroids used in the Central Valley remain at the application site and almost 6% (approximately 5.89%) degrade, with half-life (the average time it takes for the concentration of the chemical to be reduced by one half) ranging from days to months, leaving only 0.11% ultimately available for transport through the Delta (Werner and Orem 2008). Seventy sediment samples were collected from agricultural drainage–dominated irrigation canals that run through 10 Central Valley counties. Analysis showed pyrethroids in 75% of the samples (Weston et al. 2004). However, pyrethroids were not often detected in agricultural drainage waters, demonstrating their strong affinity to sediments (Weston and Lydy 2010).

Because pyrethroids have a very strong affinity for particulates, benthic organisms may be exposed to pyrethroids in sediment, and pelagic species could be exposed to pyrethroids adsorbed to particulates in the water column. Because pyrethroids are lipophilic, they have a tendency to bioaccumulate through the food chain (Werner and Orem 2008).

Breakdown of pyrethroids can occur through both chemical and biological processes and can take from days to months depending on a number of factors (Werner and Orem 2008). Half-lives and toxicity of pyrethroids are influenced by temperature and pH. At an alkaline pH, some pyrethroids can degrade through hydrolysis; however, most are stable at the relatively neutral pH of Delta waters (Werner and Oram 2008).

Many pyrethroids also are susceptible to degradation by sunlight, called photodegradation. The half-life of different pyrethroids in water varies greatly with differences in their susceptibility to sunlight, from 0.67 day for cyfluthrin to 600 days for fenpropathrin (Werner and Oram 2008). High turbidity and the presence of plants can reduce ultraviolet-light penetration and increase pyrethroid half-life, allowing increased residence times and the potential for greater adsorption to sediment.

5.D.4.5.2 Pyrethroids—Effects of Covered Activities

5.D.4.5.2.1 Water Operations

As discussed above for ammonia, ESO water operations will result in reductions in Sacramento River flow at Freeport under certain conditions, mainly due to upstream reservoir operations. This reduction in flow could limit the dilution of Sacramento WWTP effluent and urban runoff, resulting in increased pyrethroid concentrations affecting covered fish species. In their study of pyrethroids in urban runoff, WWTPs, and receiving waters, Weston and Lydy (2010) reported few to no detections or toxicity to amphipods in Sacramento River water downstream of the Sacramento WWTP.

Weston and Lydy (2010) estimated loading from the Sacramento WWTP at 9g/day in the dry season and 13 g/day in the wet season. These estimates were based on median detected levels of total pyrethroids in effluent from three dry-weather (18.2 ng/L) and three wet-weather (14.2 ng/L) sampling events. Using a 13 g/day pyrethroid load and the lowest flow rate in the Sacramento River at Freeport in an 82-year period, estimated by the CALSIM at 4,901 cfs, the resultant concentration of pyrethroids in the Sacramento River is 7.50582 E^{-07} ng/L. This is consistent with Weston and Lydy's (2010) results that showed little to no detection of pyrethroids in the Sacramento River (Table 5.D.4-19). Based on this analysis, the ESO water operations will have no effects on pyrethroids.

Table 5.D.4-19. Estimation of Resultant Pyrethroid Concentrations in Water under ESO Low-Flow Conditions in the Sacramento River

Pyrethroid Loading from Sacramento WWTP (Weston and Lydy 2010)	9 g/day	= 0.000104167 g/s	= 0.104167 ng/s
Minimum Flow over 82 years with ESO	4901 cfs	= 144,698.9497 L/sec	
Resultant Concentration	7.50582E^{-07} ng/L	Pyrethroids in the Sacramento River	

5.D.4.5.2.2 Restoration

As discussed above, pyrethroids have been applied widely to cultivated lands across the Delta; they tend to stay sequestered in soils and therefore will be present in ROA soils. Pyrethroids have a strong affinity for particulates, and would enter the water column as suspended particulates that likely would settle out over time. The lack of pyrethroids in surface water samples where they are present in sediments (Weston et al. 2004; Weston and Lydy 2010) demonstrates the strong propensity for pyrethroids to remain in sediment. During inundation of restoration areas, pyrethroids could be mobilized in the food chain via uptake by benthic organisms or uptake of particulates by pelagic organisms.

Current information does not allow estimation of resultant pyrethroid mobilization due to BDCP restoration. Concentrations of pyrethroids in ROA sediments and additional research on mobilization and uptake into the food chain would be required. Given their affinity for soils, pyrethroids are not expected to spread far from the source area, and any suspension into the water column should be localized.

5.D.4.5.2.3 Urban Stormwater Treatment (CM19)

Pyrethroid chemicals are used as pesticides in urban areas for pest control, and stormwater runoff has become an important source of pyrethroids in the Delta system. The purpose of *CM19 Urban Stormwater Treatment* is to provide treatment for stormwater to reduce input of contaminants. Thus, CM19 will result in decreased loading of pyrethroids to the Delta, although the level of this decrease cannot be defined at this time.

5.D.4.6 Organochlorine Pesticides

5.D.4.6.1 Organochlorine Pesticides—Environmental Fate and Transport

Organochlorine pesticides, specifically DDT, chlordane, and dieldrin, are legacy pesticides that are no longer in use but persist in the environment (Werner et al. 2008). These pesticides came into use from the late 1930s to the late 1940s and were phased out for general use in the 1970s; however, both chlordane and dieldrin remained in use until the late 1980s for termite control (Connor et al. 2007). These pesticides are widespread throughout the Sacramento and San Joaquin River watersheds and the Delta from widespread agricultural use (Connor et al. 2007).

Organochlorine pesticides have a very low solubility in water and are very persistent in the environment. DDT will degrade to dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethene (DDE), but these toxic by-products have very long half-lives. The Central Valley Water Board Agricultural Waiver Program recently reported detections of DDT and other organochlorine pesticides in Delta agricultural ditches and drainage channels (Werner et al. 2008). Because they do not dissolve in water, organochlorine pesticides enter the food chain in particulate form, mainly through uptake by benthic fauna. They are strongly lipophilic and biomagnify through the food chain, resulting in high concentrations in high trophic levels.

The current AWQC-Fresh Water-Chronic for the organochlorine pesticides of concern in the Delta—DDT, chlordane, and dieldrin—are 0.001, 0.0043, and 0.056 µg/L, respectively. It should be noted, however, that the EPA anticipates future revisions to the criteria.

The highest concentrations in sediments and the greatest loading of organochlorine pesticides are thought to come from the western tributaries of the San Joaquin River, and high concentrations have been reported in San Joaquin River sediments (Gilliom and Clifton 1990 in Domagalski 1998). However, total concentrations in the water column were low, consistent with the strong affinity of organochlorine pesticides for sediments. Domagalski (1998) reported low concentrations in the water column in the San Joaquin River basin, and noted that the organochlorine pesticides were highest in tributary sediments and appeared to be mobilized by storms and rainfall. A study involving collection and analysis of 70 sediment samples over 10 counties in the Central Valley showed that organochlorine pesticides continue to be present in sediments, and at high concentrations, especially in agricultural drainage canals (Weston et al. 2004). This study found DDT in almost all samples collected, with a median concentration of 6.9 ug/kg, and a maximum concentration of 408 ug/kg in a drainage canal. DDE and other organochlorine pesticides also were detected at high levels in other drainage canal sediments.

5.D.4.6.2 Organochlorine Pesticides—Effects of Covered Activities

5.D.4.6.2.1 Water Operations

ESO water operations are not likely to result in mobilization of organochlorine pesticides. In the San Joaquin watershed, where concentrations are highest, these chemicals are found primarily in sediments in tributaries draining agricultural areas, and are present at low concentrations in the water column. ESO water operations would not result in increased flows in the tributaries that would mobilize organochlorine pesticides in sediments. No changes in the concentrations of organochlorine pesticides transported into the Delta by the San Joaquin River are anticipated.

Because organochlorine pesticides adhere to soils, mobilization would have to be facilitated by erosion of contaminated soils. As significant increases in flow velocity are not expected under the ESO, organochlorine pesticides are not expected to be mobilized. Thus, no effects on organochlorine pesticide distribution are expected under the ESO water operations.

5.D.4.6.2.2 Restoration

Organochlorine pesticides likely will be sequestered in the formerly agricultural soils in ROAs. The highest concentrations will be in the ditches, creeks, and drains that received agricultural discharges. Because these chemicals tend to bind to particulates, concentrations are typically highest in sediment. Flooding of formerly cultivated land is expected to result in some level of accessibility to biota through uptake by benthic organisms. Significant increases in organochlorine pesticides are not expected in the water column because these chemicals strongly partition to sediments. Exposures to the foodweb will be through intake by benthic fauna and to a lesser extent, through particulates in the water column to pelagic organisms.

Also, concentrations in the water column should be relatively short-lived because these pesticides settle out of the water column in low-velocity flow. If eroded and transported from an ROA, it is likely that the pesticides would not be transported very far from the source area and would settle out and be deposited close to the ROA.

5.D.4.7 Organophosphate Pesticides

5.D.4.7.1 Organophosphate Pesticides—Environmental Fate and Transport

Organophosphate pesticides (organophosphates) are human-made chemicals that are used for pest control in both urban and agricultural environments. Sources of diazinon and chlorpyrifos in the Delta are predominantly agricultural as the sale of these compounds for most nonagricultural uses has been banned in recent years. In the Delta, diazinon is applied to crops during the dormant season (December–February) and irrigation or growing season (March–November) fairly equally (52% and 48%, respectively), while the majority of chlorpyrifos (97%) is applied to Delta crops during irrigation season (McClure et al. 2006).

Diazinon and chlorpyrifos have slightly different chemical properties that affect the way they behave in aquatic environments. Diazinon is fairly soluble and mobile and will bind only weakly to soil and sediment. Chlorpyrifos is less soluble than diazinon and less mobile because of its tendency to bind much more strongly to soil and sediment. Consequently, diazinon enters the Delta dissolved in runoff, while chlorpyrifos enters the Delta adsorbed to soil particles (McClure et al. 2006). Unlike organochlorine pesticides, organophosphates do not tend to bioaccumulate, as they are readily metabolized by most organisms. For example, diazinon in fish will be approximately 96% removed in just 7 days (McClure et al. 2006).

Surface water data indicate that concentrations are high for both diazinon and chlorpyrifos in back sloughs and small upland drainages, and concentrations are lower in both the main channels and main inputs to the Delta. High concentrations of chlorpyrifos also are found in Delta island drains, but concentrations of diazinon remain low in the same drains (McClure et al. 2006). In the past, elevated concentrations of diazinon and chlorpyrifos have been detected in the Sacramento and San Joaquin Rivers and in the Delta during particularly wet springs and after winter storm events (McClure et al. 2006). This could suggest that increased flow with accompanying increased suspended loads will result in increased mobilization of both diazinon and chlorpyrifos. Alternatively, the elevated concentrations may be attributable to irrigation or stormwater runoff from late winter/early spring dormant season spraying of orchard crops.

In the 2006 Staff Report for the amendments to the Basin Plan for diazinon and chlorpyrifos, updated water quality objectives developed by California Department of Fish and Game for diazinon and chlorpyrifos were compared to a broad sample set (McClure et al. 2006). Authors summarize surface water data for diazinon from 1991 to 2005, and chlorpyrifos from 1988 to 2005, from a number of previous sampling programs and studies and compared results to the updated water quality objectives of 160 and 25 ng/L for diazinon and chlorpyrifos, respectively. For context, the current AWQC-Fresh Water-Chronic for diazinon is 170 ng/L (0.17 µg/L). There is no AWQC-Fresh Water-Chronic for chlorpyrifos.

Locations where diazinon exceeded 160 ng/L in more than 10% of samples included Mosher Slough, San Joaquin River near Stockton, Stockton Diverting Channel, and French Camp Slough. Likewise chlorpyrifos results showed more than 10% of samples collected at these locations exceeded 25 ng/L, including Ulatis Creek, Mosher Slough, Middle Roberts Island Drain, French Camp Slough, Paradise Cut, and Stockton Diverting Channel.

5.D.4.7.2 Organophosphate Pesticides—Effects of Covered Activities

5.D.4.7.2.1 Water Operations

Diazinon and chlorpyrifos concentrations are highest in the back sloughs and agricultural drains that receive agricultural drainage. ESO water operations are not likely to have much effect on transport of these chemicals from the back areas; transport of the pesticides from these areas would be determined mostly by rains that would flush out the areas. When flushed during wet seasons, the Sacramento River would maintain the capacity to dilute the influx. As discussed in Section 5D.5.4 (*Ammonia/um*), reduced flows would occur during dry periods in the Sacramento River, when the back tributaries would not be flushing out. In general, ESO water operations are not expected to affect organophosphate concentrations in the Delta.

5.D.4.7.2.2 Restoration

Organophosphate pesticides are likely present in ROA soils that would be inundated under covered activities. Because the solubility, tendency to adhere to soils and particulates, and degradation rates for these compounds vary, it is difficult to estimate the extent to which inundation would cause the contaminants to be mobilized and more bioavailable in the aquatic system. Also, because organophosphate pesticides are metabolized by fish and do not bioaccumulate, effects on covered fish species would be limited, depending on the life stage.

5.D.4.8 Herbicides Associated with Conservation Measure 13 Invasive Aquatic Vegetation Control

CM13 Invasive Aquatic Vegetation Control would involve applying existing methods used by the California Department of Boating and Waterways' (DBW's) Egeria Densa Control Program and Water Hyacinth Control Program. Following is a brief summary of the types of herbicides used and the known toxic effects (Table 5.D.4-20). Additional information on the potential effects of these herbicides is included in Appendix 5.F, *Biological Stressors on Covered Fish*.

DBW uses five common herbicides—Weedar 64® (2,4-D), Rodeo® (glyphosate), R-11® (NP & NPE), Sonar® (fluridone), and Reward® (diquat). Riley and Finlayson (2004) depict the detected concentrations in the environment and the lethal concentration, 50% (LC50) values (mg/L) for larval delta smelt, fathead minnow, and Sacramento splittail.

Table 5.D.4-20. Summary of Toxicity Testing for Invasive Species Herbicides

Herbicides and Surfactant	Highest Detected Concentration (mg/L)	Delta Smelt LC50 (mg/L)	Fathead Minnow LC50 (mg/L)	Sacramento Splittail LC50 (mg/L)
Weedar 64® (2,4-D)	0.260	149	216	446
Rodeo® (glyphosate)	0.037	270	1,154	1,132
R-11® (NP & NPE)	0.167	0.7	1.1	3.9
Sonar® (fluridone)	0.012	6.1	5.7	4.8
Reward® (diquat)	0.110	1.1	0.43	3.7
mg/L= milligrams per liter; LC50 = lethal concentration, 50%.				

Rodeo®, Weedar 64®, and Sonar® 96-h LC50 values for the three fish species are several orders of magnitude higher than detected concentrations in the environment and would not be expected to cause lethal or sublethal effects in larval fish (Riley and Finlayson 2004). However, the LC50 values for Reward®, and R-11® are lower and approach the levels found in the environment (Riley and Finlayson 2004). Detected concentrations listed in Table 5.D.4-20 were reduced to background levels within 24 hours of application (Anderson pers. comm. in Riley and Finlayson 2004). R-11® is a surfactant used with both Rodeo® and Weedar 64®. R-11 was virtually undetected in the environment and can be controlled by careful application on plant surfaces only (Riley and Finlayson 2004). In conclusion, it is unlikely that acute toxicity would occur with the application of herbicides. Exposure levels are less than acute toxic levels, and the chemicals have short lives in the environment. Sonar® should be examined more closely because of its longer persistence in the environment and application procedures that require repeated treatments in the same area (Riley and Finlayson 2004).

5.D.4.9 Endocrine Disruptors—Environmental Fate and Transport

EDCs can interfere with the hormonal system in fish at extremely low (ng/L) concentrations, resulting in negative effects on reproduction and development (Bennett et al. 2008; Riordan and Biales 2008; Lavado et al. 2009). Implications for Delta fish communities include changes in population distributions (e.g., changes in sex ratios that may affect population dynamics) that may be contributing to the POD (Brander and Cherr 2010).

Major sources of EDCs in the Central Valley are thought to be pyrethroid pesticides from urban runoff (Oros and Werner 2005; Weston and Lydy 2010), WWTPs (Routledge et al. 1998), and rangelands (Kolodziej and Sedlak 2007). EDCs also include steroid hormones (such as ethinylestradiol, 17β-estradiol, and estrone), plant constituents, plasticizers, and other industrial by-products. Pyrethroids have been documented to pass through secondary treatment systems at municipal WWTPs at concentrations that are toxic to aquatic life, and still may be present in detectable concentrations following tertiary treatment (Weston and Lydy 2010). Runoff from manure-treated fields and rangelands where livestock have direct access to surface waters can result in introduction of excreted endogenous steroid hormones, including estrogens, androgens, and progestins (Kolodziej and Sedlak 2007). Cultivated fields may contribute naturally occurring estrogenic compounds, such as mycotoxins, and some agricultural pesticides and wetting agents (non-ionic detergents) can be converted to estrogenic compounds in the environment or in the liver.

Estrogenic activity is a measurement of the effects of EDCs in the environment; however, this measure does not provide information on the causative substances. Documenting presence of multiple EDCs in surface waters does not necessarily indicate the constituent(s) responsible for adverse effects on fish populations. For example, Lavado with others (2009) conducted a survey of surface waters from 16 locations in California that were analyzed for EDCs using bioassays (which indicate levels of estradiol equivalents [EEQs]) and analysis for steroid hormones, detergent metabolites, agrichemicals, and other anthropogenic contaminants indicative of pharmaceuticals and personal care products. Samples from two of the 16 survey locations with estrogenic activity identified were subjected to bioassay-directed fractionation to try to identify the contaminants responsible for the estrogenic activity. Results were inconclusive.

5.D.4.9.1 Endocrine Disruptors—Effects of Covered Activities

5.D.4.9.1.1 Water Operations

Endocrine disruptors are a diverse group of chemicals, and it is not possible to evaluate fully the potential effects on the distribution and bioavailability of these chemicals from ESO water operations.

5.D.4.9.1.2 Restoration

Given current knowledge, there is potential for endocrine disruptors associated with pesticides to be present in ROA soils and mobilized by inundation of ROAs. Because the chemical characteristics of this group are diverse, the compounds may become mobilized and more bioavailable as suspended particulates in the water column, or in the dissolved phase in the water column. The type of endocrine disruptors and the possibility of mobilization would need to be evaluated on a site-specific basis, taking into consideration the types of pesticides historically used on the property.

5.D.4.10 Other Urban Contaminants

Development accounts for only 8% of land area in the Delta, but urban sources, and specifically WWTPs, have been identified as important sources of some contaminants (see discussion of pyrethroids and ammonia in previous sections).

The primary Delta urban centers are located in both the Sacramento River watershed (cities of Sacramento and West Sacramento) and the San Joaquin River watershed (city of Stockton). Lead, PCBs, and hydrocarbons (typically oil and grease) are common urban contaminants that are introduced to aquatic systems via nonpoint-source stormwater drainage, industrial discharges, and municipal wastewater discharges. Lead, PCBs, and oil and grease all tend to adhere to soils, although some lighter components of oil and grease can become dissolved in water. Because they adhere to particulates, they tend to settle out close to the source and likely will be found at highest concentrations adjacent to the urban areas. PCBs are very persistent, adsorb to soil and organics, and bioaccumulate in the food chain. Lead also will adhere to particulates and organics but does not bioaccumulate at the same rate as PCBs. Hydrocarbons will biodegrade over time in an aqueous environment and do not tend to bioaccumulate; thus, they are not persistent.

Lead and hydrocarbons have not been identified on the 303(d) list, and information on their presence and distribution in the Delta is very limited. Thus, they are not considered in this effects analysis. PCBs are listed on the 303(d) list and are discussed below.

Under *CM19 Urban Stormwater Treatment,* the Implementation Office will provide a mechanism for implementing stormwater treatment measures that will result in decreased discharge of contaminants to the Delta. These measures will be focused on urban areas and will result in an overall beneficial effect on water quality and covered fish species.

5.D.4.10.1 Polychlorinated Biphenyls

PCBs were banned in the late 1970s, but because of their persistence in the environment, they are still found in mostly urban soils and sediments. High levels of PCBs in environmental media and fish have been studied extensively in San Francisco Bay, which historically has received large amounts of urban runoff and industrial discharge. Although the north Delta, the Natomas east main drain in

Sacramento, and the Stockton Deep Water Ship Channel are listed on the 303d list of impaired waters for PCB contamination (State Water Resources Control Board 2010), few data are available concerning current concentrations or distribution of PCBs in the Delta.

Studies have not been conducted to evaluate the concentrations or distribution of PCBs in the Delta environment. Fish studies in the Delta have indicated the presence of PCBs in the food chain, but little work has been done in characterizing PCB concentrations in surface water and sediment, and identifying the source of PCBs. Because PCBs biomagnify through the food chain, and many of the larger fish migrate through the San Francisco estuary, including the Delta, the location of the PCB source cannot be identified through fish tissue analysis.

A study of striped bass from the Sacramento River demonstrated significantly higher levels of PCBs in eggs from the river compared with hatchery-raised fish (Ostrach et al. 2008). Elevated concentrations of PCBs were reported in tissues of fish near Stockton (Lee and Jones-Lee 2002; Davis et al. 2000). Studies by deVlaming (2008) and Davis et al. (2000) reveal that PCB concentrations in fish tissue samples from the north Delta and the Stockton Deep Water Ship Channel exceeded thresholds for human health. deVlaming's 2005 fish tissue composite samples also found elevated PCB concentrations in the Mokelumne and Tuolumne Rivers. However, deVlaming points out that, as lipophilic legacy contaminants, PCBs are expected to be found in higher concentrations in older, fattier fish, such as those that were sampled. The Sacramento sucker consistently had the highest PCB concentrations in these studies but should not be considered an appropriate model for other species because of its high lipid content (deVlaming 2008).

Overall, deVlaming found that the results from the 2005 tissue samples indicate that while high concentrations of PCBs can be found in older, fattier fish in specific regions of the Delta (north Delta, Sacramento, and Stockton), Delta PCB concentrations are generally below Office of Environmental Health Hazard Assessment screening values. In addition, deVlaming suggests that his 2005 results indicate that the north Delta may be eligible for 303d de-listing. Similarly, the 2008 TMDL for PCBs in San Francisco Bay states that PCBs in the Delta are expected to attenuate naturally, thus eliminating the need for implementing action to reduce PCBs in Delta waters. Based on the information presented here, PCBs are not expected to be affected by covered activities.

5.D.5 Effects of Changes in Contaminants on Covered Fish Species

5.D.5.1 Summary of Conclusions

The BDCP involves substantial restoration that would be implemented throughout the Delta over the 50-year implementation period as well as changes in water operations that could change how some contaminants move through the Delta. As discussed in previous sections of this appendix, and further below, few to no effects on contaminants in the Delta are expected from ESO water operations. Restoration of land with metals and pesticides in soils that could be mobilized into the aquatic system when inundated is expected to increase the bioavailability of some contaminants to covered fish species. Given the current understanding of the complex processes involved in mobilizing these contaminants, it cannot be modeled or estimated with any confidence. This appendix provides a full conceptual framework to understand the relevant processes. Site-specific analyses of restoration areas will be required to estimate the magnitude of the effects. Important to this picture is that taking lands out of agricultural use will result in an overall reduction of agriculture-related contaminant loading, including pesticides, copper, and in some cases, concentrated selenium in irrigation drainage.

In general, the following conclusions can be drawn.

- ESO water operations will have few to no effects on contaminants in the Delta.
- BDCP restoration may increase bioavailability of certain contaminants, especially methylmercury, but the overall effects on covered fish species are expected to be localized and of low magnitude.
- Available data suggest that species exposure to contaminants would be below sublethal and lethal levels.
- The long-term benefits of restoration will reduce exposure to existing contaminants in the environment and eliminate sources.

The following sections provide additional detail on the specific effects of toxic constituents on covered fish species.

5.D.5.2 Conclusion of Effects of Contaminants on Covered Fish Species

Effects on covered fish species will depend on the species/life stage present in the area of elevated contaminants and the duration of exposure. Release of toxic constituents from sediments (e.g., in restored areas) is tied to inundation, and so highest concentrations will occur during seasonal high water and to a lesser extent for short time periods on a tidal cycle in marshes. A full description of fish occurrence over the species' life cycle is included in Appendix 2.A, *Species Accounts*, and is integrated into the following sections where appropriate.

5.D.5.2.1 Mercury

Model results presented in Section D.5.1.2.1 indicate that ESO water operations will not adversely affect covered fish species. However, restoration efforts have the potential to increase the exposure of fish to methylmercury mobilized during inundation of restored tidal wetlands and floodplains, which are used for rearing by covered fish species. The areas expected to have the highest potential for methylmercury are the Yolo Bypass and, to a lesser extent, the Mokelumne-Cosumnes River. The amounts of methylmercury mobilized and resultant effects on covered fish species are not currently quantifiable. Slotton et al. (2000:43) noted:

> Results to date suggest that wetlands restoration projects may result in localized mercury bioaccumulation at levels similar to, but not necessarily greater than, general levels within their surrounding Delta subregion. Nevertheless, high methylation potential, flooded wetland habitat may be the primary source of methyl mercury production in the overall system… Careful monitoring will be essential to assess the actual effects of new wetlands restoration projects.

Also, Slotton et al. (2000) have noted that inland silversides from areas adjacent to flooded Delta tracts similar to proposed restoration sites did not exhibit elevated methylmercury. It should be noted that CM12 will involve monitoring of restoration projects for mercury methylation and mobilization, as suggested by Slotton.

The following discussion is based on the assumption that some level of methylmercury will be mobilized at BDCP ROAs. It also should be noted that a methylmercury mitigation conservation measure is part of the BDCP, and requires integration of design elements into restoration projects to decrease methylmercury production.

5.D.5.2.1.1 Eggs

The direct exposure of salmonid, sturgeon, and lamprey eggs to increased levels of methylmercury as a result of the BDCP would not occur because salmonid, sturgeon, and lamprey eggs are not present anywhere that restoration is proposed. Although information could not be identified in the literature, it is potentially possible that maternal transfer could occur, i.e., prespawned eggs could be exposed to methylmercury from adult consumption of contaminated prey. Splittail, delta smelt, and longfin smelt all spawn in or near areas that would be restored under the BDCP and therefore have the potential for increased exposure to methylmercury. For delta smelt and longfin smelt that spawn directly downstream of the Yolo Bypass or other ROAs in the west or north Delta, exposure of the eggs to aqueous mercury could range from 9 to 14 days (delta smelt) and up to 40 days (longfin smelt). Exposure of splittail eggs would be even less, with eggs hatching in 3–7 days. It is not known what level of mercury would be assimilated and transferred to the larvae. Mercury exposure in eggs can lead to egg failure and developmental effects, but the levels of mercury that would have these results are not fully understood.

5.D.5.2.1.2 Larvae and Juveniles

Effects of increased methylmercury are expected to be minimal for fish rearing in the Delta. Henery and others (2010) compared methylmercury in Chinook salmon confined in the Yolo Bypass with those from the Sacramento River and found that the fish that reared in the Yolo Bypass accumulated 3.2% more methylmercury than fish held in the nearby Sacramento River. However, it should be noted that the mean methylmercury concentration for fish in the floodplain was 0.0567 μg/g and only two of the 199 individuals sampled had greater than 0.20 μg/g tissue methylmercury (a whole-body threshold of potential importance for sublethal effects on fish for growth, reproduction, development, and behavior) (Beckvar et al. 2005 in Henery et al. 2010:561). In addition, the 3.2% increase observed should be considered in the context of the life stage, i.e., the fish would subsequently be leaving the Plan Area and therefore no longer would be exposed to elevated concentrations of mercury, while also growing considerably larger in the ocean and therefore diluting accumulated mercury in their increasing body mass.

Henery also found that the body mass of free-ranging Chinook salmon that reared in the floodplain grew at a rate of 3.5% per day, compared with 2.8% per day for Chinook salmon that reared in the adjacent Sacramento River. Therefore, it appears that the increased exposure to methylmercury in rearing salmonids generally would not be high enough to elicit measurable sublethal effects. This growth dilution effect would be even more pronounced in adult fish that grow to three orders of magnitude larger over their life span, making the amount of methylmercury tissue accumulation as a juvenile insignificant (Henery et al. 2010).

Unlike salmonids, juvenile and subadult green and white sturgeon spend considerable time in the Delta. Laboratory studies have shown that high concentrations of methylmercury (25–50 ppm) in sturgeon diet are required to elicit any sort of adverse effect (Kaufman pers. comm.; Lee et al. 2011). Such elevated levels of methylmercury would not be experienced in the BDCP restoration areas or the Yolo Bypass. Although juvenile sturgeon spend more time than any other covered fish species in the Plan Area, they also have the fastest growth rate of any species. Accumulation of methylmercury in the body tissue thus is mediated by growth dilution from the rapidly increasing muscle mass (Kaufman pers. comm.). Total body burden of methylmercury may increase, but tissue concentration of methylmercury would be expected to remain relatively constant (Kaufman pers. comm.) Juvenile sturgeon are primarily benthivores, feeding mostly on secondary productivity in the food chain (small crustaceans, clams, etc.) and therefore would not bioaccumulate mercury as fast as a top predator.

Larvae and juvenile splittail, delta smelt, and longfin smelt feed very low on the food chain and, similar to sturgeon juveniles described above, would bioaccumulate methylmercury at low levels. Additionally, juvenile longfin smelt occur primarily in San Pablo Bay and San Francisco Bay, where no restoration or effects from water operations related to the ESO would occur. Similarly, juvenile delta smelt occur primarily in the west Delta and Suisun Bay, where elevated levels of methylmercury from restoration are not likely, and in Suisun Marsh, where the potential for elevated methylmercury is also low. However, juvenile smelt remaining in the north Delta area would experience exposure from food in the Yolo Bypass and Cache Slough regions.

5.D.5.2.1.3 Adults

Central Valley adult salmonids do not feed during their time in the Delta (Sasaki 1966) and potentially would be exposed to the elevated methylmercury produced in this portion of the Delta through absorption from water through their gills. Additionally, they tend to stay in the main channels through the Delta, rather than the shallow, slow-moving waters of wetlands and floodplains. As a result of their limited time in the estuary and the tendency to migrate in the main channels, adult salmonids are not likely to be exposed to a significantly different quantity of methylmercury under the BDCP than under current conditions. Elevated mercury levels in the East Delta subregion could be encountered at the confluence of the Mokelumne and Cosumnes Rivers, although the number of spawning occurrences in this area by covered fish species is relatively small.

Adult sturgeon would be using the BDCP regions primarily as a pathway for spawning migration, although they do forage in the lowest BDCP regions. Adult sturgeon would not accumulate high tissue loads of methylmercury for the same reason as the juveniles, coupled with the fact that they spend little time in areas that are projected to have increased methylmercury production. Analyses of white sturgeon from San Francisco Bay (albeit downstream of the Plan Area) found median mercury concentration in muscle below the screening level for human consumption concern of 0.3 µg/g wet weight (Greenfield et al. 2003).

Although adult life stages of splittail, delta smelt, and longfin smelt feed and spawn in areas with potential for elevated methylmercury levels, they feed primarily on lower trophic level food sources and therefore do not accumulate methylmercury at rates as high as if they preyed on fish. Additionally, they are not expected to spend excessive amounts of time in these areas, so the uptake through their gills and food is expected to be minimal. Nevertheless, delta smelt have been shown to accumulate appreciable quantities of mercury: Bennett et al. (2001) found average levels of 0.18 µg/g, which is just less than the 0.20 µg/g general threshold for effects on fish suggested by Beckvar et al. (2005 in Henery et al. 2010:561). There is no evidence for acute toxicity of mercury being related to recent declines of pelagic fish such as delta smelt and longfin smelt, although mercury, selenium, and copper may have had a chronic effect on these species (Brooks et al. 2011).

5.D.5.2.2 Selenium

As discussed in Section 5D.5.2, elevated selenium is recognized as a threat to fish in the Delta. However, few to no effects on selenium from covered activities have been identified. Historically, the San Joaquin River has been a major source of selenium to the Delta; however, the selenium source is being addressed and selenium concentrations are decreasing. Further, modeling results indicate that ESO water operations would have few to no effects on selenium concentrations in water or fish tissue. Suisun Marsh has high levels of selenium in filter-feeding clams that bioaccumulate selenium and form the base of the food chain for benthic-feeding fish, such as sturgeon. However, selenium is likely to become increasingly mobile under a very narrow set of conditions. *AMM 27 Selenium Management* (Appendix 3.C, *Avoidance and Mitigation Measures*) is included in the BDCP to minimize this risk. Further, model-estimated selenium water concentrations and fish tissue concentrations for sturgeon in the west Delta indicate that the BDCP would not result in substantial increases in selenium concentrations compared to future conditions without the BDCP.

As a conservative approach, the following discussion of the possible effects of covered activities on selenium in covered fish species assumes that some increase in selenium will occur under the covered activities. Any increases are expected to be localized and associated with inundation of ROAs, mainly in the south Delta, which receives input from the San Joaquin River, a historical source of selenium.

The bioaccumulation and effects of selenium on fish have much to do with their feeding behavior. *Potamocorbula* accumulates selenium and is key to mobilizing it into the food chain. It is abundant in Suisun Bay, but the BDCP is not expected to increase the contribution of selenium to this area given the distance from the San Joaquin River source (modeling results corroborate). Smelt, steelhead, and Chinook salmon would be expected to have low exposure to selenium as they are feeding on pelagic organisms that are able to excrete selenium at more than 10 times the rate of the *Potamocorbula*. This is in contrast to sturgeon and splittail that are at risk for teratogenesis because of their diet preference for *Potamocorbula* and high concentrations of selenium bioaccumulated in their tissues, especially reproductive organs, liver, and kidneys. Deformities occur in developing embryos when selenium replaces sulfur in sulfur-rich hard tissues (Diplock 1976). For example, recent field surveys identified Sacramento splittail from Suisun Bay (where selenium concentrations are highest) that have deformities typical of selenium exposure (Stewart et al. 2004). Both green and white sturgeon feed on *Potamocorbula* in the three lower subregions (Suisun Bay, Suisun Marsh, and West Delta) but are not likely to be affected by the BDCP–related changes in selenium because of the distance from the source area (Grassland in San Joaquin River basin). Modeling results discussed above corroborate this conclusion. Little is known about lampreys, but based on lamprey ammocoete occurrence in the Delta (mostly in the Sacramento River area), it is expected that their exposure to selenium-laden sediments and water would be minimal.

5.D.5.2.3 Copper

Copper will be present in agricultural soils and could be mobilized by inundation of the ROAs, as it is fairly immobile in soils, but is very mobile in an aquatic system. ESO water operations are not expected to have much effect on copper concentrations, although there is a slight chance of mobilization of copper from increased flow at the weir at the upstream end of the Yolo Bypass, where copper concentrations may be elevated.

Mobilized copper could have a temporary adverse effect on juvenile fish, namely salmonids, splittail, and smelt that rear in the Yolo Bypass. Additionally, splittail adults, eggs, and larvae may be exposed while in the bypass. Likewise, rearing juvenile and adult salmonids and sturgeon may be exposed in other ROAs previously used for agriculture.

It is difficult to establish precise concentrations at which copper is acutely toxic to fish, as a large number of water chemistry parameters (including temperature, pH, DOC, and ions) can affect the bioavailability of copper to the fish population (U.S. Environmental Protection Agency 2007). Also, copper may affect prey items resulting in effects on fish (Werner et al. 2009). As discussed in Section 5D.5.3, copper is present in the Sacramento River at low concentrations (2 μg/L). Connon et al. (2010) demonstrated that the median lethal concentration of dissolved copper at which 10% of delta smelt juveniles died after 7 days of exposure under experimental conditions (LC10) was 9.0 μg/L; 50% of juveniles died (LC50) when exposed to a median concentration of 17.8 μg/L. Although 96-hour larval delta smelt mortality suggested higher concentrations than juveniles (median LC10 = 9.3 μg/L; median LC50 = 80.4 μg/L), these results were complicated by differences in exposure duration and experimental conditions (particularly for factors such as temperature and conductivity that may affect copper toxicity) (Connon et al. 2010). Finlayson and Verrue (1982) also reported lethal concentrations of copper, with the LC50 at 26 to 34 μg/L for juvenile Chinook salmon.

Carreau and Pyle (2005) demonstrated that copper exposure during embryonic development of fathead minnows could result in permanent impairment of chemosensory functions but that the same exposure caused only temporary impairment in adults once copper is removed, suggesting that the specific life stage at the time of exposure also plays a role in the toxicity of copper to fish. Baldwin et al. (2003) reported inhibition of olfactory physiology in salmonids at concentrations of 6 μg/L (background plus spiked concentration), indicating that low levels of copper over a short period of exposure could affect migratory ability in salmonids. Sandahl et al. (2007) reported impairment of sensory functions and avoidance behavior in juvenile coho at copper concentrations of 2μg/L. There is some evidence that larval delta smelt swimming velocity decreases as dissolved copper concentration increases, although experimental testing did not find statistical differences between test subjects and controls (Connon et al. 2010). Various delta smelt genes have been to shown to have altered expression in copper-exposed larvae (Connon et al. 2010).

Localized, short-term increases in copper concentrations are possible near ROA areas, but the length of time and the concentrations cannot be determined with available data. Overall, because copper concentrations are generally low in Delta waters, covered activities are not expected to result in increased effects of copper on covered fish species. In fact, halting agricultural use and application of pesticides on restoration areas will result in decreased loading of copper to the Delta system and will provide a long-term net benefit to the ecosystem.

5.D.5.2.4 Ammonia

Based on the analysis presented in Section 5D.5.4, covered activities are not expected to result in substantial increases in ammonia concentrations in the aquatic system that could affect covered fish species. Analysis of the ability of the Sacramento River to dilute ammonia discharges from the Sacramento WWTP indicates that resultant concentrations would be within ecologically acceptable limits under the BDCP, once the treatment plant upgrades are implemented and the new criteria are met for effluent. Further, no addition or mobilization of ammonia to the aquatic system would result from restoration activities.

5.D.5.2.5 Pyrethroids, Organophosphate Pesticides, Organochlorine Pesticides, and Endocrine Disruptors

Based on the analyses in Sections D.5.5, D.5.6, and D.5.7, changes in concentrations of pyrethroids, organophosphate pesticides, and organochlorine pesticides resulting from the covered activities are expected in the vicinity of cultivated land that is restored to marshes and floodplains. These chemicals either have a strong affinity for sediment and will settle out of the water column, or readily degrade in an aquatic system. Thus, it is expected that increases in concentrations due to covered activities will be of relatively short duration and localized near ROAs. Specific areas of these elevated contaminants have not been identified, but they can be expected in any of the ROAs. BDCP restoration will take these agricultural areas out of production, therefore eliminating the source and reducing these chemicals in the Delta system, providing a long-term ecological benefit.

Endocrine disruptors are a group of chemicals with widely varying fate and transport and toxicological effects, which are not completely understood. Some pesticides are endocrine disruptors, and the sources and distribution are is similar to those of pesticide groups.

Pyrethroids have been shown to be lethal as low as 1 μg/L, although there are many different chemicals in this group with varying toxicities for fish. Likewise, little is known on the effects of organophosphates on covered fish species, but elevated concentrations of organophosphates are more likely to affect the lower trophic levels that the covered fish species prey on than the fish directly (Turner 2002). As these pesticides are neurotoxins, behavioral effects are of primary concern; however, Scholz et al. (2000) points out that the effects are not well understood. Scholz et al. (2000) found that diazinon concentrations as low as 1 μg/L resulted in significant impairment of predator-alarm responses, and slightly higher concentrations of 10 μg/L caused the impairment of homing behavior in Chinook salmon. Organochlorine pesticides are neurotoxic, are likely carcinogenic, and have been implicated as endocrine disruptors because of their estrogenic nature and effects on reproductive development (Leatherbarrow et al. 2006). These pesticides are highly persistent and lipophilic, and as such, they strongly bioaccumulate (Werner et al. 2008). Because of their persistence in the environment and biomagnifications through the foodweb, the main concern with organochlorines is bioaccumulation in the higher trophic levels and implications for human consumption. However, organochlorine pesticides and degradation products can directly affect fish through toxicity to lower-level invertebrates on the food chain, and toxicity to small and early life stage fish, but there is little information specific to effects on individual species. Sublethal effects may include reproductive failure and behavioral changes. Ostrach et al. (2008) suggest that striped bass have been experiencing reproductive failure due to organochlorine compounds in San Francisco Bay, which is likely due to concentrations accumulated through biomagnifications. Because they tend to adhere to soils and particulates, organochlorine compounds may take longer to flush out than some of the more environmentally mobile constituents discussed above (e.g., copper).

In the Delta, fish in higher trophic levels are particularly vulnerable to these pesticides, as the chemicals will biomagnify and bioaccumulate in their tissues. These fish include white and green sturgeon, salmonids, and lampreys. As smaller fish at lower trophic levels, smelt and splittail can be expected to have less biomagnification of these pesticides.

More detailed analysis of pyrethroid, organophosphate pesticide, organochlorine pesticide, and endocrine disruptor effects would require site-specific information, but overall the BDCP is not expected to substantially increase the potential exposure of fish because elevated bioavailability likely would be localized near ROAs and over a relatively short time period. Additionally, restoration of cultivated land will result in an overall reduction in these chemicals in the Delta system, with an overall net ecological benefit.

5.D.5.3 Uncertainties and Information Needs

As discussed throughout this appendix, the amount of contaminants that will be mobilized and made more bioavailable to covered fish species due to inundation of ROAs is uncertain. This uncertainty is most critical for methylmercury, and to a lesser extent for pesticides and other metals. For each of the contaminants, the chemical-specific and site-specific factors that will determine resultant effects vary. CM12 is included in the BDCP to support site specific evaluation and monitoring of methylmercury production in restored areas. Data from this monitoring will assist in evaluating the effects of restoration actions and reduce the uncertainty associated with the potential exposure of covered fish to methylmercury mobilized by these actions.

5.D.6 References Cited

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Attachment 5D.A

Bioaccumulation Model Development for Mercury Concentrations in Fish

Attachment 5D.A

Bioaccumulation Model Development for Mercury Concentrations in Fish

Contents

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Acronyms and Abbreviations

µg/L	microgram(s) per liter
BDCP	Bay Delta Conservation Plan
Central Valley Water Board	Central Valley Regional Water Quality Control Board
Delta	Sacramento–San Joaquin River Delta
EBC	existing baseline conditions
ELT	early long-term
ESO	evaluated starting operation
Hg	mercury
LLT	late long-term
MeHg	methylmercury
mg/kg	milligrams/kilogram
mm	millimeters
ng/L	nanogram(s) per liter
SFEI	San Francisco Estuary Institute
TMDL	total maximum daily load
ww	wet weight

Attachment 5D.A

Bioaccumulation Model Development for Mercury Concentrations in Fish

5D.A.1 Introduction

The purpose of this bioaccumulation model is to provide an evaluation of the potential for the Bay Delta Conservation Plan (BDCP) evaluated starting operation (ESO) (see Chapter 3, *Conservation Strategy*, for a more complete description) to affect concentrations of mercury in Sacramento–San Joaquin River Delta (Delta) water and potential for bioaccumulation in fish. This attachment presents the approach and methods for this analysis.

The Central Valley Regional Water Quality Control Board (Central Valley Water Board) used the general approach of linking waterborne mercury concentrations and largemouth bass mercury concentrations for broad areas of the Delta as part of developing the methylmercury total maximum daily load (TMDL) (Wood et al 2010). The Central Valley Water Board modeling goal was to estimate water concentrations that would relate to their fish tissue TMDL target. However, for the BDCP, it was desirable to determine the linkages between mercury water concentrations and resulting fish tissue concentrations at specific defined locations, rather than general Delta conditions over broad areas. Thus, the approach in the current analysis was to identify a model that could be used to estimate fish tissue concentrations based on water concentrations of mercury. The benchmark used for this evaluation is the Central Valley Water Board TMDL tissue concentration goal of 0.24 milligrams per kilogram (mg/kg) wet weight (ww) of mercury for normalized 350-millimeter (mm) total length largemouth bass tissue (Central Valley Regional Water Quality Control Board 2008).

5D.A.2 Mercury Concentrations in Water and Fish

Water concentrations under EBC2, EBC2_LLT and the ESO_LLT[1] were estimated by assigning mercury and methylmercury concentrations to five source waters that contribute to the Delta (based on sampling data; see Table 5D.A-1), and using DSM2 to model the mixing and hydrodynamics of these contributing source waters in the system. DSM2 was used to model year 2000 hydrologic conditions because fish tissue data were from 1999 and 2000, as discussed below. Mercury and methylmercury water sample data used to characterize the five source waters were each averaged over the years indicated in Table 5D.A-1 and Table 5D.A-2 to produce the long-term averages used for source-water blending.

The DSM2 model results provide an estimate of the resulting concentrations of mercury and methylmercury in water at specific locations (see Table 5D.A-3). Note that the first quarter DSM2 model results were discarded because the model “ramps up” for a new year, and the average values from those first months were distinctly lower than for the other quarters. Ramping in water quality models is based on the use of previous months in the subsequent months’ values and the use of unrealistically low startup values. Therefore, a surrogate for the annual average for the year was

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[1] EBC = existing baseline conditions; ELT = early long-term; LLT = late long-term.

computed from the last three quarters. The next step in the evaluation was to identify a model that linked these water concentrations to fish tissue concentrations in samples collected from the same location.

Largemouth bass were chosen for this analysis because they are popular sport fish, top predators, live for several years, and tend to stay in the same area (that is, they exhibit high site fidelity). Consequently, they are excellent indicators of long-term average mercury exposure, risk, and spatial pattern for both ecological and human health. Also a methylmercury/mercury fish tissue dataset was available for largemouth bass from defined locations across the Delta. The largemouth bass tissue mercury concentrations were presented as edible fillet concentrations for fish normalized to 350 mm in total length as supplied directly by the San Francisco Estuary Institute (SFEI) (San Francisco Estuary Institute 2010). It is important to standardize concentrations to the same size fish at each location because of the well-established positive relationship between fish size and age and tissue mercury concentrations (Alpers et al. 2008). This same normalization technique was used by the Central Valley Water Board for their model (Central Valley Regional Water Quality Control Board 2008).

5D.A.3 Selection of a Bioaccumulation Model Predicting Mercury in Fish

Two methods to establish the relationship between water concentrations and fish tissue concentrations were evaluated:

1. Linear regression analyses using either annual average or quarterly water values calculated using the SAS institute's Statview 5 analytic software (SAS Institute 1998).
2. Central Valley Water Board TMDL model based on the concentration averages over broad areas of the Delta.

5D.A.3.1 Regression Analysis

Standard, linear regression analyses were created using the SAS institute's Statview 5 analytic software (SAS Institute1998). DSM2 model outputs of mercury or methylmercury concentrations in water were graphed against fish tissue field sample concentrations of total mercury (assumed to be all as methylmercury) at the exact same nodes and approximate dates. The data were log-transformed to improve normality. The positive relationships between fish tissue and waterborne mercury were not as strong as with waterborne methylmercury, and therefore methylmercury was retained as the best predictor. The best fit for a predictive model was the linear regression with the transformed data between average waterborne methylmercury concentrations in water from the third quarter of the year and largemouth bass tissue mercury concentrations (Figure 5D.A-1). Each point in the figure represents one fish sample paired with the DSM-2 prediction of methylmercury concentrations from the nearest Delta location. Although the linear relationship is not strong ($r^2 = 0.383$), the third quarter data from the Year 2000 produced the best fit. The regression equation (below) was used as the best identified predictor of mercury in fish tissue based on methylmercury water concentrations.

$$\text{Fish mercury (mg/kg ww)} = 10^{(4.217 + (\text{Log methylmercury in water, }\mu\text{g/L} \times 1.164))} \quad \text{(Eq. 1)}$$

($r^2 = 0.383$, $P = 0.024$)

μg/L = micorgrams per liter

The results of this regression model in Figure D.A-1 can be compared to those using the alternative from the Central Valley Water Board TMDL model, which also predicts 350-mm normalized largemouth bass fillets from methylmercury in water. This comparison is shown in Table 5D.A-4.

The Central Valley Water Board developed a nonlinear model based on largemouth bass as grouped in major, large areas of the Delta (rather than specific locations) compared to average methylmercury concentrations in water for those same, general areas (Central Valley Regional Water Quality Control Board 2008):

Fish mercury (mg/kg ww) = 20.365 × ((methylmercury in water, ng/L)^1.6374) [Eq. 2]

($r^2 = 0.910$, $P < 0.05$)

ng = nanograms per liter

The difference between the model results and the actual fish tissue results were more variable for the Central Valley Water Board model (-0.399 to 0.85 mg/kg) compared with the regression model (-0.505 to 0.299 (Table 5D.A-4). It is likely the averaging used in the Central Valley Water Board model parameters contributed to this relative imprecision; the DSM2-based model was constructed specifically to work for DSM2 output locations of interest for this study. For this reason, the regression model as shown in Figure 5D.A-1 was used to predict bass fillet concentrations for this study. Note that the Central Valley Water Board TMDL model was not established to predict fish tissue concentrations, but to provide the linkage between the 0.24 mg/kg tissue mercury TMDL target and the waterborne goal of 0.066 ng methylmercury/L.

5D.A.4 Tables

Table 5D.A-1. Historical Methylmercury Concentrations in the Five Delta Source Waters for the Period Period 2000–2008

	Source Water									
	Sacramento River		**San Joaquin River**		**San Francisco Bay**		**East Side Tributaries**		**Agriculture in the Delta**	
Data Parameters	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**
Mean (ng/L)	0.10	0.03	0.15	0.03	0.032	–	0.22	0.08	0.25	–
Minimum (ng/L)	0.05	0.03	0.09	0.01	–	–	0.02	0.02	–	–
Maximum (ng/L)	0.24	0.03	0.26	0.08	–	–	0.32	0.41	–	–
75th Percentile (ng/L)	0.12	0.03	0.18	0.06	–	–	0.20	0.15	–	–
99th Percentile (ng/L)	0.23	0.03	0.26	0.08	–	–	0.31	0.39	–	–
Data Source	Central Valley Water Board 2008		BDAT 2010; Central Valley Water Board 2008		SFEI 2010	–	Central Valley Water Board 2008		Central Valley Water Board 2008	–
				USGS 2010				USGS 2010		
Station(s)	Sacramento River at Freeport		San Joaquin River at Vernalis		Martinez		Mokelumne and Calaveras Rivers		Mid-Delta locations, median	
Date Range	2000–2003	2000	2000–2001; 2003–2004	2000–2002	2007	–	2000–2001; 2003–2004	2000; 2002	2008	–
Non-Detect Replaced with Reporting Limit	Not Applicable		Not Applicable	Yes	–		Yes		Not Applicable	
Data Omitted	None		None		–		None		None	
No. of Data Points	36	1	49	25	–	–	27	9	–	–

Sources: BDAT Website 2010; Central Valley Regional Water Quality Control Board 2008; San Francisco Estuary Institute (SFEI) Website 2010; U.S. Geological Survey (USGS) Website 2010.

Notes:

Means are geometric means.

ng/L = nanograms per liter.

* The total recoverable concentration of the analyte is presented in first cell, and the dissolved concentration of the analyte is presented in the second column.

Table 5D.A-2. Historical Mercury Concentrations in the Five Delta Source Waters for the Period 1999–2008

	Source Water									
	Sacramento River		**San Joaquin River**		**San Francisco Bay**		**East Side Tributaries**		**Agriculture in the Delta**	
Data Parameters	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**
Mean (ng/L)	4.1	–	7.6	0.8	7.8	–	8.6	1.4	6.5	–
Minimum (ng/L)	1.2	–	3.1	0.3		–	0.3	1.4	–	–
Maximum (ng/L)	30.6	–	21.7	3.0		–	26.2	1.4	–	–
75th Percentile (ng/L)	5.5	–	8.6	1.2		–	7.5	1.4	–	–
99th Percentile (ng/L)	24.2	–	17.4	2.8		–	25.2	1.4	–	–
Data Source	Central Valley Water Board 2008	–	BDAT 2010; Central Valley Water Board 2008	BDAT 2010; USGS 2010	SFEI2010	–	Central Valley Water Board 2008	USGS 2010	Central Valley Water Board 2008	–
Station(s)	Sacramento River at Freeport		San Joaquin River at Vernalis		Martinez		Mokelumne and Calaveras Rivers[a,b]	Cosumnes River[c]	Mid-Delta locations, median	
Date Range	1999–2002	–	2000–2004	2000–2002	2007	–	2000–2001; 2003–2004	2002	2008	
Non-Detect Replaced with Reporting Limit	Not Applicable		Not Applicable		–		Not Applicable	Not Applicable		
Data Omitted	None		None		–		None	None		
No. of Data Points	45	–	49	19	–	–	25	1	–	–

[a] Mokelumne River at I-5.

[b] Calaveras River at railroad upstream of West Lane.

[c] Cosumnes River at Michigan Bar.

Notes: Means are geometric means. ng/L: nanograms per liter.

Sources: BDAT Website 2010; Central Valley Regional Water Quality Control Board 2008; San Francisco Estuary Institute (SFEI) Website 2010; U.S. Geological Survey (USGS) Website 2010.

1 **Table 5D.A-3. Modeled Mercury and Methylmercury Concentration Estimates in Water at Selected Locations in the Delta**

	Concentration (ng/L)							
	Second Quarter		Third Quarter		Fourth Quarter		Annual Average	
DSM2 Output Location	**Hg**	**MeHg**	**Hg**	**MeHg**	**Hg**	**MeHg**	**Hg**	**MeHg**
Sacramento River River Mile 44	4.1	0.1	4.1	0.1	4.1	0.1	4.1	0.1
Mokelumne River downstream of Cosumnes	8.56	0.22	8.45	0.22	8.55	0.22	8.52	0.22
Cosumnes River	8.6	0.22	8.6	0.22	8.6	0.22	8.6	0.22
Cache Slough	4.11	0.1	4.13	0.1	4.12	0.1	4.12	0.1
Sacramento River at Isleton	4.1	0.1	4.11	0.1	4.11	0.1	4.11	0.1
San Joaquin River Potato Slough	5.32	0.13	4.2	0.1	4.24	0.1	4.59	0.11
Sherman Island	4.79	0.11	4.5	0.1	4.75	0.09	4.68	0.1
White Slough downstream of Disappointment Slough	6.86	0.16	4.66	0.12	4.9	0.13	5.47	0.14
Franks Tract	5.46	0.13	4.26	0.11	4.29	0.1	4.67	0.11
Big Break	4.93	0.12	4.36	0.1	4.48	0.1	4.59	0.11
Mildred Island	6.99	0.15	4.61	0.12	5.09	0.12	5.56	0.13
San Joaquin River Naval Station	7.62	0.16	7.63	0.16	7.61	0.15	7.62	0.16

Hg = mercury.
MeHg = methylmercury.

2

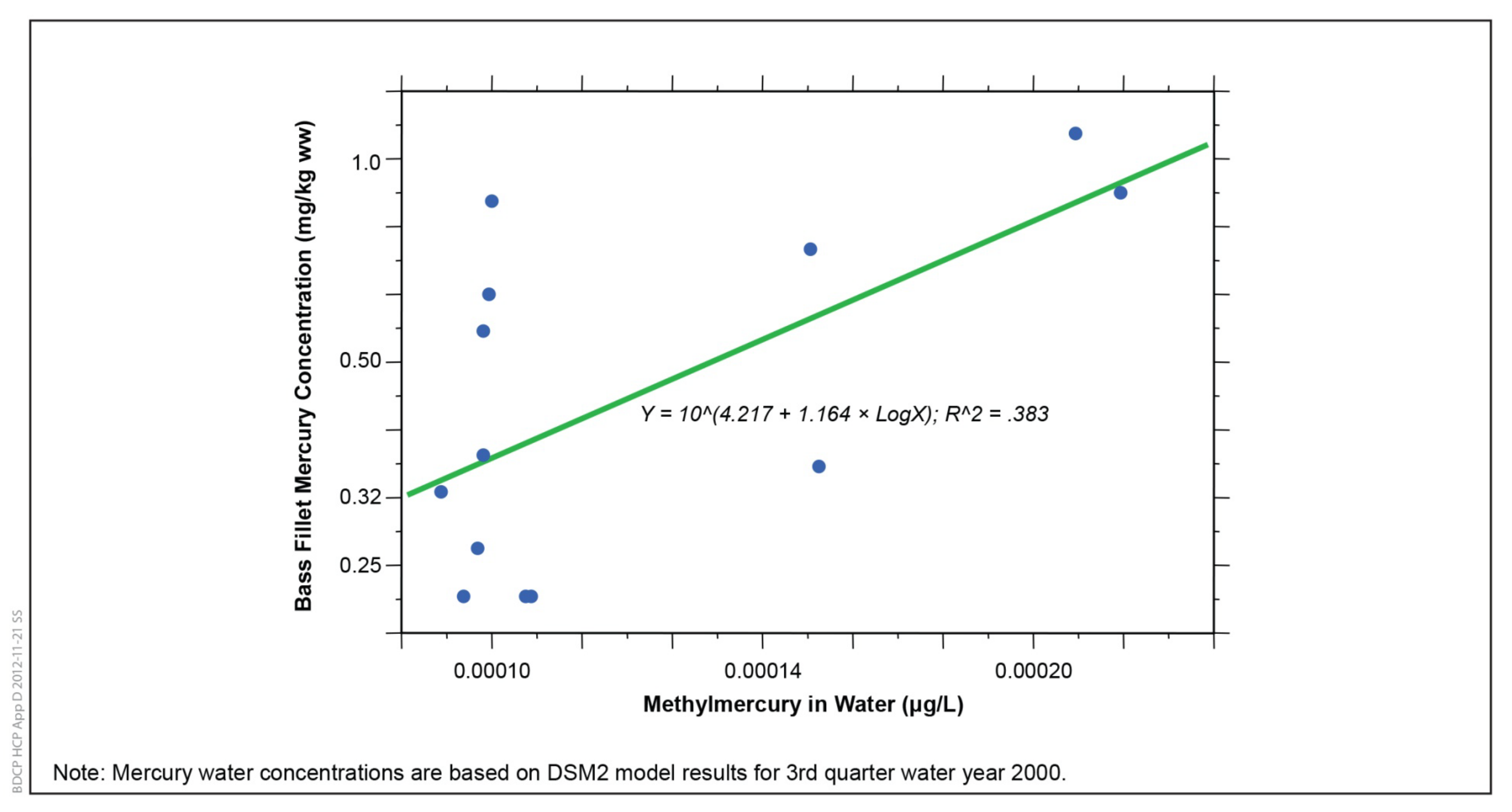
1 **Table 5D.A-4. Comparison of Model Results with Measured Bass Fillet Mercury Concentrations**

	Bass Tissue Mercury Concentration (mg/kg ww)				
Site	**Measured in Fish Samples**	**Regression Model**	**Difference Regression—Measured**	**Central Valley Water Board TMDL Model**	**Difference Central Valley Water Board —Measured**
Sacramento River River Mile 44	0.869	0.364	-0.505	0.47	-0.399
Mokelumne River downstream of Cosumnes	1.091	0.93	-0.161	1.758	0.667
Cosumnes River	0.895	0.926	0.031	1.745	0.85
Cache Slough	0.559	0.372	-0.187	0.484	-0.075
Sacramento River at Isleton	0.628	0.366	-0.262	0.473	-0.155
San Joaquin River Potato Slough	0.365	0.413	0.048	0.56	0.195
Sherman Island	0.323	0.371	0.048	0.482	0.159
White Slough downstream of Disappointment Slough	0.226	0.525	0.299	0.785	0.559
Franks Tract	0.265	0.42	0.155	0.574	0.309
Big Break	0.226	0.39	0.164	0.518	0.292
Mildred Island	0.226	0.498	0.272	0.729	0.503
San Joaquin River Naval Station	0.352	0.621	0.269	0.996	0.644
San Joaquin River Vernalis	0.739	0.583	-0.156	0.912	0.173
Geometric mean	0.446	0.493			
Maximum	1.091	0.93			
Minimum	0.226	0.364			

mg/kg ww = milligram per kilogram wet weight.

2

5D.A.5 Figure



Note: Mercury water concentrations are based on DSM2 model results for 3rd quarter water year 2000.

Figure 5D.A-1. Predictive Model Showing the Relationship between DSM2 Model Estimates of Waterborne Methylmercury for the 3rd Quarter, Water Year 2000, and Measured Concentrations of Mercury in Largemouth Bass Fillets, Normalized to 350-mm-Length Fish

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Attachment 5D.B

Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets

Attachment 5D.B
Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets

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Acronyms and Abbreviations

µg/kg dw	micrograms/kilogram, dry weight
µg/L	micrograms/liter
Delta	Sacramento–San Joaquin River Delta
Kd	particulate/water ratio
RM	River Mile
TL-	trophic level-
TTFs	trophic transfer factors
ww	wet weight

Attachment 5D.B
Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets

5D.B.1 Introduction

Project-related changes in waterborne concentrations of selenium in the Sacramento–San Joaquin River Delta (Delta) may result in increased selenium bioaccumulation and/or toxicity to aquatic and semi-aquatic receptors using the Delta. Historical fish tissue data and measured (at Vernalis) or DSM2-modeled (other locations) waterborne selenium concentrations for selected locations in 2000, 2005, and 2007 were used to model water to tissue relationships, generally following procedures described by Presser and Luoma (2010 and 2013).

The output from the DSM2 model (expressed as percent inflow from different sources) was used in combination with the available measured waterborne selenium concentrations to model concentrations of selenium at locations throughout the Delta. These modeled waterborne selenium concentrations were used in the relationship model to estimate bioaccumulation of selenium in whole-body fish. Selenium concentrations in fish fillets were then estimated from those in whole-body fish.

The data and processes used to develop the final models to estimate this selenium bioaccumulation are described here, and also in Attain the following sections. Additional analysis of bioaccumulation in sturgeon at the two western-most locations in the Delta using factors from Presser and Luoma (2013) were also conducted, and methods are described in an Addendum to this document, which is attached.

5D.B.2 Selenium Concentrations in Water

Dissolved selenium data were available for six inflow locations to the Delta (shown in Table 5D.B-1; all tables are provided at the end of this appendix). Whole-body largemouth bass data for selenium were available from the following DSM2 output locations:

- Big Break
- Cache Slough Ryer
- Franks Tract
- Knights Landing
- Middle River Bullfrog
- Old River Near Paradise Cut
- Sacramento River Mile (RM) 44
- San Joaquin River Potato Slough

- Vernalis

The geometric mean selenium concentrations from the inflow locations were combined with the modeled quarterly average percent inflow for each DSM2 output location to estimate waterborne selenium concentrations at selected DSM2 output locations.

The quarterly average mix of water from the six inflow sources (Table 5D.B-1) was calculated from daily percent inflows provided by the DSM2 model output for the nine DSM2 output locations for which fish data were available. DSM2 data were not available at or near Veteran's Bridge on the Sacramento River or at Vernalis on the San Joaquin River. Historical data of selenium concentrations in water collected near these locations were used to represent quarterly averages. The geometric mean of total selenium concentrations in water collected from years 2003, 2004, 2007, and 2008 (California Department of Water Resources 2009) at Knights Landing were used to represent quarterly averages of selenium concentrations in water for all years. The geometric means of selenium concentrations (total or dissolved was not specified) in water collected from years 1999–2007 (Central Valley Regional Water Quality Control Board 2009) were used to represent quarterly averages for all years of selenium concentrations in water at Vernalis.

The quarterly waterborne selenium concentrations at DSM2 locations were calculated using the following equation:

$$C_{water\ quarterly} = \frac{(I_1 \bullet C_1) + (I_2 \bullet C_2) + (I_3 \bullet C_3) + (I_4 \bullet C_4) + (I_5 \bullet C_5) + (I_6 \bullet C_6)}{100} \qquad \text{(Eq. 1)}$$

Where:

$C_{water\ quarterly}$ = quarterly average selenium concentration in water (micrograms/liter [μg/L]) at a DSM2 output location

$I_{1–6}$ = modeled quarterly inflow from each of the six sources of water to the Delta for each DSM2 output location (percentage)

$C_{1–6}$ = selenium concentration in water (μg/L) from each of the six inflow sources to the Delta (1–6)

Example Calculation: Modeled Selenium Concentration at Franks Tract Year 2000, First Quarter:

> (43.94 [% inflow from Sacramento River water source at Franks Tract] × 0.32 μg/L [Selenium concentration at Sacramento River at Freeport]) + (11.56 [% inflow from East Delta Tributaries water source at Franks Tract] × 0.10 μg/L [Selenium concentration at Mokelumne, Calaveras, and Cosumnes Rivers]) + (15.79 [% inflow from San Joaquin River water source at Franks Tract] × 0.84 μg/L [Selenium concentration at San Joaquin River at Vernalis]) + (0.02 [% inflow from Martinez/Suisun Bay water source at Franks Tract] × 0.09 μg/L [Selenium concentration at San Joaquin River near Mildred Island]) + (0.32 [% inflow from Yolo Bypass water source at Franks Tract] × 0.45 μg/L [Selenium concentration at Sacramento River at Knights Landing]) + (5.06 [% inflow from Delta Agriculture water source at Franks Tract] × 0.11 μg/L [Selenium concentration at Mildred Island, Center])/100 = 0.29 μg/L

The quarterly and average annual waterborne selenium concentrations for the DSM2 output locations are shown in Table 5D.B-2 (Year 2000), Table 5D.B-3 (Year 2005), and Table 5D.B-4 (Year 2007).

5D.B.3 Bioaccumulation of Selenium into Whole-Body Fish

Selenium concentrations in whole-body fish were calculated using ecosystem-scale models developed by Presser and Luoma (2010). The models were developed using biogeochemical and physiological factors from laboratory and field studies; information on loading, speciation, and transformation to particulate material; bioavailability; bioaccumulation in invertebrates; and trophic transfer to predators. Important components of the methodology included (1) empirically determined environmental partitioning factors between water and particulate material that quantify the effects of dissolved speciation and phase transformation; (2) concentrations of selenium in living and nonliving particulates at the base of the foodweb that determine selenium bioavailability to invertebrates; and (3) selenium biodynamic foodweb transfer factors that quantify the physiological potential for bioaccumulation from particulate matter to consumer organisms and prey to their predators.

5D.B.3.1 Selenium Concentration in Particulates

Phase transformation reactions from dissolved to particulate selenium are the primary form by which selenium enters the foodweb. Presser and Luoma (2010) used field observations to quantify the relationship between particulate material and dissolved selenium as provided below.

$$C_{particulate} = K_d \bullet C_{water\ column} \qquad \text{(Eq. 2)}$$

Where:

$C_{particulate}$ = selenium concentration in particulate material (micrograms/kilogram, dry weight [µg/kg dw])

$C_{water\ column}$ = selenium concentration in water column (µg/L)

K_d = particulate/water ratio

The K_d describes the particulate/water ratio at the moment the sample was taken and should not be interpreted as an equilibrium constant (as it sometimes is). It can vary widely among hydrologic environments and potentially among seasons (Presser and Luoma 2010). In addition, other factors such as speciation, residence time, and particle type affect K_d. Residence time of selenium is usually the most influential factor on the conditions in the receiving water environment. Short water residence times (e.g., streams and rivers) limit partitioning of selenium into particulate material. Conversely, longer residence times (e.g., sloughs, lakes, estuaries) allow greater uptake by plants, algae, and microorganisms. Furthermore, environments in downstream portions of a watershed can receive cumulative contributions of upstream recycling in a hydrologic system. Due to its high variability, K_d is a large source of uncertainty in the model, especially if translation of selenium concentration in the water column is necessary.

5D.B.3.2 Selenium Concentrations in Invertebrates

Species-specific trophic transfer factors (TTFs) for transfer of selenium from particulates to prey and to predators were developed using data from laboratory experiments and field studies (Presser and Luoma 2010). TTFs are species-specific, but the range of TTFs for freshwater invertebrates was found to be similar to TTFs for marine invertebrates determined in laboratory experiments.

TTFs for estimating selenium concentrations in invertebrates were calculated using the following equation:

$$TTF_{invertebrate} = \frac{C_{invertebrate}}{C_{particulate}} \tag{Eq. 3}$$

Where:

$TTF_{invertebrate}$ = trophic transfer factor from particulate material to invertebrate

$C_{invertebrate}$ = concentration of selenium in invertebrate (μg/g dw)

$C_{particulate}$ = concentration of selenium in particulate material (μg/g dw)

A mean aquatic insect TTF was calculated from TTFs for aquatic insect species with similar bioaccumulative potential, including mayfly (Baetidae; Heptageniidae; Ephemerellidae), caddisfly (Rhyacophilidae; Hydropsychidae), crane fly (Tipulidae), stonefly (Perlodidae/Perlidae; Chloroperlidae), damselfly (Coenagrionidae), corixid (*Cenocorixa* sp.), and chironomid (*Chironomus* sp.) aquatic life stages. Species-specific TTFs ranged from 2.14 to 3.2 with a mean TTF of 2.8.

5D.B.3.3 Selenium Concentrations in Whole-body Fish

The mechanistic equation for modeling of selenium bioaccumulation in fish tissue is similar to that of invertebrates if whole-body concentrations are the endpoint (Presser and Luoma 2010), as follows:

$$TTF_{fish} = \frac{C_{fish}}{C_{invertebrate}}$$

$$where:$$

$$C_{invertebrate} = C_{particulate} \bullet TTF_{invertebrate}$$

$$therefore:$$

$$C_{fish} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \tag{Eq. 4}$$

Where:

C_{fish} = concentration of selenium in fish (μg/g dw)

$C_{invertebrate}$ = concentration of selenium in invertebrate (μg/g dw)

$C_{particulate}$ = concentration of selenium in particulate material (μg/g dw)

$TTF_{invertebrate}$ = trophic transfer factor from particulate material to invertebrate

TTF_{fish} = trophic transfer factor from invertebrate to fish

Modeling of bioaccumulation into a particular fish species includes physiology of the organism and its preferred foods. Therefore, variability in fish tissue concentrations of selenium is driven more by dietary choices and their respective levels of bioaccumulation (i.e., $TTF_{invertebrate}$) than by differences in the dietary transfer to the fish (TTF_{fish}). A diet of mixed prey (including invertebrates or other fish) can be modeled as follows:

$$C_{fish} = TTF_{fish} \bullet \left[(C_1 \bullet F_1) + (C_2 \bullet F_2) + (C_3 \bullet F_3) \right] \quad \text{(Eq. 5)}$$

Where:

C_{fish} = concentration of selenium in fish (µg/g dw)

TTF_{fish} = trophic transfer factor for fish species

$C_{1\text{–}3}$ = concentration of selenium in invertebrate or fish prey items 1, 2, and 3 (µg/g dw)

$F_{1\text{–}3}$ = fraction of diet composed of prey items 1, 2, and 3

Modeling of selenium concentrations in longer foodwebs with higher trophic levels (e.g., forage fish being consumed by predator fish) can be completed by incorporating additional TTFs; for example:

$$C_{predator\ fish} = TTF_{invertebrate} \bullet C_{particulate} \bullet TTF_{forage\ fish} \bullet TTF_{predator\ fish} \quad \text{(Eq. 6)}$$

Where:

$C_{predator\ fish}$ = concentration of selenium in fish (µg/g dw)

$TTF_{invertebrate}$ = trophic transfer factor from particulate material to invertebrate

$C_{particulate}$ = concentration of selenium in particulate material (µg/g dw)

$TTF_{forage\ fish}$ = trophic transfer factor for invertebrates to foraging fish species

$TTF_{predator\ fish}$ = trophic transfer factor for forage fish to predator species

The fish TTFs reported in Presser and Luoma (2010) ranged from 0.5 to 1.6, so the average fish TTF of 1.1 was used for all trophic levels of fish, which also is consistent with the recently published model for fish in the Delta by Presser and Luoma (2013). Although there is variability in the TTF within species and among species due to exposure conditions when bioaccumulation is measured, the mean value provides a reasonable measure of tissue accumulation for comparison between all BDCP scenarios for the modeled species (largemouth bass) as a representative species across the Delta. Additional modeling was conducted for white sturgeon in the western Delta because of higher bioaccumulation of selenium through the benthic food chain upon which the sturgeon depends (see addendum to this attachment).

Modeled selenium concentrations in whole-body fish were used to estimate selenium concentrations in fish fillets, as described below in Section 5D.B.4.

5D.B.4 Refinement of Selenium Bioaccumulation Models for the Delta

Several models were evaluated and refined to estimate selenium uptake in fish from waters in the Delta. Input parameters to the model (K_{ds} and TTF_s) were varied among the models as refinements were made. A summary of the input parameters is presented in Table 5D.B-5. Rationale for each refinement is presented below with the discussion of each model. In addition, largemouth bass collected in the Delta from areas near DSM2 output locations were used to calculate the geometric mean selenium concentration in whole-body fish (Foe 2010a). The ratio of the estimated selenium concentration in fish to measured selenium in whole-body bass was used to evaluate each fish model and to focus refinements to the model. The models evaluated are presented in the following subsections.

5D.B.4.1 Bioaccumulation in Whole-Body Fish

Seven models were evaluated for estimating whole-body selenium concentrations in fish. The basic models were refined by dietary fraction and input parameters to provide a model that would most closely represent conditions in the Delta. Each model is described in this section.

Model 1 was a basic representative of uptake by a forage fish, while Models 2 and 3 calculated sequential bioaccumulation in longer foodwebs representative of predatory fish of increasing complexity as shown below:

- Model 1: Trophic level 3 (TL-3) fish eating invertebrates

$$C_{fish} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \qquad \text{(Eq. 9)}$$

- Model 2: Trophic level 4 (TL-4) fish eating TL-3 fish

$$C_{fish} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \bullet TTF_{fish} \qquad \text{(Eq. 10)}$$

- Model 3: TL-4 fish eating TL-3 fish eating TL-3 and trophic level 2 (TL-2) invertebrates

$$C_{fish} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \bullet TTF_{fish} \qquad \text{(Eq. 11)}$$

Where:

C_{fish} = concentration of selenium in fish (μg/g dw)

$C_{particulate}$ = concentration of selenium in particulate material (μg/g dw)

$TTF_{invertebrate}$ = Trophic transfer factor from particulate material to invertebrate

TTF_{fish} = Trophic transfer factor from invertebrate or fish to fish

In each model, the particulate selenium concentration was estimated using Equation 2 and a default K_d of 1,000. The average TTFs for invertebrates (2.8) and fish (1.1) were also used in each model. The outputs of estimated selenium concentrations and the ratios of estimated fish selenium concentration to measured bass selenium concentration for Models 1, 2, and 3 are presented in Table 5D.B-6 and Figure 5D.B-1 (all figures are provided at the end of this attachment).

Model 1 tended to underestimate the whole-body selenium concentrations in fish when compared to bass data reported in Foe (2010a). This was most likely because Model 1 was estimating a forage fish (TL-3), whereas bass are a predatory fish with expected higher dietary exposure. Consequently, Model 1 was not further developed as the selenium bioaccumulation model to represent fish in the Delta.

Models 2 and 3 are both representative of predatory fish, but Model 2 was very similar to Model 1 in distribution of data and in underestimating bass data. Conversely, Model 3 had a larger distribution and greater variation in the data and significantly overestimated the bass data. These models were used as the basis for Models 4 and 5.

Models 4 and 5 were developed to represent a mixed diet using prey fractions to characterize the diet of fish in the Delta, as follows:

- Model 4: 50% of Model 2 and 50% of Model 3

$$C_{fish\,Model\,4} = (0.5 \bullet C_{fish\,Model\,2}) + (0.5 \bullet C_{fish\,Model\,3}) \qquad \text{(Eq. 12)}$$

- Model 5: 75% of Model 2 and 25% of Model 3

$$C_{fish\,Model\,5} = (0.75 \bullet C_{fish\,Model\,2}) + (0.25 \bullet C_{fish\,Model\,3}) \qquad \text{(Eq. 13)}$$

Models 4 and 5 used the default K_d (1,000), average invertebrate TTF (2.8), and average fish TTF (1.1). The outputs of estimated selenium concentrations and ratios of the estimated selenium concentration in fish to measured selenium concentration in bass data for Models 4 and 5 are presented in Table 5D.B-6 and Figure 5D.B-1. Data distribution and variation were comparatively large in Model 4. Model 5 was relatively predictive of bass data, but was not considered representative of the general population of predatory fish in the Delta. Consequently, it was determined that Model 2 was the most representative of the prey base used by fish in the Delta (i.e., number of trophic levels in the model); therefore, further evaluation and refinement of the selenium bioaccumulation model was limited to Model 2.

In addition, review of Models 1 through 5 indicated that the default value of 1,000 for K_d was not representative of the Delta's potentially high variability and uncertainty with regard to residence time. The Delta tends to have a long water residence time and receives upstream contributions of selenium, and greater recycling and higher concentrations of selenium entering the foodweb are expected. Model 6 was developed using an extrapolated K_d value of 1,400 with Model 2 (Equation 10). The average invertebrate and fish TTFs were used. Model 6 was generally predictive of bass data (ratio median 1.04). The outputs of estimated selenium concentrations and ratios of the estimated selenium concentration in fish to measured selenium concentration in bass data for Model 6 are presented in Table 5D.B-7 and Figure 5D.B-1.

Model 7 was a further refinement whereby site-specific data for dissolved selenium in water and selenium in particulate samples collected in the Delta (Lucas and Stewart 2007) were used to calculate a site-specific K_d of 1,760 (geometric mean). Model 7 used the more representative site-specific K_d (1,760) with Model 2 (Equation 10) and the average invertebrate and fish TTFs (2.8 and 1.1, respectively). The outputs from Model 7 slightly overestimated selenium concentrations in fish compared to selenium concentrations in bass (ratio median 1.30), as shown in Table 5D.B-7 and Figure 5D.B-1.

Model 8 used the site-specific K_d (1,760) and the average fish TTF (1.1). The invertebrate TTF was revised so that mayflies and stoneflies were not included in the average, because these species would not be readily available in the Delta to contribute to fish diets. The revised invertebrate TTF of 2.1 was used in Model 8. The outputs from Model 8 are presented in Table 5D.B-8 and Figure 5D.B-1.

As expected in a large, complex, and diverse ecological habitat such as the Delta, variations in the data distribution and in the outputs of all models including Model 8 (minimum ratio 0.45, maximum ratio 2.21, and median ratio 0.98) were observed. The variation in the models' outputs is primarily influenced by (1) the selenium concentration in water, used to estimate the selenium concentration in fish tissue, and (2) the measured selenium concentration in bass. Variation in selenium concentrations in water among the years was small, so the variation in selenium concentrations in bass was the primary factor determining the temporal variation among the models. One prominent outlier was observed in all models, seasons, and years as shown by the overestimation of selenium concentration in fish to measured selenium in bass collected at Vernalis. The overestimation is likely the result of high selenium concentrations in water calculated during different years (1999–2007) from those when bass were collected (2000, 2005, or 2007).

Data from Year 2000 were the most predictive in estimating selenium concentrations in fish tissue compared to measured selenium concentrations in bass with Model 8 (minimum ratio = 0.53, maximum ratio = 2.21, and median ratio = 0.98; Figure 5D.B-2). Foe (2010a) reported the water-year type for 2000 as "above normal" for both the Sacramento River and San Joaquin River watersheds. It came after "wet" water years and was followed by "dry" water years. Year 2005 selenium concentrations in bass were comparatively lower than those estimated for Year 2000. Year 2005 was wetter than Year 2000 (reported as "above normal" for the Sacramento River watershed and wet for the San Joaquin River watershed), and occurred between periods of wetter water years than reported for Year 2000. As expected in a wet water year, the water residence time is shorter, resulting in less selenium recycling and lower concentrations of selenium entering the foodweb. Under these influences, Model 8 tended to overestimate selenium concentrations in fish for Year 2005 (minimum ratio = 0.79, maximum ratio = 2.12, and median ratio = 1.21; Figure 5D.B-2). For Year 2007, the model generally underestimated the comparatively higher measured selenium concentration in bass (minimum ratio = 0.45, maximum ratio = 1.57, and median ratio = 0.62). Water Year 2007 was reported as dry (Sacramento River watershed) and "critically dry" (San Joaquin River watershed). It came after wet water years and was followed by critically dry water years. This dry water year resulted in a longer water residence time, greater selenium recycling, and higher concentrations of selenium entering the foodweb. Because the influences of a dry water year were not captured in the selenium concentrations in water and were reflected only in bass, Model 8 underestimated selenium concentrations in bass for Year 2007. Therefore, these results illustrate how Model 8 best predicts selenium concentration in fish during normal to wet water years but not dry water years. However, as shown above, Model 8 also can represent selenium bioaccumulation when all water-year types were combined (represented by 2000, 2005, and 2007).

Further evaluation of water-year effects on selenium concentration in bass concluded that a more representative model was needed for dry water years. Therefore, Model 9 used an extrapolated K_d of 2,840, the revised invertebrate TTF of 2.1, and the average fish TTF of 1.1 with Model 2 to provide a better fit for the bass data in dry water years. The outputs of estimated selenium concentrations and ratios of the estimated selenium concentration in fish to measured selenium concentration in bass data for Model 9 are presented in Table 5D.B-9 and Figure 5D.B-3.

Model 8 is relatively predictive of selenium concentration in whole-body bass during normal to wet water years (ratio median 1.04; Figure 5D.B-3) or all water years (ratio median 0.98; Figure 5D.B-1), and Model 9 is considered predictive for dry water years (ratio median 1.00; Figure 5D.B-3). These models were selected as the selenium bioaccumulative models to estimate selenium concentration in whole-body fish in the Delta and are summarized below for ease of reference; see Table 5D.B-5 for K_{ds} and TTF_s:

- Model 8: Trophic level 4 (TL-4) fish eating TL-3 fish

$$\begin{aligned} C_{fish} &= C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \bullet TTF_{fish} \\ &\textit{where:} \\ C_{particulate} &= K_d \bullet C_{water} \end{aligned} \qquad \text{(Eq. 14)}$$

- Model 9: Trophic level 4 (TL-4) fish eating TL-3 fish

$$C_{fish} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \bullet TTF_{fish}$$

$$where:$$

$$C_{particulate} = K_d \bullet C_{water} \quad \text{(Eq. 15)}$$

Where:

$C_{particulate}$ = Concentration of selenium in particulate material (µg/g dw)

C_{water} = selenium concentration in water column (µg/L)

K_d = equilibrium constant

$TTF_{invertebrate}$ = Trophic transfer factor from particulate material to invertebrate

TTF_{fish} = Trophic transfer factor from invertebrate to fish

Because all models greatly overestimated selenium bioaccumulation in fish at Vernalis in all seasons and years, Models 8 and 9 were modified by adjusting the K_d downward to reflect the lower rate of bioaccumulation at that location. The adjusted models used K_d values of 850 for Model 8a and 1,130 for Model 9a. With these adjustments, Model 8a produced a ratio of 1.01 for the comparison of modeled fish to the bass data and Model 9a produced a ratio of 1.00.

5D.B.5 Bioaccumulation in Fish Fillets

Selenium concentrations in whole-body fish were converted to selenium concentrations in skinless fish fillets. The relation between whole-body fish and fish muscle tissue can vary by species and exposure conditions. For modeling purposes, the regression equation provided in Saiki et al. (1991) for largemouth bass from the San Joaquin River system was considered to be the most representative of fish in the Delta and was used for the conversion of these selenium concentrations as follows:

$$SF = -0.388 + 1.322\,WB \quad \text{(Eq. 18)}$$

Where:

SF = selenium concentration in skinless fish fillet (µg/g dw)

WB = selenium concentration in whole-body fish (µg/g dw)

Fish fillet data will be compared to the advisory tissue level (2.5 µg/g) in wet weight (ww) (Office of Environmental Health Hazard Assessment 2008); therefore, wet-weight concentrations were estimated from dry-weight concentrations using the standard conversion equation as follows:

$$WW = DW \bullet (100 - Moist)/100 \quad \text{(Eq. 19)}$$

Where:

WW = selenium concentration in wet weight (µg/g ww)

DW = selenium concentration in dry weight (µg/g dw)

Moist = mean moisture content of the species

Because moisture content in fish varies among species, sample handling, and locations, the mean moisture content of 70% as used by Foe (2010b) was used as an assumed approximation for fish in the Delta for consistency with that report. The final equation used to estimate selenium concentration in skinless fish fillets (wet weight) from selenium concentration in whole-body fish (dry weight) is as follows:

$$SF \quad = \quad (-0.388 + 1.322\,WB) \bullet 0.3 \qquad \text{(Eq. 20)}$$

Where:

SF = selenium concentrations in skinless fish fillet (µg/g ww)

WB = selenium concentration in whole-body fish (µg/g dw)

Using the moisture content of 73.6% for the largemouth bass as reported by Saiki et al. (1991) would result in a slightly lower wet-weight selenium concentration for the fish, because the conversion factor would be 0.26 rather than 0.3.

5D.B.6 Tables

Table 5D.B-1. Selenium Concentrations in Water at Inflow Sources to the Delta

Delta Sources	Representative Inflow Site	Se Concentration in Water (µg/L)[a]	Years	Source
Delta Agriculture	Mildred Island, Center	0.11	2000, 2003–2004	Lucas and Stewart 2007
East Delta Tributaries	Mokelumne, Calaveras, and Cosumnes Rivers[b]	0.1	None	None
Martinez/Suisun Bay	San Joaquin River near Mallard Island	0.09	2000–2008	SFEI Website 2010
Sacramento River	Sacramento River at Freeport	0.32	1996–2001, 2007–2010	USGS Website 2010
San Joaquin River	San Joaquin River at Vernalis (Airport Way)[c]	0.84	1999–2007	SWAMP Website 2009
Yolo Bypass	Sacramento River at Knights Landing[d]	0.45	2003, 2004, 2007, 2008	DWR Website 2009

Notes:

[a] Selenium concentrations are in dissolved fraction unless otherwise noted.

[b] Dissolved selenium concentration is assumed to be 0.1 µg/L due to lack of available data and lack of sources that would be expected to result in concentrations greater than 0.1 µg/L.

[c] Not specified whether total or dissolved selenium.

[d] Total selenium concentration in water.

µg/L = microgram(s) per liter.

GM = geometric mean.

Se = selenium.

Table 5D.B-2. Calculation of Quarterly Average Selenium Concentrations for DSM2 Output Locations: Year 2000

		First Quarter Inflow Percentage						Second Quarter Inflow Percentage						Third Quarter Inflow Percentage					
	Inflow Source →	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**
	Inflow Location →	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**
	Selenium (µg/L) →	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**
DSM2 Output Water Location	**Location ID**																		
Big Break	BIGBRK_MID	2.94	6.88	53.15	6.59	0.18	5.70	2.95	6.37	73.59	13.55	0.27	3.12	3.13	0.45	85.63	0.44	4.15	6.12
Cache Slough	CACHS_LEN	1.46	0	53.38	0	0	31.91	1.24	1.5E-05	85.07	2.5E-05	0	13.25	1.66	4.7E-07	85.95	4.3E-07	5.9E-07	12.23
Cache Slough Ryer	CACHSR_MID	2.88	0	54.86	0	0	20.48	3.36	9.8E-07	79.75	1.9E-06	0	16.25	1.90	9.3E-08	84.53	1.8E-07	9.2E-12	13.38
Cosumnes River	COSR_LEN	8.1E-06	98.82	0	0	0	0	0	100.00	0	0	0	0	0	100.00	0	0	0	0
Franks Tract	FRANKST_MID	5.06	11.56	43.94	15.79	0.02	0.32	4.17	9.42	61.16	23.89	0.01	1.22	4.04	0.57	90.34	0.41	0.80	3.78
Little Holland Tract	LHOLND_L0	72.35	0	5.06	0	0	6.50	23.38	8.2E-07	63.10	1.6E-06	0	13.03	18.48	2.2E-07	68.67	4.2E-07	7.2E-13	12.68
Middle R Bullfrog	MIDRBULFRG_LEN	10.54	13.07	18.37	32.20	1.9E-03	3.2E-03	5.49	9.19	14.96	70.17	4.2E-04	0.10	7.81	6.43	69.63	14.94	0.12	1.02
Mildred Island	MILDDRISL_MID	7.47	14.31	22.79	30.23	2.4E-03	1.8E-03	4.77	10.05	18.48	66.48	6.7E-04	0.13	6.57	4.57	83.28	4.14	0.15	1.25
Mokelumne River below Cosumnes	MOKBCOS_LEN	2.07	96.19	0	0	0	0	1.65	98.35	0	0	0	0	7.23	92.77	4.7E-09	0	0	0
Mokelumne River downstream Cosumnes	MOKDCOS_MID	2.07	96.43	0	0	0	0	1.68	98.32	0	0	0	0	7.08	92.92	0	0	0	0
Old R. near Paradise Cut	OLDRNPARADSEC_MID	6.24	0	0	87.26	0	0	14.40	1.67	5.21	78.66	1.2E-05	0.04	10.56	3.9E-05	1.3E-04	89.44	8.8E-28	3.0E-07
Paradise Cut	PARADSECUT_LEN	4.69	0	0	91.37	0	0	2.62	0.06	0.15	97.16	1.5E-07	1.1E-03	3.43	0	0	96.57	0	0
Port of Stockton	PORTOSTOCK_L0	1.67	0	0	18.85	0	0	2.22	0	0	60.73	0	0	3.09	0	0	81.32	0	0
Sacramento River at Isleton	SACRISLTON_L0	0.33	0	95.77	0	0	0	0.31	0.00	99.60	0	0	5.5E-05	0.44	0	99.55	0	0	1.3E-05
Sacramento River RM 44	SACR44_L0	0.14	0	97.93	0	0	0	0.11	0	99.81	0	0	0	0.13	0	99.86	0	0	0
Sandmound Slough	SANDMND_MID	6.36	10.51	43.82	12.90	0.03	0.57	5.22	8.81	63.78	20.40	0.03	1.63	5.24	0.61	87.78	0.49	1.22	4.59
Sherman Island	SHERMNILND_L0	1.64	3.45	52.71	3.93	0.60	12.10	2.48	4.95	76.80	10.96	0.96	3.67	2.60	0.40	81.69	0.46	8.21	6.56
San Joaquin River Bowman	SJRBOWMN_MID	1.40	0	0	94.03	0	0	1.52	0	0	98.48	0	0	3.00	0	0	97.00	0	0
San Joaquin River N Hwy4	SJRNHWY4_MID	3.49	0	0	89.96	0	0	1.87	0	0	98.13	0	0	3.91	0	0	96.09	0	0
San Joaquin River Naval St	SJRNAVLST_L0	8.89	12.70	0.00	65.44	0	0	2.69	6.26	0	90.94	0	0	5.98	10.89	0	83.00	0	0
San Joaquin River Potato Slough	SJRPOTSL_MID	3.15	12.62	55.38	12.40	0.01	0.06	3.05	10.32	65.93	19.73	0.01	0.86	2.63	0.35	93.54	0.20	0.45	2.79
San Joaquin River Turner	SJRTURNR_MID	8.81	9.28	2.55	56.31	5.3E-05	1.0E-05	3.33	5.77	0.41	90.39	6.3E-06	2.4E-03	8.69	13.75	17.87	59.41	0.01	0.16
San Joaquin River /Pt. Antioch/fish pier	ASRANTFSH_MID	1.92	4.35	55.13	4.50	0.44	10.23	2.45	4.72	77.70	10.28	0.76	3.91	2.64	0.35	83.38	0.38	6.66	6.52
Suisun Bay	SUISNB_LEN	0.81	1.22	45.93	1.24	16.49	15.94	0.92	1.66	49.51	3.61	41.10	2.95	0.80	0.23	27.56	0.40	68.55	2.42
Sycamore Slough	SYCAMOR_MID	6.50	50.69	15.18	0	0	0	5.89	76.86	16.89	2.8E-07	0	0	5.04	14.29	80.66	1.2E-31	0	0
White Slough	WHITESL_L0	22.32	11.88	17.97	25.51	1.7E-08	6.0E-11	16.54	12.10	16.87	54.46	3.7E-09	6.1E-05	9.89	7.76	82.34	3.8E-03	3.0E-05	5.3E-04
White Slough DS Disappointment Sl.	WHTSLDISPONT_LEN	14.83	22.63	29.02	22.45	5.4E-08	0	12.45	13.97	21.21	52.32	2.2E-09	2.3E-04	8.74	7.78	83.47	2.4E-03	4.0E-05	5.6E-04

Table 5D.B-2. Continued

		Fourth Quarter Inflow Percentage						Estimated Waterborne Selenium Concentrations (µg/L)				
	Inflow Source →	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**					
	Inflow Location →	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**1st Quarter**	**2nd Quarter**	**3rd Quarter**	**4th Quarter**	**Annual**
	Selenium (µg/L) →	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**					
DSM2 Output Water Location	**Location ID**											
Big Break	BIGBRK_MID	2.13	0.20	84.85	0.02	8.76	3.96	0.26	0.37	0.31	0.30	0.33
Cache Slough	CACHS_LEN	1.32	2.8E-06	89.83	1.1E-07	2.3E-05	8.67	0.32	0.33	0.33	0.33	0.33
Cache Slough Ryer	CACHSR_MID	1.81	1.0E-07	89.45	6.2E-10	3.0E-06	8.54	0.27	0.33	0.33	0.33	0.33
Cosumnes River	COSR_LEN	0	100.00	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Franks Tract	FRANKST_MID	2.76	0.62	91.38	0.12	2.42	2.64	0.29	0.42	0.32	0.31	0.35
Little Holland Tract	LHOLND_L0	19.63	2.6E-09	72.79	0	0	7.42	0.13	0.29	0.30	0.29	0.29
Middle River Bullfrog	MIDRBULFRG_LEN	4.86	6.31	59.79	27.84	1	0.68	0.35	0.65	0.37	0.44	0.49
Mildred Island	MILDDRISL_MID	4.50	6.63	71.28	16.13	0.61	0.82	0.35	0.63	0.32	0.38	0.44
Mokelumne River below Cosumnes	MOKBCOS_LEN	2.47	97.53	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Mokelumne River downstream Cosumnes	MOKDCOS_MID	2.34	97.66	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Old River near Paradise Cut	OLDRNPARADSEC_MID	2.50	1.1E-04	3.5E-04	97.50	2.8E-20	1.7E-07	0.74	0.70	0.76	0.82	0.76
Paradise Cut	PARADSECUT_LEN	0.96	0	0	99.04	0	0	0.77	0.82	0.82	0.83	0.82
Port of Stockton	PORTOSTOCK_L0	2.70	0	0	89.89	0	0	0.16	0.51	0.69	0.76	0.65
Sacramento River at Isleton	SACRISLTON_L0	0.28	0	99.72	0	0	1.1E-03	0.31	0.32	0.32	0.32	0.32
Sacrament River RM 44	SACR44_L0	0.05	0	99.94	0	0	0	0.31	0.32	0.32	0.32	0.32
Sandmound Slough	SANDMND_MID	3.31	0.43	89.58	0.06	3.44	3.11	0.27	0.40	0.31	0.31	0.34
Sherman Island	SHERMNILND_L0	1.77	0.11	77.64	0.01	16.46	3.94	0.26	0.36	0.31	0.28	0.32
San Joaquin River Bowman	SJRBOWMN_MID	0.33	0	0	99.67	0	0	0.79	0.83	0.82	0.84	0.83
San Joaquin River N Hwy4	SJRNHWY4_MID	0.72	0	0	99.28	0	0	0.76	0.83	0.81	0.83	0.82
San Joaquin River Naval St	SJRNAVLST_L0	2.02	3.10	0.00	94.84	0	0	0.57	0.77	0.71	0.80	0.76
San Joaquin River Potato Slough	SJRPOTSL_MID	2.06	0.80	93.46	0.06	1.47	2.11	0.30	0.39	0.32	0.31	0.34
San Joaquin River Turner	SJRTURNR_MID	3.23	4.83	7.34	84.49	0.03	0.05	0.50	0.77	0.58	0.74	0.70
San Joaquin River /Pt. Antioch/fish pier	ASRANTFSH_MID	1.82	0.12	80.54	0.01	13.33	4.11	0.27	0.36	0.31	0.29	0.32
Suisun Bay	SUISNB_LEN	0.60	0.03	28.62	0.01	69.16	1.54	0.25	0.24	0.16	0.16	0.19
Sycamore Slough	SYCAMOR_MID	4.23	31.10	64.66	0	0	0	0.11	0.14	0.28	0.24	0.22
White Slough	WHITESL_L0	11.19	12.92	75.64	0.24	4.2E-04	6.4E-04	0.31	0.54	0.28	0.27	0.36
White Slough DS Disappointment Sl.	WHTSLDISPONT_LEN	5.28	14.84	79.82	0.05	5.0E-04	7.3E-04	0.32	0.54	0.28	0.28	0.37

Table 5D.B-3. Calculation of Quarterly Average Selenium Concentrations for DSM2 Output Locations: Year 2005

		First Quarter Inflow Percentage						Second Quarter Inflow Percentage						Third Quarter Inflow Percentage					
	Inflow Source →	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**
	Inflow Location →	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**
	Selenium (µg/L) →	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**
DSM2 Output Water Location	**Location ID**																		
Big Break	BIGBRK_MID	5.87	7.57	83.73	2.41	0.24	0.18	2.90	17.21	52.77	26.69	1.6E-03	0.43	3.31	2.21	88.77	1.70	3.98	0.03
Cache Slough	CACHS_LEN	4.89	2.2E-07	93.64	8.E-07	3.8E-07	1.47	1.48	7.1E-07	94.13	8.0E-07	1.1E-08	4.38	1.94	1.7E-05	98.02	1.0E-05	1.6E-06	0.05
Cache Slough Ryer	CACHSR_MID	8.13	3.0E-07	91.14	1.2E-06	1.3E-06	0.73	3.74	2.5E-08	91.89	1.0E-07	2.9E-08	4.38	2.15	5.6E-07	97.77	2.6E-07	4.5E-09	0.08
Cosumnes River	COSR_LEN	0	100.00	0	0	0	0	0.00	100.00	0.00	0	0	0	0	100	0	0	0	0
Franks Tract	FRANKST_MID	8.65	11.65	72.50	7.E+00	0.19	0.05	4.63	16.63	26.97	51.74	1.1E-04	0.03	4.27	3.20	89.93	1.81	0.77	0.02
Little Holland Tract	LHOLND_L0	97.11	3.2E-09	2.88	9.E-09	3.9E-09	0.01	44.12	6.5E-09	53.25	2E-08	1.2E-08	2.63	18.61	5.6E-07	81.24	0.00	0.00	0.16
Middle R Bullfrog	MIDRBULFRG_LEN	13.67	9.76	28.26	48.24	0.08	0.01	5.55	5.64	2.70	86.11	7.1E-05	8.4E-04	7.43	12.50	53.07	26.88	0.12	3.1E-03
Mildred Island	MILDDRISL_MID	12.36	11.39	32.28	43.87	8.4E-02	0.01	4.81	6.98	2.78	85.43	3.6E-05	6.7E-04	6.73	12.68	65.46	14.98	0.15	3.9E-03
Mokelumne River below Cosumnes	MOKBCOS_LEN	2.18	97.82	0	0.00	0	0	0.53	99.47	0	0	0	0	3.05	96.95	0	0	0	0
Mokelumne River downstream Cosumnes	MOKDCOS_MID	2.22	97.78	0	0.00	0	0	0.53	99.47	0	0	0	0	3.05	96.95	0	0	0	0
Old R. near Paradise Cut	OLDRNPARADSEC_MID	8.95	4.7E-05	1.5E-03	91.05	1.4E-05	1.4E-06	1.43	1.7E-07	1.6E-05	98.57	1.7E-08	3.5E-10	6.64	0	5.E-09	93.36	0	0
Paradise Cut	PARADSECUT_LEN	10.28	1.6E-07	6.8E-07	89.72	1.6E-11	1.7E-08	0.82	0	0	99.18	0	0	2.39	0	0	97.61	0	0
Port of Stockton	PORTOSTOCK_L0	4.70	0	0	95.30	0	0	2.83	0	0	97.16	0	0	2.20	0	0	97.80	0	0
Sacramento River at Isleton	SACRISLTON_L0	0.55	0	99.45	0.00	0	0	0.18	0	99.82	0.00	0	0	0.45	0	99.55	0.00	0	0
Sacramento River RM 44	SACR44_L0	0.21	0	99.79	0.00	0	0	0.07	0	99.93	0.00	0	0	0.14	0	99.86	0.00	0	0
Sandmound Slough	SANDMND_MID	10.51	10.17	74.35	4.65	0.25	0.07	5.35	18.03	32.15	44.41	1.5E-04	0.06	5.61	3.13	87.97	2.10	1.17	0.02
Sherman Island	SHERMNILND_L0	4.89	5.04	87.74	1.52	0.56	0.23	2.43	14.17	61.17	21.31	0.03	0.89	2.76	1.84	86.03	1.72	7.62	0.04
San Joaquin River Bowman	SJRBOWMN_MID	1.10	0	0.00	98.90	0	0	0.45	0	0	99.55	0	0	2.06	0	0	97.94	0	0
San Joaquin River N Hwy4	SJRNHWY4_MID	1.89	0	0.00	98.11	0	0	0.59	0	0	99.41	0	0	2.64	0	0	97.36	0	0
San Joaquin River Naval St	SJRNAVLST_L0	4.70	5.45	0.00	89.85	0	0	1.06	5.10	0	93.84	0	0	4.11	9.43	0	86.46	0	0
San Joaquin River Potato Slough	SJRPOTSL_MID	6.24	16.03	71.18	6.45	0.07	0.03	2.65	23.15	38.61	35.59	1.1E-05	0.01	2.75	2.58	93.40	0.83	0.42	0.01
San Joaquin River Turner	SJRTURNR_MID	6.75	4.55	1.37	87.31	0.01	0	1.49	3.20	0.00	95.31	0	0	6.05	11.77	4.90	77.27	0.01	8.4E-05
San Joaquin River /Pt. Antioch/fish pier	ASRANTFSH_MID	4.87	5.29	87.53	1.67	0.37	0.27	2.37	13.56	62.61	20.61	0.02	0.84	2.82	1.68	87.76	1.46	6.24	0.03
Suisun Bay	SUISNB_LEN	2.63	1.36	66.87	0.33	28.58	0.23	1.35	6.21	59.91	8.33	22.38	1.82	0.83	0.82	31.47	1.16	65.65	0.07
Sycamore Slough	SYCAMOR_MID	14.41	68.02	17.57	8.8E-17	0	3.5E-29	3.66	95.02	1.31	1.E-18	0	3.9E-33	4.79	40.41	54.81	2.9E-20	0	1.1E-32
White Slough	WHITESL_L0	47.62	12.39	33.06	6.93	8.2E-04	2.7E-06	15.95	8.06	2.95	73.04	1.4E-05	1.5E-07	10.03	26.20	63.17	0.61	3.0E-05	8.1E-08
White Slough DS Disappointment Sl.	WHTSLDISPONT_LEN	20.77	29.09	44.03	6.11	2.4E-04	3.6E-06	14.40	8.89	3.00	73.72	7.9E-06	0	9.10	26.19	64.27	0.45	3.1E-05	0

Table 5D.B-3. Continued

		Fourth Quarter Inflow Percentage						Estimated Waterborne Selenium Concentrations (µg/L)				
	Inflow Source →	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**					
	Inflow Location →	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**1st Quarter**	**2nd Quarter**	**3rd Quarter**	**4th Quarter**	**Annual**
	Selenium (µg/L) →	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**					
DSM2 Output Water Location	**Location ID**											
Big Break	BIGBRK_MID	2.39	0.24	90.17	0.01	6.48	0.70	0.30	0.42	0.31	0.30	0.33
Cache Slough	CACHS_LEN	2.30	1.2E-05	92.72	4.6E-07	0.00	4.98	0.31	0.32	0.32	0.32	0.32
Cache Slough Ryer	CACHSR_MID	2.66	8.8E-07	96.37	1.9E-08	7.6E-06	0.97	0.30	0.32	0.32	0.32	0.31
Cosumnes River	COSR_LEN	1.2E-04	100.00	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Franks Tract	FRANKST_MID	3.17	0.81	94.16	0.06	1.74	0.05	0.31	0.54	0.31	0.31	0.37
Little Holland Tract	LHOLND_L0	46.22	6.1E-08	53.77	2.8E-08	2.6E-09	0.01	0.12	0.23	0.28	0.22	0.21
Middle River Bullfrog	MIDRBULFRG_LEN	5.54	8.75	65.65	19.67	0.39	1.1E-03	0.52	0.74	0.42	0.39	0.52
Mildred Island	MILDDRISL_MID	4.81	7.16	77.85	9.71	0.47	1.8E-03	0.50	0.74	0.36	0.34	0.48
Mokelumne River below Cosumnes	MOKBCOS_LEN	3.00	97.00	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Mokelumne River downstream Cosumnes	MOKDCOS_MID	2.93	97.07	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Old River near Paradise Cut	OLDRNPARADSEC_MID	14.49	0.24	3.16	82.09	0.02	8.1E-05	0.77	0.83	0.79	0.72	0.78
Paradise Cut	PARADSECUT_LEN	1.08	0	0	98.92	0	0	0.77	0.83	0.82	0.83	0.81
Port of Stockton	PORTOSTOCK_L0	2.20	0	0	97.79	0	0	0.81	0.82	0.82	0.82	0.82
Sacramento River at Isleton	SACRISLTON_L0	0.41	0	99.59	0	0	8.2E-08	0.32	0.32	0.32	0.32	0.32
Sacrament River RM 44	SACR44_L0	0.17	0	99.83	0	0	0	0.32	0.32	0.32	0.32	0.32
Sandmound Slough	SANDMND_MID	3.93	0.55	92.97	0.03	2.45	0.07	0.30	0.50	0.31	0.31	0.35
Sherman Island	SHERMNILND_L0	1.95	0.11	84.69	0.01	11.76	1.48	0.31	0.40	0.30	0.29	0.32
San Joaquin River Bowman	SJRBOWMN_MID	0.80	0	0	99.20	0	0	0.83	0.84	0.83	0.83	0.83
San Joaquin River N Hwy4	SJRNHWY4_MID	1.94	0.00	0	98.06	0	0	0.83	0.84	0.82	0.83	0.83
San Joaquin River Naval St	SJRNAVLST_L0	4.97	12.46	0	82.57	0	0	0.77	0.79	0.74	0.71	0.75
San Joaquin River Potato Slough	SJRPOTSL_MID	2.16	1.30	95.35	0.02	1.04	0.13	0.31	0.45	0.31	0.31	0.34
San Joaquin River Turner	SJRTURNR_MID	5.55	16.96	10.99	66.44	0.06	7.4E-05	0.75	0.81	0.68	0.62	0.71
San Joaquin River /Pt. Antioch/fish pier	ASRANTFSH_MID	2.05	0.14	86.70	0.01	9.68	1.42	0.31	0.39	0.30	0.29	0.32
Suisun Bay	SUISNB_LEN	0.68	0.05	32.01	0.03	66.56	0.68	0.25	0.30	0.17	0.17	0.22
Sycamore Slough	SYCAMOR_MID	5.24	32.04	62.72	2.6E-18	7.7E-14	1.0E-30	0.14	0.10	0.22	0.24	0.18
White Slough	WHITESL_L0	9.32	12.33	78.34	0.01	4.6E-04	4.6E-08	0.23	0.65	0.24	0.27	0.35
White Slough DS Disappointment Sl.	WHTSLDISPONT_LEN	6.26	14.39	79.35	1.9E-03	6.8E-04	0	0.24	0.65	0.25	0.28	0.36

Table 5D.B-4. Calculation of Quarterly Average Selenium Concentrations for DSM2 Output Locations: Year 2007

		First Quarter Inflow Percentage						Second Quarter Inflow Percentage						Third Quarter Inflow Percentage					
	Inflow Source →	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**
	Inflow Location →	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**
	Selenium (µg/L) →	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**
DSM2 Output Water Location	**Location ID**																		
Big Break	BIGBRK_MID	2.66	1.75	93.01	0.07	2.30	0.21	4.40	3.10	84.13	4.24	1.24	2.89	3.58	0.32	81.60	0.79	9.45	4.27
Cache Slough	CACHS_LEN	1.86	1.4E-05	97.14	2.2E-07	2.8E-05	1.01	1.99	5.1E-04	88.84	8.8E-04	1.6E-05	9.17	1.92	9.1E-06	89.20	1.9E-05	1.6E-06	8.88
Cache Slough Ryer	CACHSR_MID	2.85	1.8E-06	96.46	4.7E-08	1.5E-05	0.68	2.66	1.2E-04	88.76	1.8E-04	1.4E-06	8.58	2.16	1.5E-05	88.35	3.1E-05	3.1E-07	9.49
Cosumnes River	COSR_LEN	0.00	100.00	0	0	0	0.00	0.01	99.99	0	0	0	0	0.09	99.91	0	0	0	0
Franks Tract	FRANKST_MID	3.85	4.08	90.69	0.32	0.94	0.11	6.16	5.35	77.86	9.10	0.16	1.38	4.86	0.34	88.03	0.84	2.96	2.98
Little Holland Tract	LHOLND_L0	29.80	0.00	69.38	1.2E-07	5.3E-05	0.81	22.80	8.0E-05	71.18	1.1E-04	5.2E-06	6.02	18.52	2.4E-05	73.18	0.00	4.9E-07	8.30
Middle R Bullfrog	MIDRBULFRG_LEN	8.32	10.69	59.08	21.39	0.48	0.04	9.69	10.67	38.75	40.64	0.03	0.22	8.41	3.92	81.16	4.51	0.87	1.14
Mildred Island	MILDDRISL_MID	7.42	11.13	68.24	12.63	0.54	0.04	8.53	10.39	42.57	38.23	0.03	0.25	6.49	1.12	88.25	1.83	1.00	1.30
Mokelumne River below Cosumnes	MOKBCOS_LEN	1.46	98.54	0	0	0	0	6.32	93.68	6.5E-04	0	0	0	15.09	84.81	0.10	6.2E-35	0	0
Mokelumne River downstream Cosumnes	MOKDCOS_MID	1.46	98.54	0	0	0	0	6.42	93.58	0	0	0	0	15.19	84.81	3.2E-04	0	0	0
Old R. near Paradise Cut	OLDRNPARADSEC_MID	3.95	5E-12	3E-06	96.05	1.7E-16	2.5E-17	15.73	1.81	12.66	69.68	0.02	0.10	10.18	1.9E-05	1.6E-04	89.82	6.9E-08	6.5E-07
Paradise Cut	PARADSECUT_LEN	1.91	0	0	98.09	0	0	4.98	0.11	0.61	94.29	6.7E-04	3.7E-03	7.14	0	0	92.86	0	0
Port of Stockton	PORTOSTOCK_L0	1.48	0	0	98.52	0	0	2.29	0	0	97.71	0	0	6.32	0.04	0	93.64	0	0
Sacramento River at Isleton	SACRISLTON_L0	0.45	0	99.55	0	0	2.1E-06	0.63	8.8E-05	99.36	5.7E-08	0	0.01	0.49	0	99.51	0	0	2.9E-04
Sacramento River RM 44	SACR44_L0	0.20	0	99.80	0	0	0	0.30	0	99.70	0	0	0	0.15	0	99.85	0	0	0
Sandmound Slough	SANDMND_MID	4.47	3.23	90.83	0.17	1.17	0.13	7.20	4.64	79.23	6.98	0.23	1.71	6.15	0.39	84.96	0.98	4.06	3.46
Sherman Island	SHERMNILND_L0	2.14	0.95	92.16	0.04	4.49	0.23	3.69	2.31	83.94	2.94	4.01	3.11	2.99	0.32	77.36	0.77	14.22	4.34
San Joaquin River Bowman	SJRBOWMN_MID	0.88	0	0	99.12	0	0	3.52	0	0	96.48	0	0	8.49	2.5E-04	0	91.51	0	0
San Joaquin River N Hwy4	SJRNHWY4_MID	1.82	2.8E-08	0	98.18	0	0	4.35	1.4E-07	0	95.65	0	0	12.54	0.08	4.0E-26	87.39	0	0
San Joaquin River Naval St	SJRNAVLST_L0	4.83	6.83	0	88.35	0	0	5.86	11.12	1.3E-06	83.02	0	0	12.06	40.15	3.4E-03	47.78	6.2E-07	6.3E-06
San Joaquin River Potato Slough	SJRPOTSL_MID	2.91	5.22	91.00	0.15	0.61	0.10	4.89	5.67	79.70	8.49	0.10	1.16	3.16	0.19	91.86	0.46	1.88	2.44
San Joaquin River Turner	SJRTURNR_MID	7.22	10.11	10.82	71.76	0.08	0.01	7.49	11.95	7.23	73.31	2.9E-03	0.02	11.09	11.29	65.50	11.02	0.46	0.63
San Joaquin River /Pt. Antioch/fish pier	ASRANTFSH_MID	2.17	1.01	92.90	0.04	3.62	0.26	3.74	2.30	84.37	3.04	3.24	3.31	3.00	0.27	79.62	0.65	12.05	4.40
Suisun Bay	SUISNB_LEN	0.87	0.23	46.77	0.01	51.97	0.14	0.94	0.51	31.58	0.43	65.55	0.98	0.84	0.16	21.30	0.36	76.08	1.25
Sycamore Slough	SYCAMOR_MID	10.20	72.58	17.22	5.1E-10	9.7E-14	4.3E-29	13.62	50.90	35.47	0.01	4.0E-09	1.1E-07	5.33	3.90	90.77	1.9E-16	3.8E-25	1.1E-22
White Slough	WHITESL_L0	20.35	16.73	61.67	1.25	4.8E-03	2.4E-04	33.31	13.41	23.49	29.78	3.9E-04	3.2E-03	15.53	1.33	83.05	0.09	1.2E-03	2.0E-03
White Slough DS Disappointment Sl.	WHTSLDISPONT_LEN	10.09	24.12	65.07	0.71	4.1E-03	1.9E-04	17.00	13.60	32.29	37.10	1.4E-03	0.01	7.70	1.46	90.83	1.5E-03	1.3E-03	2.2E-03

Table 5D.B-4. Continued

		Fourth Quarter Inflow Percentage						Estimated Waterborne Selenium Concentrations (µg/L)				
	Inflow Source →	**Delta Ag.**	**East Delta Tributaries**	**Sacramento River**	**San Joaquin River**	**Martinez/ Suisun Bay**	**Yolo Bypass**					
	Inflow Location →	**Mildred Island, Center**	**Mokelumne Calaveras Cosumnes Rivers**	**Freeport**	**Vernalis**	**Mallard Island, Center**	**Knights Landing**	**1st Quarter**	**2nd Quarter**	**3rd Quarter**	**4th Quarter**	**Annual**
	Selenium (µg/L) →	**0.113**	**0.100**	**0.320**	**0.840**	**0.088**	**0.450**					
DSM2 Output Water Location	**Location ID**											
Big Break	BIGBRK_MID	2.60	0.11	84.06	0.04	8.53	4.65	0.31	0.33	0.30	0.30	0.31
Cache Slough	CACHS_LEN	1.64	1.9E-05	91.73	8.5E-06	5.1E-04	6.62	0.32	0.33	0.33	0.33	0.32
Cache Slough Ryer	CACHSR_MID	1.96	4.5E-06	90.83	2.8E-06	1.9E-04	7.21	0.31	0.33	0.33	0.33	0.32
Cosumnes River	COSR_LEN	0	100.00	0	0	0	0.00	0.10	0.10	0.10	0.10	0.10
Franks Tract	FRANKST_MID	3.19	0.32	91.15	0.17	2.23	2.95	0.30	0.34	0.31	0.31	0.32
Little Holland Tract	LHOLND_L0	21.64	5.2E-07	71.72	1.4E-06	4.9E-05	6.64	0.26	0.28	0.29	0.28	0.28
Middle River Bullfrog	MIDRBULFRG_LEN	5.81	4.90	72.42	15.36	0.57	0.94	0.39	0.49	0.32	0.38	0.39
Mildred Island	MILDDRISL_MID	4.91	4.55	80.81	7.99	0.66	1.08	0.34	0.48	0.31	0.34	0.37
Mokelumne River below Cosumnes	MOKBCOS_LEN	2.30	97.70	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Mokelumne River downstream Cosumnes	MOKDCOS_MID	2.27	97.73	0	0	0	0	0.10	0.10	0.10	0.10	0.10
Old River near Paradise Cut	OLDRNPARADSEC_MID	2.31	9.2E-04	0.01	97.68	0	9.7E-05	0.81	0.65	0.77	0.82	0.76
Paradise Cut	PARADSECUT_LEN	1.24	4.1E-03	0.05	98.71	4.1E-04	4.5E-04	0.83	0.80	0.79	0.83	0.81
Port of Stockton	PORTOSTOCK_L0	7.16	0.05	0	92.78	0	0	0.83	0.82	0.79	0.79	0.81
Sacramento River at Isleton	SACRISLTON_L0	0.39	1.0E-08	99.61	0	6.7E-07	0.01	0.32	0.32	0.32	0.32	0.32
Sacrament River RM 44	SACR44_L0	0.11	0	99.89	0	0	0	0.32	0.32	0.32	0.32	0.32
Sandmound Slough	SANDMND_MID	3.79	0.22	89.26	0.10	3.11	3.51	0.30	0.33	0.31	0.31	0.31
Sherman Island	SHERMNILND_L0	2.22	0.06	75.89	0.03	17.11	4.68	0.30	0.32	0.29	0.28	0.30
San Joaquin River Bowman	SJRBOWMN_MID	0.91	0	0	99.09	0	0	0.83	0.81	0.78	0.83	0.81
San Joaquin River N Hwy4	SJRNHWY4_MID	1.89	1.3E-04	0	98.11	0	0	0.83	0.81	0.75	0.83	0.80
San Joaquin River Naval St	SJRNAVLST_L0	4.73	6.37	2.5E-04	88.90	5.4E-09	7.0E-09	0.75	0.72	0.46	0.76	0.67
San Joaquin River Potato Slough	SJRPOTSL_MID	2.37	0.33	93.43	0.10	1.44	2.33	0.30	0.34	0.31	0.31	0.32
San Joaquin River Turner	SJRTURNR_MID	6.16	6.57	36.18	50.55	0.19	0.35	0.66	0.66	0.33	0.56	0.55
San Joaquin River /Pt. Antioch/fish pier	ASRANTFSH_MID	2.27	0.07	78.73	0.03	14.08	4.82	0.31	0.32	0.29	0.29	0.30
Suisun Bay	SUISNB_LEN	0.59	0.02	21.39	0.01	76.63	1.36	0.20	0.17	0.14	0.14	0.16
Sycamore Slough	SYCAMOR_MID	3.69	20.36	75.95	6.0E-19	1.1E-37	2.4E-31	0.14	0.18	0.30	0.27	0.22
White Slough	WHITESL_L0	9.35	8.62	81.98	0.04	3.7E-04	7.1E-04	0.25	0.38	0.29	0.28	0.30
White Slough DS Disappointment Sl.	WHTSLDISPONT_LEN	5.21	9.69	85.06	0.03	9.7E-04	2.1E-03	0.25	0.45	0.30	0.29	0.32

Table 5D.B-5. Summary of Parameter Values Used in Model Calculations

Model	Use	K_d	Trophic Transfer Factors	
			$TTF_{invertebrate}$	TTF_{fish}
1	NA	1,000	2.8	1.1
2	NA	1,000	2.8	1.1
3	NA	1,000	2.8	1.1
4	NA	1,000	2.8	1.1
5	NA	1,000	2.8	1.1
6	NA	1,400	2.8	1.1
7	NA	1,760	2.8	1.1
8	Normal to Wet Years	1,760	2.1	1.1
9	Dry Years	2,840	2.1	1.1

Notes:
NA = not applicable.
K_d = water to sediment partition coefficient.
TTF = trophic transfer factor.
Sources:
K_d 1,000: default value.
K_d 1,760: site-specific value calculated from Lucas and Stewart (2007).
K_d 2,840: extrapolated to address dry water years.
TTFs: mean of selected species (Presser and Luoma 2010).

1 **Table 5D.B-6. Selenium Bioaccumulation from Water (µg/L) to Particulates and Fish (µg/g, dw) Using Models 1 through 5**

	Year 2000														Year 2005														Year 2007													
	Concentration									Fish-to-Bass Ratio					Concentration									Fish-to-Bass Ratio					Concentration									Fish-to-Bass Ratio				
DSM2 Delta Water Location	DSM2 Water	Particulate from Water	Invert. from Particulate	Model 1 Fish	Model 2 Fish	Model 3 Fish	Model 4 Fish	Model 5 Fish	Whole-Body Bass[a]	Model 1	Model 2	Model 3	Model 4	Model 5	DSM2 Water	Particulate from Water	Invert. from Particulate	Model 1 Fish	Model 2 Fish	Model 3 Fish	Model 4 Fish	Model 5 Fish	Whole-Body Bass[a]	Model 1	Model 2	Model 3	Model 4	Model 5	DSM2 Water	Particulate from Water	Invert. from Particulate	Model 1 Fish	Model 2 Fish	Model 3 Fish	Model 4 Fish	Model 5 Fish	Whole-Body Bass[a]	Model 1	Model 2	Model 3	Model 4	Model 5
	First Quarter														First Quarter														First Quarter													
Sac River RM 44	0.31	0.31	0.88	0.97	1.06	2.97	2.02	1.54	2.6	0.37	0.40	1.13	0.77	0.58	0.32	0.32	0.89	0.98	1.08	3.03	2.06	1.57	1.5	0.68	0.74	2.08	1.41	1.08	0.32	0.32	0.89	0.98	1.08	3.03	2.06	1.57	1.8	0.53	0.59	1.64	1.12	0.85
Cache Slough Ryer[b]	0.27	0.27	0.76	0.83	0.92	2.57	1.74	1.33	1.5	0.56	0.61	1.72	1.17	0.89	0.30	0.30	0.85	0.94	1.03	2.89	1.96	1.49	1.7	0.54	0.60	1.67	1.13	0.86	0.31	0.31	0.88	0.97	1.07	2.99	2.03	1.55	2.5	0.38	0.42	1.17	0.80	0.61
SJR Potato Slough	0.30	0.30	0.83	0.92	1.01	2.83	1.92	1.46	1.4	0.68	0.74	2.08	1.41	1.08	0.31	0.31	0.85	0.94	1.03	2.90	1.96	1.50	1.3	0.72	0.79	2.21	1.50	1.15	0.30	0.30	0.85	0.93	1.02	2.86	1.94	1.48	2.5	0.37	0.41	1.15	0.78	0.60
Franks Tract	0.29	0.29	0.82	0.90	0.99	2.77	1.88	1.43	1.6	0.55	0.60	1.68	1.14	0.87	0.31	0.31	0.87	0.96	1.06	2.96	2.01	1.53	1.1	0.84	0.92	2.59	1.76	1.34	0.30	0.30	0.85	0.93	1.03	2.87	1.95	1.49	3.0	0.31	0.34	0.96	0.65	0.50
Big Break	0.26	0.26	0.73	0.81	0.89	2.48	1.68	1.28	1.6	0.52	0.57	1.60	1.09	0.83	0.30	0.30	0.85	0.93	1.03	2.88	1.95	1.49	1.0	0.92	1.01	2.82	1.91	1.46	0.31	0.31	0.86	0.94	1.04	2.90	1.97	1.50	2.8	0.33	0.37	1.02	0.69	0.53
Middle R. Bullfrog	0.35	0.35	0.99	1.09	1.20	3.36	2.28	1.74	NA	NA	NA	NA	NA	NA	0.52	0.52	1.46	1.60	1.76	4.94	3.35	2.56	1.9	0.8	0.9	2.6	1.8	1.3	0.39	0.39	1.09	1.20	1.32	3.69	2.51	1.91	2.1	0.6	0.6	1.7	1.2	0.9
Old R. near Paradise Cut[c]	0.74	0.74	2.07	2.28	2.51	7.02	4.76	3.64	NA	NA	NA	NA	NA	NA	0.77	0.77	2.17	2.39	2.63	7.35	4.99	3.81	2.4	1.0	1.1	3.1	2.1	1.6	0.81	0.81	2.27	2.50	2.75	7.70	5.22	3.99	NA	NA	NA	NA	NA	NA
Knights Landing[d]	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	2.2	0.6	0.7	1.9	1.3	1.0	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA
Vernalis[e]	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.7	1.52	1.67	4.69	3.18	2.43	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.9	1.36	1.50	4.19	2.85	2.17	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	2.4	1.08	1.19	3.32	2.25	1.72
	Second Quarter														Second Quarter														Second Quarter													
Sac River RM 44	0.32	0.32	0.89	0.98	1.08	3.03	2.06	1.57	2.6	0.37	0.41	1.15	0.78	0.60	0.32	0.32	0.90	0.99	1.08	3.03	2.06	1.57	1.5	0.68	0.74	2.09	1.42	1.08	0.32	0.32	0.89	0.98	1.08	3.03	2.06	1.57	1.8	0.53	0.59	1.64	1.12	0.85
Cache Slough Ryer[b]	0.33	0.33	0.93	1.02	1.13	3.15	2.14	1.63	1.5	0.69	0.75	2.11	1.43	1.09	0.32	0.32	0.89	0.98	1.08	3.02	2.05	1.56	1.7	0.57	0.62	1.75	1.18	0.90	0.33	0.33	0.91	1.00	1.10	3.09	2.10	1.60	2.5	0.39	0.43	1.21	0.82	0.63
SJR Potato Slough	0.39	0.39	1.10	1.21	1.34	3.74	2.54	1.94	1.4	0.89	0.98	2.76	1.87	1.43	0.45	0.45	1.26	1.38	1.52	4.26	2.89	2.20	1.3	1.06	1.16	3.25	2.21	1.68	0.34	0.34	0.96	1.06	1.16	3.25	2.21	1.68	2.5	0.43	0.47	1.31	0.89	0.68
Franks Tract	0.42	0.42	1.16	1.28	1.41	3.95	2.68	2.04	1.6	0.78	0.86	2.40	1.63	1.24	0.54	0.54	1.52	1.67	1.84	5.15	3.49	2.67	1.1	1.46	1.61	4.50	3.05	2.33	0.34	0.34	0.96	1.06	1.17	3.27	2.22	1.69	3.0	0.35	0.39	1.09	0.74	0.57
Big Break	0.37	0.37	1.05	1.15	1.26	3.54	2.40	1.83	1.6	0.74	0.82	2.28	1.55	1.18	0.42	0.42	1.16	1.28	1.41	3.94	2.67	2.04	1.0	1.25	1.38	3.86	2.62	2.00	0.33	0.33	0.92	1.01	1.11	3.10	2.10	1.61	2.8	0.36	0.39	1.09	0.74	0.57
Middle R. Bullfrog	0.65	0.65	1.83	2.01	2.21	6.20	4.20	3.21	NA	NA	NA	NA	NA	NA	0.74	0.74	2.08	2.29	2.52	7.06	4.79	3.65	1.9	1.2	1.3	3.7	2.5	1.9	0.49	0.49	1.37	1.50	1.65	4.63	3.14	2.40	2.1	0.7	0.8	2.2	1.5	1.1
Old R. near Paradise Cut[c]	0.70	0.70	1.95	2.14	2.36	6.60	4.48	3.42	NA	NA	NA	NA	NA	NA	0.83	0.83	2.32	2.56	2.81	7.87	5.34	4.08	2.4	1.1	1.2	3.3	2.2	1.7	0.65	0.65	1.81	1.99	2.19	6.13	4.16	3.17	NA	NA	NA	NA	NA	NA
Knights Landing[d]	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	2.2	0.6	0.7	1.9	1.3	1.0	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA
Vernalis[e]	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.7	1.52	1.67	4.69	3.18	2.43	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.9	1.36	1.50	4.19	2.85	2.17	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	2.4	1.08	1.19	3.32	2.25	1.72
	Third Quarter														Third Quarter														Third Quarter													
Sac River RM 44	0.32	0.32	0.90	0.98	1.08	3.03	2.06	1.57	2.6	0.37	0.41	1.15	0.78	0.60	0.32	0.32	0.90	0.98	1.08	3.03	2.06	1.57	1.5	0.68	0.74	2.08	1.41	1.08	0.32	0.32	0.90	0.98	1.08	3.03	2.06	1.57	1.8	0.53	0.59	1.65	1.12	0.85
Cache Slough Ryer[b]	0.33	0.33	0.93	1.03	1.13	3.16	2.14	1.64	1.5	0.69	0.76	2.11	1.44	1.10	0.32	0.32	0.88	0.97	1.07	2.99	2.03	1.55	1.7	0.56	0.62	1.73	1.18	0.90	0.33	0.33	0.92	1.01	1.11	3.11	2.11	1.61	2.5	0.40	0.44	1.22	0.83	0.63
SJR Potato Slough	0.32	0.32	0.89	0.98	1.07	3.01	2.04	1.56	1.4	0.72	0.79	2.22	1.50	1.15	0.31	0.31	0.87	0.96	1.06	2.96	2.01	1.53	1.3	0.73	0.81	2.26	1.53	1.17	0.31	0.31	0.88	0.97	1.06	2.98	2.02	1.54	2.5	0.39	0.43	1.20	0.82	0.62
Franks Tract	0.32	0.32	0.88	0.97	1.07	2.99	2.03	1.55	1.6	0.59	0.65	1.82	1.23	0.94	0.31	0.31	0.87	0.96	1.06	2.96	2.01	1.53	1.1	0.84	0.92	2.58	1.75	1.34	0.31	0.31	0.87	0.96	1.05	2.95	2.00	1.53	3.0	0.32	0.35	0.99	0.67	0.51
Big Break	0.31	0.31	0.88	0.96	1.06	2.97	2.01	1.54	1.6	0.62	0.68	1.91	1.30	0.99	0.31	0.31	0.86	0.95	1.04	2.92	1.98	1.51	1.0	0.93	1.02	2.86	1.94	1.48	0.30	0.30	0.84	0.92	1.02	2.84	1.93	1.47	2.8	0.33	0.36	1.00	0.68	0.52
Middle R. Bullfrog	0.37	0.37	1.03	1.13	1.25	3.49	2.37	1.81	NA	NA	NA	NA	NA	NA	0.42	0.42	1.17	1.28	1.41	3.95	2.68	2.05	1.9	0.7	0.7	2.1	1.4	1.1	0.32	0.32	0.89	0.98	1.07	3.01	2.04	1.56	2.1	0.5	0.5	1.4	1.0	0.7
Old R. near Paradise Cut[c]	0.76	0.76	2.14	2.35	2.59	7.24	4.91	3.75	NA	NA	NA	NA	NA	NA	0.79	0.79	2.22	2.44	2.68	7.51	5.10	3.89	2.4	1.0	1.1	3.2	2.1	1.6	0.77	0.77	2.14	2.36	2.60	7.27	4.93	3.76	NA	NA	NA	NA	NA	NA
Knights Landing[d]	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	2.2	0.6	0.7	1.9	1.3	1.0	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA
Vernalis[e]	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.7	1.52	1.67	4.69	3.18	2.43	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.9	1.36	1.50	4.19	2.85	2.17	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	2.4	1.08	1.19	3.32	2.25	1.72
	Fourth Quarter														Fourth Quarter														Fourth Quarter													
Sac River RM 44	0.32	0.32	0.90	0.99	1.08	3.03	2.06	1.57	2.6	0.37	0.41	1.15	0.78	0.60	0.32	0.32	0.90	0.98	1.08	3.03	2.06	1.57	1.5	0.68	0.74	2.08	1.41	1.08	0.32	0.32	0.90	0.98	1.08	3.03	2.06	1.57	1.8	0.53	0.59	1.65	1.12	0.85
Cache Slough Ryer[b]	0.33	0.33	0.91	1.01	1.11	3.10	2.10	1.61	1.5	0.67	0.74	2.08	1.41	1.08	0.32	0.32	0.88	0.97	1.07	3.00	2.03	1.55	1.7	0.56	0.62	1.73	1.18	0.90	0.33	0.33	0.91	1.00	1.10	3.09	2.09	1.60	2.5	0.39	0.43	1.21	0.82	0.63

DSM2 Delta Water Location	Year 2000														Year 2005														Year 2007													
	Concentration								Whole-Body Bass[a]	Fish-to-Bass Ratio					Concentration								Whole-Body Bass[a]	Fish-to-Bass Ratio					Concentration								Whole-Body Bass[a]	Fish-to-Bass Ratio				
	DSM2 Water	Particulate from Water	Invert. from Particulate	Model 1 Fish	Model 2 Fish	Model 3 Fish	Model 4 Fish	Model 5 Fish		Model 1	Model 2	Model 3	Model 4	Model 5	DSM2 Water	Particulate from Water	Invert. from Particulate	Model 1 Fish	Model 2 Fish	Model 3 Fish	Model 4 Fish	Model 5 Fish		Model 1	Model 2	Model 3	Model 4	Model 5	DSM2 Water	Particulate from Water	Invert. from Particulate	Model 1 Fish	Model 2 Fish	Model 3 Fish	Model 4 Fish	Model 5 Fish		Model 1	Model 2	Model 3	Model 4	Model 5
SJR Potato Slough	0.31	0.31	0.88	0.97	1.06	2.97	2.02	1.54	1.4	0.71	0.78	2.19	1.49	1.13	0.31	0.31	0.87	0.96	1.05	2.95	2.00	1.53	1.3	0.73	0.80	2.25	1.53	1.17	0.31	0.31	0.88	0.97	1.07	2.98	2.03	1.55	2.5	0.39	0.43	1.20	0.82	0.62
Franks Tract	0.31	0.31	0.87	0.96	1.05	2.95	2.00	1.53	1.6	0.58	0.64	1.79	1.22	0.93	0.31	0.31	0.86	0.95	1.04	2.92	1.98	1.51	1.1	0.83	0.91	2.55	1.73	1.32	0.31	0.31	0.87	0.96	1.06	2.96	2.01	1.53	3.0	0.32	0.35	0.99	0.67	0.51
Big Break	0.30	0.30	0.84	0.92	1.02	2.84	1.93	1.47	1.6	0.60	0.66	1.83	1.25	0.95	0.30	0.30	0.84	0.93	1.02	2.85	1.93	1.48	1.0	0.91	1.00	2.79	1.90	1.45	0.30	0.30	0.84	0.93	1.02	2.85	1.94	1.48	2.8	0.33	0.36	1.01	0.68	0.52
Middle R. Bullfrog	0.44	0.44	1.23	1.36	1.49	4.18	2.84	2.16	NA	NA	NA	NA	NA	NA	0.39	0.39	1.09	1.20	1.32	3.71	2.51	1.92	1.9	0.6	0.7	1.9	1.3	1.0	0.38	0.38	1.06	1.16	1.28	3.58	2.43	1.85	2.1	0.5	0.6	1.7	1.1	0.9
Old R. near Paradise Cut[c]	0.82	0.82	2.30	2.53	2.78	7.80	5.29	4.04	NA	NA	NA	NA	NA	NA	0.72	0.72	2.01	2.21	2.43	6.80	4.61	3.52	2.4	0.9	1.0	2.9	1.9	1.5	0.82	0.82	2.30	2.54	2.79	7.81	5.30	4.04	NA	NA	NA	NA	NA	NA
Knights Landing[d]	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	2.2	0.6	0.7	1.9	1.3	1.0	0.45	0.45	1.26	1.39	1.52	4.27	2.90	2.21	NA	NA	NA	NA	NA	NA
Vernalis[e]	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.7	1.52	1.67	4.69	3.18	2.43	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	1.9	1.36	1.50	4.19	2.85	2.17	0.84	0.84	2.35	2.59	2.85	7.97	5.41	4.13	2.4	1.08	1.19	3.32	2.25	1.72

Notes:

Equations from Presser and Luoma (2010) were used to calculate selenium concentrations for fish (Models 1–5) using the default K_d (1000), the average selenium trophic transfer factors to aquatic insects (2.8), and fish (1.1 for all trophic levels).

Model 1 = TL-3 Fish Eating Invertebrates
Model 2 = TL-4 Fish Eating TL-3 Fish
Model 3 = TL-4 Fish Eating TL-3 Fish Eating TL-3 and TL-2 Invertebrates
Model 4 = 50% of Model 2 + 50% of Model 3
Model 5 = 75% of Model 2 + 25% of Model 3
Invert. = invertebrate
K_d = equilibrium constant
μg/g, dw = micrograms per gram, dry weight
NA = not available; bass not collected here
RM = river mile
TL = trophic level

[a] Geometric mean calculated from whole-body largemouth bass data presented in Foe (2010a).

[b] Fish data collected at Rio Vista (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[c] Fish data collected at Old River near Tracy (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[d] Geometric mean of total selenium concentrations in water collected from years 2003, 2004, 2007, and 2008 (DWR Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available). Fish data collected at Sacramento River at Veterans Bridge (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[e] Geometric mean of selenium concentrations (total or dissolved was not specified) in water collected from years 1999–2007 (SWAMP Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available).

Table 5D.B-7. Selenium Bioaccumulation from Water (µg/L) to Particulates and Fish (µg/g, dw) Using Models 6 and 7

	Year 2000										Year 2005										Year 2007									
	Concentration							Whole-Body Bass[a]	Fish-to-Bass Ratio		Concentration							Whole-Body Bass[a]	Fish-to-Bass Ratio		Concentration							Whole-Body Bass[a]	Fish-to-Bass Ratio	
		Model 6			Model 7							Model 6			Model 7							Model 6			Model 7					
DSM2 Delta Water Location	DSM2 Water	Particulate From Water	Invert. From Particulate	Fish	Particulate From Water	Invert. From Particulate	Fish		Model 6	Model 7	DSM2 Water	Particulate From Water	Invert. from Particulate	Fish	Particulate From Water	Invert. From Particulate	Fish		Model 6	Model 7	DSM2 Water	Particulate From Water	Invert. From Particulate	Fish	Particulate From Water	Invert. From Particulate	Fish		Model 6	Model 7
	First Quarter										First Quarter										First Quarter									
Sac River RM 44	0.31	0.44	1.23	1.49	0.55	1.55	1.87	2.6	0.56	0.71	0.32	0.45	1.25	1.52	0.56	1.57	1.91	1.5	1.04	1.31	0.32	0.45	1.25	1.52	0.56	1.57	1.91	1.8	0.82	1.03
Cache Slough Ryer[b]	0.27	0.38	1.06	1.29	0.48	1.34	1.62	1.5	0.86	1.08	0.30	0.43	1.19	1.44	0.54	1.50	1.81	1.7	0.84	1.05	0.31	0.44	1.23	1.49	0.55	1.55	1.88	2.5	0.59	0.74
SJR Potato Slough	0.30	0.42	1.17	1.41	0.52	1.47	1.78	1.4	1.04	1.31	0.31	0.43	1.20	1.45	0.54	1.50	1.82	1.3	1.11	1.39	0.30	0.42	1.18	1.43	0.53	1.49	1.80	2.5	0.58	0.73
Franks Tract	0.29	0.41	1.14	1.38	0.51	1.44	1.74	1.6	0.84	1.06	0.31	0.44	1.22	1.48	0.55	1.54	1.86	1.1	1.29	1.63	0.30	0.42	1.19	1.44	0.53	1.49	1.80	3.0	0.48	0.60
Big Break	0.26	0.37	1.02	1.24	0.46	1.29	1.56	1.6	0.80	1.01	0.30	0.42	1.19	1.44	0.53	1.50	1.81	1.0	1.41	1.77	0.31	0.43	1.20	1.45	0.54	1.51	1.82	2.8	0.51	0.64
Middle R. Bullfrog	0.35	0.50	1.39	1.68	0.62	1.75	2.11	NA	NA	NA	0.52	0.73	2.04	2.47	0.92	2.57	3.11	1.9	1.3	1.6	0.39	0.55	1.53	1.85	0.69	1.92	2.32	2.1	0.9	1.1
Old R. near Paradise Cut[c]	0.74	1.04	2.90	3.51	1.30	3.65	4.41	NA	NA	NA	0.77	1.08	3.04	3.68	1.36	3.82	4.62	2.4	1.5	1.9	0.81	1.14	3.18	3.85	1.43	4.00	4.84	NA	NA	NA
Knights Landing[d]	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA	0.45	0.63	1.76	2.13	0.79	2.22	2.68	2.2	1.0	1.2	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA
Vernalis[e]	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.7	2.34	2.95	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.9	2.10	2.64	0.84	1.18	3.29	3.98	1.48	4.14	5.01	2.4	1.66	2.09
	Second Quarter										Second Quarter										Second Quarter									
Sac River RM 44	0.32	0.45	1.25	1.52	0.56	1.57	1.91	2.6	0.58	0.72	0.32	0.45	1.25	1.52	0.56	1.58	1.91	1.5	1.04	1.31	0.32	0.45	1.25	1.51	0.56	1.57	1.90	1.8	0.82	1.03
Cache Slough Ryer[b]	0.33	0.46	1.30	1.58	0.58	1.64	1.98	1.5	1.06	1.33	0.32	0.45	1.25	1.51	0.56	1.57	1.90	1.7	0.87	1.10	0.33	0.46	1.28	1.54	0.57	1.60	1.94	2.5	0.61	0.76
SJR Potato Slough	0.39	0.55	1.55	1.87	0.69	1.94	2.35	1.4	1.38	1.73	0.45	0.63	1.76	2.13	0.79	2.21	2.68	1.3	1.63	2.04	0.34	0.48	1.34	1.63	0.60	1.69	2.04	2.5	0.66	0.82
Franks Tract	0.42	0.58	1.63	1.97	0.73	2.05	2.48	1.6	1.20	1.51	0.54	0.76	2.13	2.58	0.96	2.68	3.24	1.1	2.25	2.83	0.34	0.48	1.35	1.63	0.61	1.70	2.05	3.0	0.55	0.69
Big Break	0.37	0.52	1.46	1.77	0.66	1.84	2.23	1.6	1.14	1.44	0.42	0.58	1.63	1.97	0.73	2.05	2.48	1.0	1.93	2.43	0.33	0.46	1.28	1.55	0.58	1.61	1.95	2.8	0.55	0.69
Middle R. Bullfrog	0.65	0.91	2.56	3.10	1.15	3.22	3.89	NA	NA	NA	0.74	1.04	2.92	3.53	1.31	3.67	4.44	1.9	1.8	2.3	0.49	0.68	1.91	2.31	0.86	2.41	2.91	2.1	1.1	1.4
Old R. near Paradise Cut[c]	0.70	0.97	2.73	3.30	1.22	3.43	4.15	NA	NA	NA	0.83	1.16	3.25	3.94	1.46	4.09	4.95	2.4	1.7	2.1	0.65	0.90	2.53	3.06	1.14	3.18	3.85	NA	NA	NA
Knights Landing[d]	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA	0.45	0.63	1.76	2.13	0.79	2.22	2.68	2.2	1.0	1.2	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA
Vernalis[e]	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.7	2.34	2.95	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.9	2.10	2.64	0.84	1.18	3.29	3.98	1.48	4.14	5.01	2.4	1.66	2.09
	Third Quarter										Third Quarter										Third Quarter									
Sac River RM 44	0.32	0.45	1.25	1.52	0.56	1.58	1.91	2.6	0.58	0.72	0.32	0.45	1.25	1.52	0.56	1.58	1.91	1.5	1.04	1.31	0.32	0.45	1.25	1.52	0.56	1.58	1.91	1.8	0.82	1.03
Cache Slough Ryer[b]	0.33	0.47	1.30	1.58	0.59	1.64	1.98	1.5	1.06	1.33	0.32	0.44	1.24	1.50	0.56	1.56	1.88	1.7	0.87	1.09	0.33	0.46	1.29	1.56	0.58	1.62	1.96	2.5	0.61	0.77
SJR Potato Slough	0.32	0.44	1.24	1.50	0.56	1.56	1.89	1.4	1.11	1.39	0.31	0.44	1.22	1.48	0.55	1.54	1.86	1.3	1.13	1.42	0.31	0.44	1.23	1.49	0.55	1.55	1.87	2.5	0.60	0.76
Franks Tract	0.32	0.44	1.24	1.50	0.56	1.55	1.88	1.6	0.91	1.14	0.31	0.44	1.22	1.48	0.55	1.54	1.86	1.1	1.29	1.62	0.31	0.43	1.22	1.47	0.55	1.53	1.85	3.0	0.49	0.62
Big Break	0.31	0.44	1.23	1.48	0.55	1.54	1.87	1.6	0.96	1.20	0.31	0.43	1.21	1.46	0.54	1.52	1.84	1.0	1.43	1.80	0.30	0.42	1.17	1.42	0.53	1.48	1.79	2.8	0.50	0.63
Middle R. Bullfrog	0.37	0.52	1.44	1.75	0.65	1.81	2.20	NA	NA	NA	0.42	0.58	1.63	1.98	0.73	2.05	2.48	1.9	1.0	1.3	0.32	0.44	1.24	1.50	0.56	1.56	1.89	2.1	0.7	0.9
Old R. near Paradise Cut[c]	0.76	1.07	2.99	3.62	1.34	3.76	4.55	NA	NA	NA	0.79	1.11	3.10	3.76	1.39	3.90	4.72	2.4	1.6	2.0	0.77	1.07	3.00	3.63	1.35	3.77	4.57	NA	NA	NA
Knights Landing[d]	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA	0.45	0.63	1.76	2.13	0.79	2.22	2.68	2.2	1.0	1.2	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA
Vernalis[e]	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.7	2.34	2.95	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.9	2.10	2.64	0.84	1.18	3.29	3.98	1.48	4.14	5.01	2.4	1.66	2.09

	Year 2000										Year 2005										Year 2007									
	Concentration							Whole-Body Bass[a]	Fish-to-Bass Ratio		Concentration							Whole-Body Bass[a]	Fish-to-Bass Ratio		Concentration							Whole-Body Bass[a]	Fish-to-Bass Ratio	
		Model 6			Model 7							Model 6			Model 7							Model 6			Model 7					
DSM2 Delta Water Location	DSM2 Water	Particulate From Water	Invert. From Particulate	Fish	Particulate From Water	Invert. From Particulate	Fish		Model 6	Model 7	DSM2 Water	Particulate From Water	Invert. from Particulate	Fish	Particulate From Water	Invert. From Particulate	Fish		Model 6	Model 7	DSM2 Water	Particulate From Water	Invert. From Particulate	Fish	Particulate From Water	Invert. From Particulate	Fish		Model 6	Model 7
	Fourth Quarter										Fourth Quarter										Fourth Quarter									
Sac River RM 44	0.32	0.45	1.25	1.52	0.56	1.58	1.91	2.6	0.58	0.72	0.32	0.45	1.25	1.52	0.56	1.58	1.91	1.5	1.04	1.31	0.32	0.45	1.25	1.52	0.56	1.58	1.91	1.8	0.82	1.03
Cache Slough Ryer[b]	0.33	0.46	1.28	1.55	0.58	1.61	1.95	1.5	1.04	1.30	0.32	0.44	1.24	1.50	0.56	1.56	1.88	1.7	0.87	1.09	0.33	0.46	1.28	1.54	0.57	1.60	1.94	2.5	0.61	0.76
SJR Potato Slough	0.31	0.44	1.23	1.49	0.55	1.54	1.87	1.4	1.10	1.38	0.31	0.43	1.22	1.47	0.55	1.53	1.85	1.3	1.13	1.42	0.31	0.44	1.23	1.49	0.55	1.55	1.88	2.5	0.60	0.76
Franks Tract	0.31	0.44	1.22	1.48	0.55	1.53	1.86	1.6	0.90	1.13	0.31	0.43	1.21	1.46	0.54	1.52	1.84	1.1	1.28	1.60	0.31	0.44	1.22	1.48	0.55	1.54	1.86	3.0	0.50	0.62
Big Break	0.30	0.42	1.18	1.42	0.53	1.48	1.79	1.6	0.92	1.15	0.30	0.42	1.18	1.43	0.53	1.48	1.79	1.0	1.40	1.76	0.30	0.42	1.18	1.43	0.53	1.48	1.79	2.8	0.50	0.63
Middle R. Bullfrog	0.44	0.62	1.73	2.09	0.78	2.17	2.63	NA	NA	NA	0.39	0.55	1.53	1.85	0.69	1.93	2.33	1.9	1.0	1.2	0.38	0.53	1.48	1.79	0.66	1.86	2.25	2.1	0.8	1.1
Old R. near Paradise Cut[c]	0.82	1.15	3.22	3.90	1.45	4.05	4.90	NA	NA	NA	0.72	1.00	2.81	3.40	1.26	3.53	4.27	2.4	1.4	1.8	0.82	1.15	3.23	3.90	1.45	4.06	4.91	NA	NA	NA
Knights Landing[d]	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA	0.45	0.63	1.76	2.13	0.79	2.22	2.68	2.2	1.0	1.2	0.45	0.63	1.76	2.13	0.79	2.22	2.68	NA	NA	NA
Vernalis[e]	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.7	2.34	2.95	0.84	1.18	3.29	3.98	1.48	4.14	5.01	1.9	2.10	2.64	0.84	1.18	3.29	3.98	1.48	4.14	5.01	2.4	1.66	2.09

Notes:

Model 6 = Equations from Presser and Luoma (2010) were used to calculate selenium concentrations in Trophic Level 4 (TL-4) Fish eating TL-3 Fish using an extrapolated K_d (1400), the average selenium trophic transfer factors to aquatic insects (2.8), and fish (1.1 for TL-4 and TL-3 fish).

Model 7 = Equations from Presser and Luoma (2010) were used to calculate selenium concentrations in Trophic Level 4 (TL-4) Fish eating TL-3 Fish using a K_d of 1760 (calculated from data reported in Lucas and Stewart [2007]), the average selenium trophic transfer factors to aquatic insects (2.8), and fish (1.1, for TL-3 and TL-4).

Invert. = invertebrate

K_d = equilibrium constant

µg/g, dw = micrograms per gram, dry weight

NA = not available; bass not collected here

RM = river mile

TL = trophic level

[a] Geometric mean calculated from whole-body largemouth bass data presented in Foe (2010a).

[b] Fish data collected at Rio Vista (Foe 2010a) were used to calculate geometric whole-body largemouth bass and ratios.

[c] Fish data collected at Old River near Tracy (Foe 2010a) were used to calculate geometric whole-body largemouth bass and ratios.

[d] Geometric mean of total selenium concentrations in water collected from years 2003, 2004, 2007, and 2008 (DWR Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available). Fish data collected at Sacramento River at Veterans Bridge (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[e] Geometric mean of selenium concentrations (total or dissolved was not specified) in water collected from years 1999–2007 (SWAMP Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available).

1

1 **Table 5D.B-8. Selenium Bioaccumulation from Water (µg/L) to Particulates, and Whole-body Fish (µg/g, dw) Using Model 8 (Normal to Wet Years)**

DSM2 Delta Water Location	Year 2000						Year 2005						Year 2007					
	Concentration						Concentration						Concentration					
	DSM2 Water	Particulate From Water	Invert. From Particulate	Model 8 Fish	Whole-body Bass[a]	Model 8-to-Bass Ratio	DSM2 Water	Particulate From Water	Invert. From Particulate	Model 8 Fish	Whole-body Bass[a]	Model 8-to-Bass Ratio	DSM2 Water	Particulate From Water	Invert. From Particulate	Model 8 Fish	Whole-body Bass[a]	Model 8-to-Bass Ratio
	First Quarter						First Quarter						First Quarter					
Sacramento River RM 44	0.31	0.55	1.16	1.40	2.6	0.53	0.32	0.56	1.18	1.43	1.5	0.98	0.32	0.56	1.18	1.43	1.8	0.78
Cache Slough Ryer[b]	0.27	0.48	1.00	1.21	1.5	0.81	0.30	0.54	1.12	1.36	1.7	0.79	0.31	0.55	1.16	1.41	2.5	0.55
San Joaquin River Potato Slough	0.30	0.52	1.10	1.33	1.4	0.98	0.31	0.54	1.13	1.37	1.3	1.04	0.30	0.53	1.12	1.35	2.5	0.54
Franks Tract	0.29	0.51	1.08	1.31	1.6	0.79	0.31	0.55	1.15	1.40	1.1	1.22	0.30	0.53	1.12	1.35	3.0	0.45
Big Break	0.26	0.46	0.97	1.17	1.6	0.75	0.30	0.53	1.12	1.36	1.0	1.33	0.31	0.54	1.13	1.37	2.2	0.62
Middle River Bullfrog	0.35	0.62	1.31	1.58	NA	NA	0.52	0.92	1.93	2.33	1.9	1.2	0.39	0.69	1.44	1.74	2.1	0.8
Old River near Paradise Cut[c]	0.74	1.30	2.74	3.31	NA	NA	0.77	1.36	2.86	3.47	2.4	1.5	0.81	1.43	3.00	3.63	NA	NA
Knights Landing[d]	0.45	0.79	1.66	2.01	NA	NA	0.45	0.79	1.66	2.01	2.2	0.9	0.45	0.79	1.66	2.01	NA	NA
Vernalis[e]	0.84	1.48	3.10	3.76	1.7	2.21	0.84	1.48	3.10	3.76	1.9	1.98	0.84	1.48	3.10	3.76	2.4	1.57
	Second Quarter						Second Quarter						Second Quarter					
Sacramento River RM 44	0.32	0.56	1.18	1.43	2.6	0.54	0.32	0.56	1.18	1.43	1.5	0.98	0.32	0.56	1.18	1.43	1.8	0.77
Cache Slough Ryer[b]	0.33	0.58	1.23	1.49	1.5	0.99	0.32	0.56	1.18	1.42	1.7	0.82	0.33	0.57	1.20	1.46	2.5	0.57
San Joaquin River Potato Slough	0.39	0.69	1.46	1.76	1.4	1.30	0.45	0.79	1.66	2.01	1.3	1.53	0.34	0.60	1.27	1.53	2.5	0.62
Franks Tract	0.42	0.73	1.54	1.86	1.6	1.13	0.54	0.96	2.01	2.43	1.1	2.12	0.34	0.61	1.27	1.54	3.0	0.51
Big Break	0.37	0.66	1.38	1.67	1.6	1.08	0.42	0.73	1.54	1.86	1.0	1.82	0.33	0.58	1.21	1.46	2.2	0.66
Middle River Bullfrog	0.65	1.15	2.41	2.92	NA	NA	0.74	1.31	2.75	3.33	1.9	1.7	0.49	0.86	1.80	2.18	2.1	1.0
Old River near Paradise Cut[c]	0.70	1.22	2.57	3.11	NA	NA	0.83	1.46	3.07	3.71	2.4	1.6	0.65	1.14	2.39	2.89	NA	NA
Knights Landing[d]	0.45	0.79	1.66	2.01	NA	NA	0.45	0.79	1.66	2.01	2.2	0.9	0.45	0.79	1.66	2.01	NA	NA
Vernalis[e]	0.84	1.48	3.10	3.76	1.7	2.21	0.84	1.48	3.10	3.76	1.9	1.98	0.84	1.48	3.10	3.76	2.4	1.57
	Third Quarter Selenium						Third Quarter						Third Quarter					
Sacramento River RM 44	0.32	0.56	1.18	1.43	2.6	0.54	0.32	0.56	1.18	1.43	1.5	0.98	0.32	0.56	1.18	1.43	1.8	0.78
Cache Slough Ryer[b]	0.33	0.59	1.23	1.49	1.5	1.00	0.32	0.56	1.17	1.41	1.7	0.82	0.33	0.58	1.21	1.47	2.5	0.58
San Joaquin River Potato Slough	0.32	0.56	1.17	1.42	1.4	1.05	0.31	0.55	1.15	1.40	1.3	1.07	0.31	0.55	1.16	1.41	2.5	0.57
Franks Tract	0.32	0.56	1.17	1.41	1.6	0.86	0.31	0.55	1.15	1.39	1.1	1.22	0.31	0.55	1.15	1.39	3.0	0.46
Big Break	0.31	0.55	1.16	1.40	1.6	0.90	0.31	0.54	1.14	1.38	1.0	1.35	0.30	0.53	1.11	1.34	2.2	0.61
Middle River Bullfrog	0.37	0.65	1.36	1.65	NA	NA	0.42	0.73	1.54	1.86	1.9	1.0	0.32	0.56	1.17	1.42	2.1	0.7
Old River near Paradise Cut[c]	0.76	1.34	2.82	3.41	NA	NA	0.79	1.39	2.93	3.54	2.4	1.5	0.77	1.35	2.83	3.43	NA	NA
Knights Landing[d]	0.45	0.79	1.66	2.01	NA	NA	0.45	0.79	1.66	2.01	2.2	0.9	0.45	0.79	1.66	2.01	NA	NA
Vernalis[e]	0.84	1.48	3.10	3.76	1.7	2.21	0.84	1.48	3.10	3.76	1.9	1.98	0.84	1.48	3.10	3.76	2.4	1.57
	Fourth Quarter						Fourth Quarter						Fourth Quarter					
Sacramento River RM 44	0.32	0.56	1.18	1.43	2.6	0.54	0.32	0.56	1.18	1.43	1.5	0.98	0.32	0.56	1.18	1.43	1.8	0.78
Cache Slough Ryer[b]	0.33	0.58	1.21	1.46	1.5	0.98	0.32	0.56	1.17	1.41	1.7	0.82	0.33	0.57	1.20	1.45	2.5	0.57
San Joaquin River Potato Slough	0.31	0.55	1.16	1.40	1.4	1.03	0.31	0.55	1.15	1.39	1.3	1.06	0.31	0.55	1.16	1.41	2.5	0.57
Franks Tract	0.31	0.55	1.15	1.39	1.6	0.85	0.31	0.54	1.14	1.38	1.1	1.20	0.31	0.55	1.15	1.40	3.0	0.47
Big Break	0.30	0.53	1.11	1.34	1.6	0.86	0.30	0.53	1.11	1.34	1.0	1.32	0.30	0.53	1.11	1.35	2.2	0.61
Middle River Bullfrog	0.44	0.78	1.63	1.97	NA	NA	0.39	0.69	1.44	1.75	1.9	0.9	0.38	0.66	1.39	1.69	2.1	0.8

	Year 2000						**Year 2005**						**Year 2007**					
	Concentration				**Whole-body Bass**[a]	**Model 8-to-Bass Ratio**	**Concentration**				**Whole-body Bass**[a]	**Model 8-to-Bass Ratio**	**Concentration**				**Whole-body Bass**[a]	**Model 8-to-Bass Ratio**
DSM2 Delta Water Location	**DSM2 Water**	**Particulate From Water**	**Invert. From Particulate**	**Model 8 Fish**			**DSM2 Water**	**Particulate From Water**	**Invert. From Particulate**	**Model 8 Fish**			**DSM2 Water**	**Particulate From Water**	**Invert. From Particulate**	**Model 8 Fish**		
Old River near Paradise Cut[c]	0.82	1.45	3.04	3.68	NA	NA	0.72	1.26	2.65	3.20	2.4	1.3	0.82	1.45	3.04	3.68	NA	NA
Knights Landing[d]	0.45	0.79	1.66	2.01	NA	NA	0.45	0.79	1.66	2.01	2.2	0.9	0.45	0.79	1.66	2.01	NA	NA
Vernalis[e]	0.84	1.48	3.10	3.76	1.7	2.21	0.84	1.48	3.10	3.76	1.9	1.98	0.84	1.48	3.10	3.76	2.4	1.57

Notes:

Model 8 = Equations from Presser and Luoma (2010) were used to calculate selenium concentrations in Trophic Level 4 (TL-4) Fish eating TL-3 Fish (Model 8) using a K_d of 1760 (calculated from data reported in Lucas and Stewart [2007]), a revised selenium trophic transfer factor to aquatic insects (2.1), and the average selenium trophic transfer factors to fish (1.1 for TL-3 and TL-4).

Invert. = invertebrate

K_d = equilibrium constant

µg/g, dw = micrograms per gram, dry weight

NA = not available; bass not collected here

RM = River Mile

TL = Trophic Level

[a] Geometric mean calculated from whole-body largemouth bass data presented in Foe (2010a).

[b] Fish data collected at Rio Vista (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[c] Fish data collected at Old River near Tracy (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[d] Geometric mean of total selenium concentrations in water collected from Years 2003, 2004, 2007, and 2008 (DWR Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available). Fish data collected at Sacramento River at Veterans Bridge (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[e] Geometric mean of selenium concentrations (total or dissolved was not specified) in water collected from years 1999–2007 (SWAMP Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available). Note that the model over-predicts selenium concentrations in whole-body fish by 50% at this location.

Table 5D.B-9. Selenium Bioaccumulation from Water (µg/L) to Particulates, and Whole-Body Fish (µg/g, dw) Using Model 9 (Dry Years)

	Year 2007					
	Concentration					
DSM2 Delta Water Location	DSM2 Water	Particulate From Water	Invert. From Particulate	Model 9 Fish	Whole-body Bass[a]	Model 9-to-Bass Ratio
	First Quarter					
Sacramento River RM 44	0.32	0.91	1.91	2.31	1.8	1.25
Cache Slough Ryer[b]	0.31	0.89	1.88	2.27	2.5	0.89
San Joaquin River Potato Slough	0.30	0.86	1.80	2.18	2.5	0.88
Franks Tract	0.30	0.86	1.81	2.18	3.0	0.73
Big Break	0.31	0.87	1.82	2.21	2.2	1.00
Middle River Bullfrog	0.39	1.11	2.32	2.81	2.1	1.3
Old River near Paradise Cut[c]	0.81	2.30	4.84	5.85	NA	NA
Knights Landing[d]	0.45	1.28	2.68	3.25	NA	NA
Vernalis[e]	0.84	2.39	5.01	6.06	2.4	2.53
	Second Quarter					
Sacramento River RM 44	0.32	0.91	1.90	2.30	1.8	1.25
Cache Slough Ryer[b]	0.33	0.92	1.94	2.35	2.5	0.92
San Joaquin River Potato Slough	0.34	0.97	2.04	2.47	2.5	1.00
Franks Tract	0.34	0.98	2.05	2.48	3.0	0.83
Big Break	0.33	0.93	1.95	2.36	2.2	1.07
Middle River Bullfrog	0.49	1.39	2.91	3.52	2.1	1.7
Old River near Paradise Cut[c]	0.65	1.83	3.85	4.66	NA	NA
Knights Landing[d]	0.45	1.28	2.68	3.25	NA	NA
Vernalis[e]	0.84	2.39	5.01	6.06	2.4	2.53
	Third Quarter					
Sacramento River RM 44	0.32	0.91	1.91	2.31	1.8	1.25
Cache Slough Ryer[b]	0.33	0.93	1.96	2.37	2.5	0.93
San Joaquin River Potato Slough	0.31	0.89	1.87	2.27	2.5	0.91
Franks Tract	0.31	0.88	1.85	2.24	3.0	0.75
Big Break	0.30	0.85	1.79	2.16	2.2	0.98
Middle River Bullfrog	0.32	0.90	1.89	2.29	2.1	1.1
Old River near Paradise Cut[c]	0.77	2.18	4.57	5.53	NA	NA
Knights Landing[d]	0.45	1.28	2.68	3.25	NA	NA
Vernalis[e]	0.84	2.39	5.01	6.06	2.4	2.53
	Fourth Quarter					
Sacramento River RM 44	0.32	0.91	1.91	2.31	1.8	1.25
Cache Slough Ryer[b]	0.33	0.92	1.94	2.35	2.5	0.92
San Joaquin River Potato Slough	0.31	0.89	1.88	2.27	2.5	0.91
Franks Tract	0.31	0.89	1.86	2.25	3.0	0.75
Big Break	0.30	0.85	1.79	2.17	2.2	0.99

DSM2 Delta Water Location	**Year 2007**					
	Concentration				**Whole-body Bass**[a]	**Model 9-to-Bass Ratio**
	DSM2 Water	**Particulate From Water**	**Invert. From Particulate**	**Model 9 Fish**		
Middle River Bullfrog	0.38	1.07	2.25	2.72	2.1	1.3
Old River near Paradise Cut[c]	0.82	2.34	4.91	5.94	NA	NA
Knights Landing[d]	0.45	1.28	2.68	3.25	NA	NA
Vernalis[e]	0.84	2.39	5.01	6.06	2.4	2.53

Notes:

Model 9 = Equations from Presser and Luoma (2010) were used to calculate selenium concentrations in Trophic Level 4 (TL-4) Fish eating TL-3 Fish (Model 8) using a K_d of 2840 (calculated from data reported in Lucas and Stewart [2007]), an extrapolated selenium trophic transfer factor to aquatic insects (2.1), and the average selenium trophic transfer factors to fish (1.1 for TL-3 and TL-4).

K_d = equilibrium constant

µg/g, dw = micrograms per gram, dry weight

NA = not available; bass not collected here

RM = river mile

TL = trophic level

[a] Geometric mean calculated from whole-body largemouth bass data presented in Foe (2010a).

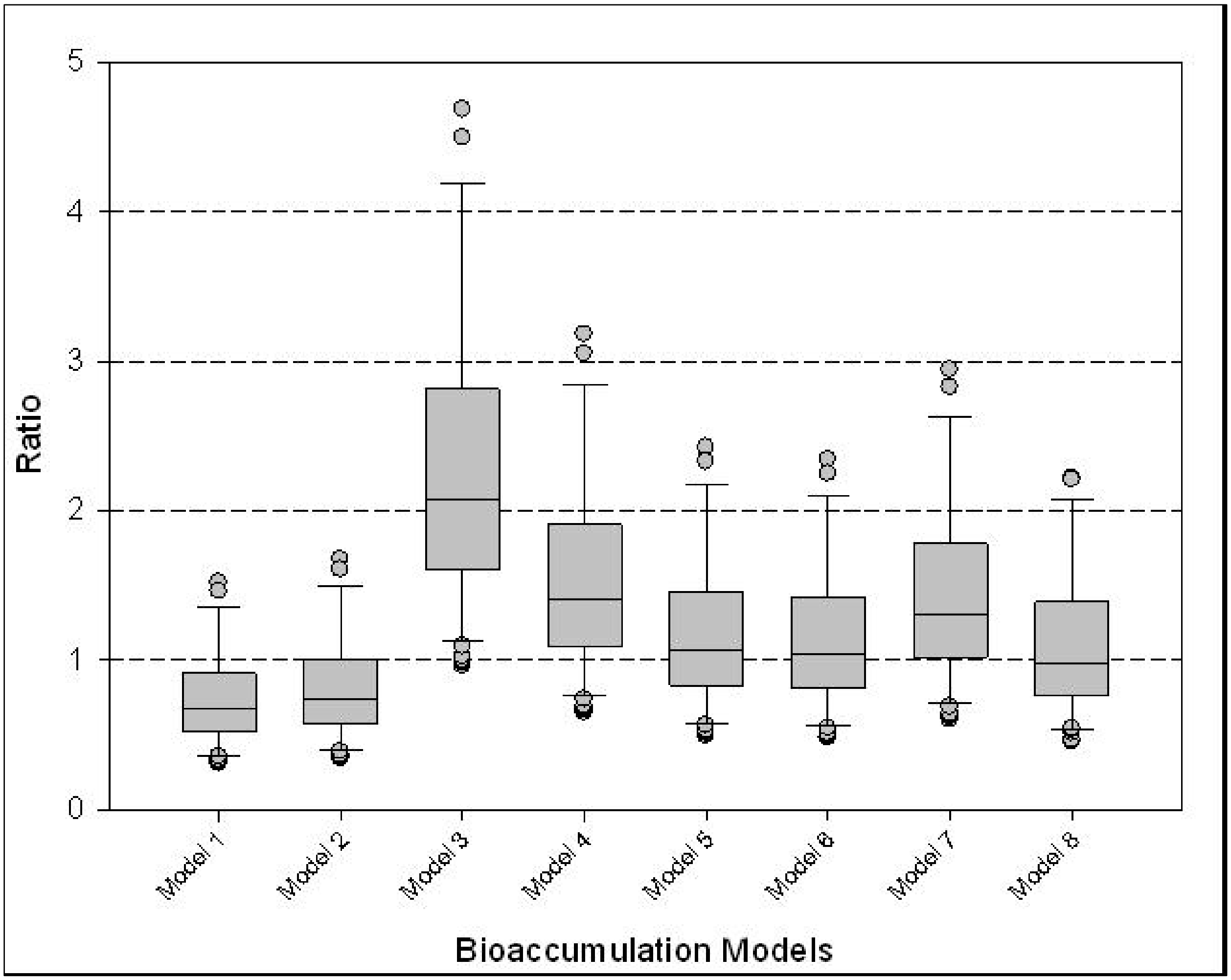
[b] Fish data collected at Rio Vista (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[c] Fish data collected at Old River near Tracy (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

[d] Geometric mean of total selenium concentrations in water collected from years 2003, 2004, 2007, and 2008 (DWR Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available). Fish data collected at Sacramento River at Veterans Bridge (Foe 2010a) were used to calculate geometric mean whole-body largemouth bass and ratios.

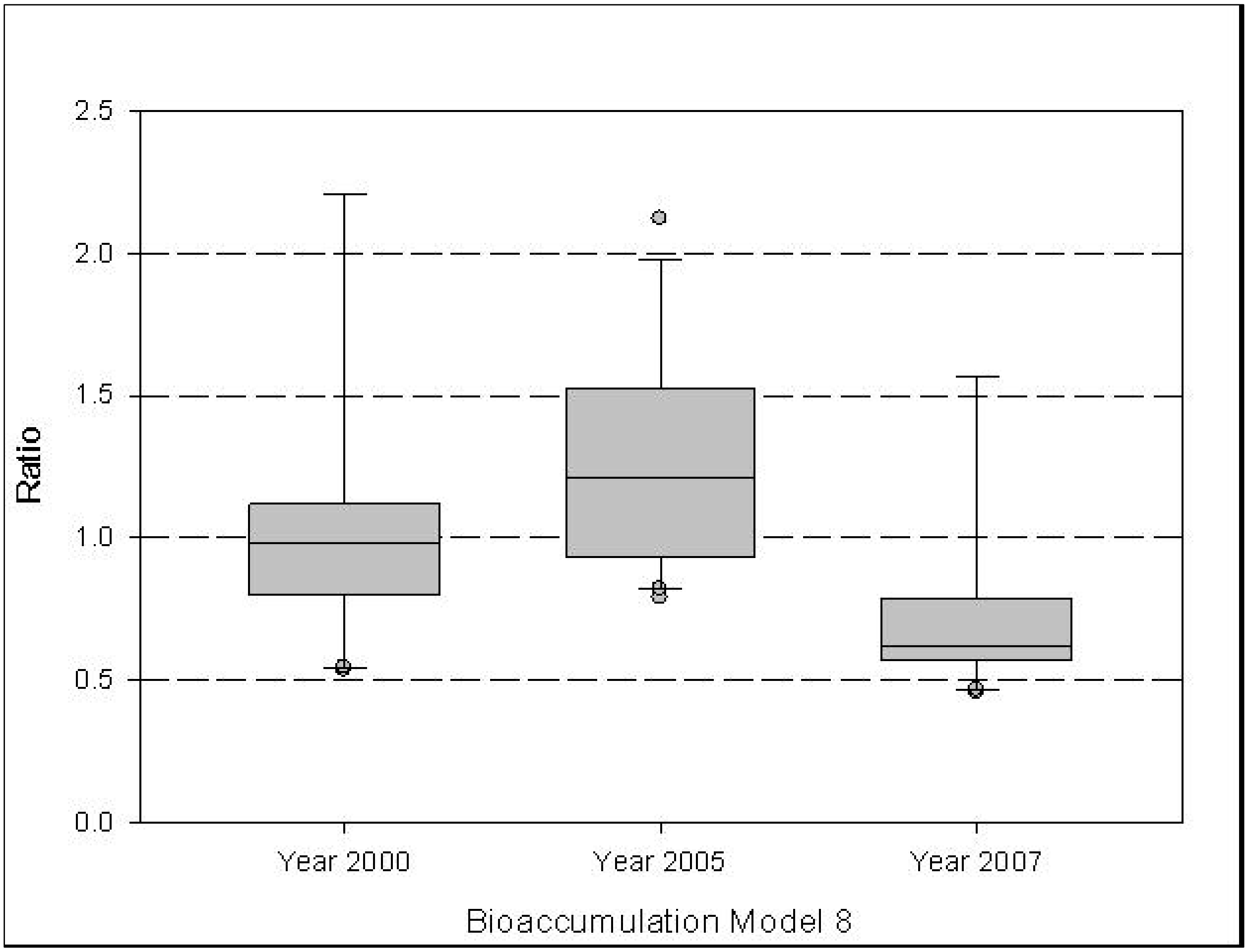
[e] Geometric mean of selenium concentrations (total or dissolved was not specified) in water collected from years 1999–2007 (SWAMP Website 2009) was used to estimate selenium concentrations in particulate and biota (DSM2 data were not available). Note that the model overpredicts selenium concentrations in whole-body fish by more than twofold at this location.

5D.B.7 Figures



For Models 1 through 5, K_d (1000), $TTF_{invertebrate}$ (2.8), and TTF_{fish} (1.1) were used in calculations.
Model 1 = Trophic Level 3 (TL-3) fish eating invertebrates
Model 2 = TL-4 fish eating TL-3 fish
Model 3 = TL-4 fish eating TL-3 fish eating two insect TLs
Model 4 = 50% Model 2 + 50% Model 3
Model 5 = 75% Model 2 + 25% Model 3
Model 6 = Model 2 using K_d (1400), $TTF_{invertebrate}$ (2.8), and TTF_{fish} (1.1)
Model 7 = Model 2 using K_d (1760), $TTF_{invertebrate}$ (2.8), and TTF_{fish} (1.1)
Model 8 = Model 2 using K_d (1760), $TTF_{invertebrate}$ (2.1), and TTF_{fish} (1.1)

Figure 5D.B-1. Ratios of Estimated Selenium Concentrations in Fish Models 1 through 8 to Measured Selenium Concentrations in Largemouth Bass



Model 8 = K_d (1760), $TTF_{invertebrate}$ (2.1), and TTF_{fish} (1.1)

Figure 5D.B-2. Ratios of Estimated Selenium Concentrations in Fish Model 8 to Measured Selenium Concentrations in Largemouth Bass for Years 2000, 2005, and 2007

Model 8 = K_d (1760), $TTF_{invertebrate}$ (2.1), and TTF_{fish} (1.1)
Model 9 = K_d (2840), $TTF_{invertebrate}$ (2.1), and TTF_{fish} (1.1)

Figure 5D.B-3. Ratios of Estimated Selenium Concentrations in Fish Model 8 (2000 and 2005 Wet Years) and Model 9 (2007 Dry Year) to Measured Selenium Concentrations in Largemouth Bass

5D.B.8 References Cited

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5D.B.8.1 Personal Communications

Foe, C. 2010b. Staff Environmental Scientist, Central Valley Regional Water Quality Control Board, Sacramento, CA. April 23, 2010—Email to H. Ohlendorf, Technology Fellow, CH2M HILL, Sacramento, CA.

Attachment 5D.C

Addendum to Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets

Attachment 5D.C
Addendum to Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets

Contents

List of Tables

Acronyms and Abbreviations

µg/kg dw	micrograms/kilogram, dry weight
µg/L	micrograms/liter
BiOps	biological opinions
Delta	Sacramento–San Joaquin River Delta
K_d	particulate/water ratio
mg/kg dw	milligram/kilogram, dry weight
NMFS	National Marine Fisheries Service
TTFs	trophic transfer factors
USFWS	U.S. Fish and Wildlife Service

Attachment 5D.C

Addendum to Bioaccumulation Model Development for Selenium Concentrations in Whole-Body Fish and Fish Fillets

5D.C.1 Introduction

Comments from the U.S. Fish and Wildlife Service (USFWS) and discussions with Dr. Sam Luoma indicated that selenium bioaccumulation in largemouth bass is not representative of the greater bioaccumulation rates observed for sturgeon (green sturgeon, *Acipenser medirostris,* and white sturgeon, *A. transmontanus*) that feed, in part, on overbite clams (*Corbula* [*Potamocorbula*] *amurensis*) in Suisun Bay and may do so in the western portion of the Delta under future conditions. Therefore, DSM2-modeled waterborne selenium concentrations from the two western-most locations in the Delta (Sacramento River at Mallard Island and San Joaquin River at Antioch Ship Channel) were used to model selenium bioaccumulation for sturgeon at those two locations to supplement the modeling done for largemouth bass, which is described in Attachment 5D-B. The data and processes used to estimate this selenium bioaccumulation in sturgeon in the western Delta are described in the following sections.

5D.C.2 Estimation of Selenium Concentrations in Water

Dissolved selenium concentrations in water were estimated for the Sacramento River at Mallard Island and San Joaquin River at Antioch Ship Channel locations as described in. Selenium concentrations were estimated under four late long-term (LLT) scenarios for “All” and “Drought” conditions. The late long-term scenarios are defined as follows:

- EBC2: Current operations based on the USFWS (2008) and NMFS (2009) biological opinions (BiOps), including management of outflows to achieve the Fall X2 provisions of the USFWS (2008) BiOp.
- EBC2_LLT: EBC2 projected into year 50 (2060) accounting for climate changes conditions expected at that time.
- LOS_LLT: Low-outflow operations (low-outflow outcomes of decision tree for management of spring and fall outflow) in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
- ESO_LLT: Evaluated starting operations in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
- HOS_LLT: High-outflow operations (high-outflow outcomes of decision tree for management of spring and fall outflow) in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.

DSM2-modeled selenium concentrations for the Sacramento River at Mallard Island and the San Joaquin River at Antioch Ship Channel are presented in Table 5D.C-1.

Table 5D.C-1. Model-Estimated Selenium Concentrations in Water – West Delta

Location	Period a	EBC_2 LLT	LOS_LLT	ESO_LLT	HOS_LLT
San Joaquin River at Antioch	All	0.31	0.33	0.34	0.34
	Drought	0.27	0.28	0.28	0.28
Sacramento River at Mallard Island	All	0.25	0.26	0.27	0.27
	Drought	0.21	0.21	0.22	0.22

Notes:
LLT - late long term
µg/L - microgram per liter
[a] All: Water years 1975–1991 represent the 16-year period modeled using DSM2.
Drought: Represents a 5-consecutive-year (Water Years 1987–1991) drought period consisting of dry and critical water-year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

5D.C.3 Methodology for Bioaccumulation of Selenium into Whole-Body Sturgeon

Selenium concentrations in whole-body surgeon were calculated using ecosystem-scale models developed by Presser and Luoma (2013). The models were developed using biogeochemical and physiological factors from laboratory and field studies; information on loading, speciation, and transformation to particulate material; bioavailability; bioaccumulation in invertebrates; and trophic transfer to predators. Important components of the methodology included (1) empirically determined environmental partitioning factors between water and particulate material that quantify the effects of dissolved speciation and phase transformation; (2) concentrations of selenium in living and nonliving particulates at the base of the foodweb that determine selenium bioavailability to invertebrates; and (3) selenium biodynamic foodweb transfer factors that quantify the physiological potential for bioaccumulation from particulate matter to consumer organisms and prey to their predators.

5D.C.3.1 Methodology for Estimation of Selenium Concentration in Particulates

Phase transformation reactions from dissolved to particulate selenium are the primary form by which selenium enters the foodweb. Presser and Luoma (2013) used field observations to quantify the relationship between particulate material and dissolved selenium as provided below.

$$C_{particulate} = K_d \bullet C_{water\ column} \quad \text{(Eq. 1)}$$

Where:

$C_{particulate}$ = selenium concentration in particulate material (micrograms/kilogram, dry weight [µg/kg dw])

$C_{water\ column}$ = selenium concentration in water column (µg/L)

K_d = particulate/water ratio

The K_d describes the particulate/water ratio at the moment the sample was taken and should not be interpreted as an equilibrium constant (as it sometimes is). It can vary widely among hydrologic environments and potentially among seasons (Presser and Luoma 2010). In addition, other factors such as speciation, residence time, and particle type affect K_d. Residence time of selenium is usually the most influential factor on the conditions in the receiving water environment. Short water residence times (e.g., streams and rivers) limit partitioning of selenium into particulate material. Conversely, longer residence times (e.g., sloughs, lakes, and estuaries) allow greater uptake by plants, algae, and microorganisms. Furthermore, environments in downstream portions of a watershed can receive cumulative contributions of upstream recycling in a hydrologic system. Due to its high variability, K_d is a large source of uncertainty in the model, especially if translation of selenium concentration in the water column is necessary.

Presser and Luoma (2013) determined K_d values for San Francisco Bay (including Carquinez Strait – Suisun Bay) during “low flow” conditions (5,986) and “average” conditions (3,317). These values were used to model selenium concentrations in particulates for “Drought” and “All” conditions at the two locations in the western Delta.

5D.C.3.2 Methodology for Estimation of Selenium Concentrations in Invertebrates

Species-specific trophic transfer factors (TTFs) for transfer of selenium from particulates to prey and to predators were developed using data from laboratory experiments and field studies (Presser and Luoma 2013). TTFs are species-specific.

TTFs for estimating selenium concentrations in invertebrate prey were calculated using the following equation:

$$TTF_{invertebrate} = \frac{C_{invertebrate}}{C_{particulate}} \quad \text{(Eq. 2)}$$

Where:

$TTF_{invertebrate}$ = trophic transfer factor from particulate material to invertebrate prey

$C_{invertebrate}$ = concentration of selenium in invertebrate prey (µg/g dw)

$C_{particulate}$ = concentration of selenium in particulate material (µg/g dw)

Sturgeon in the western Delta, Carquinez Strait, and Suisun Bay typically prey on a mix of clams (including *Corbicula amurensis*, which is known to be an efficient bioaccumulator of selenium) and crustaceans. Presser and Luoma (2013) assumed a diet of 50 percent clams and 50 percent amphipods and other crustaceans in their model. Based on this diet, the authors reported a TTF of 9.2 (identified as TTF_{prey} in Table 1 of Presser and Luoma [2013]). This TTF was used to calculate concentrations in sturgeon invertebrate prey at the San Joaquin River at Antioch and Sacramento River at Mallard Island locations.

5D.C.3.3 Methodology for Estimation of Selenium Concentrations in Whole-Body Sturgeon

The mechanistic equation for modeling of selenium bioaccumulation in fish tissue is similar to that for invertebrates if whole-body concentrations are the endpoint (Presser and Luoma 2013), as follows:

$$TTF_{fish} = \frac{C_{fish}}{C_{invertebrate}}$$

$$where:$$

$$C_{invertebrate} = C_{particulate} \bullet TTF_{invertebrate}$$

$$therefore:$$

$$C_{fish} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \qquad \text{(Eq. 3)}$$

Where:

C_{fish} = concentration of selenium in fish (μg/g dw)

$C_{invertebrate}$ = concentration of selenium in invertebrate (μg/g dw)

$C_{particulate}$ = concentration of selenium in particulate material (μg/g dw)

$TTF_{invertebrate}$ = trophic transfer factor from particulate material to invertebrate

TTF_{fish} = trophic transfer factor from invertebrate to fish

A TTF of 1.3 (identified as $TTF_{predator}$ in the paper) was reported for sturgeon in Table 1 of Presser and Luoma (2013) and was used to calculate concentrations of selenium in sturgeon for the two western Delta locations according to the following model:

$$C_{sturgeon} = C_{particulate} \bullet TTF_{invertebrate} \bullet TTF_{fish} \qquad \text{(Eq. 4)}$$

Where:

$C_{sturgeon}$ = concentration of selenium in whole-body sturgeon (μg/g dw)

$C_{particulate}$ = concentration of selenium in particulate material (μg/g dw)

$TTF_{invertebrate}$ = Trophic transfer factor from particulate material to invertebrate prey (9.2)

TTF_{fish} = Trophic transfer factor from invertebrate to fish predator (1.3)

In this model, the particulate selenium concentration was estimated using Equation 1 and a K_d of 5,986 (for Drought) or 3,317 (for All).

5D.C.4 Results of Estimation of Selenium Concentrations in Whole-body Sturgeon

5D.C.4.1 Selenium Concentrations in Sturgeon

The outputs of estimated selenium concentrations in sturgeon at the two western Delta locations under each scenario are presented in Table 5D.C-2.

Table 5D.C-2. Model-Estimated Annual Average Selenium Concentrations in Sturgeon – West Delta

		Modeled Estimated Tissue Concentations - Selenium (mg/kg dw)			
Location	**Period [a]**	**EBC2_LLT**	**LOS_LLT**	**ESO_LLT**	**HOS_LLT**
San Joaquin River at Antioch	All	12.3	13.1	13.5	13.5
	Drought	19.3	20	20	20
Sacramento River at Mallard Island	All	9.92	10.3	10.7	10.7
	Drought	15	15	15.8	15.8

[a] All: Water years 1975–1991 represent the 16-year period modeled using DSM2 mg/kg dw = milligrams Selenium per kilogram dry weight whole body fish tissue

Modeled selenium concentrations for sturgeon at both locations and under all scenarios are lowest during “All” conditions compared to “Drought” conditions. For the San Joaquin River at Antioch, modeled selenium concentrations for sturgeon ranged from 12.3 mg/kg (dw) during “All” conditions to a high of 20.0 mg/kg (dw) during “Drought” conditions. Of these, scenario EBC2_LLT had the lowest selenium concentrations in whole-body sturgeon for both “All” and “Drought” conditions. Similarly, scenario EB2_LLT had the lowest concentrations (9.92 mg/kg, dw for “All” and 15.0 mg/kg, dw for “Drought”) among the four scenarios modeled for the Sacramento River at Mallard Island. Scenarios ESO_LLT and HOS_LLT had the highest concentrations, with 10.7 mg/kg (dw) for “All” conditions and 15.8 mg/kg (dw) for “Drought” conditions.

Presser and Luoma (2013) present low and high benchmark values for whole-body fish tissue that they developed from the available toxicity data. The low benchmark is 5 mg/kg (dw) and the high value is 8 mg/kg (dw) in whole-body fish. Modeled selenium concentrations in whole-body sturgeon exceeded these benchmarks under every scenario and for both “All” and “Drought” conditions at both western Delta locations.

However, as noted in Table 5D.C-2, the differences among scenarios within location and water year type (i.e., All or Drought) are relatively small, so the differences in their biological significance with respect to impacts on sturgeon likewise are likely to be small. For example, the largest difference among scenarios (San Joaquin River at Antioch under All) is just 1.2 mg/kg and the difference between LOS_LLT and EBC2_LLT are all less than 1 mg/kg.

5D.C.5 References Cited

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