Appendix 5.C
Flow, Passage, Salinity, and Turbidity

Appendix 5.C
Flow, Passage, Salinity, and Turbidity

5C.0 Executive Summary

Flows originating upstream and flowing through the Sacramento and San Joaquin River systems and into and through the Sacramento–San Joaquin River Delta (Delta) play a significant role in creating the habitat conditions that fish experience throughout their life cycles. The velocity, depth, duration, timing, and quality of flow can affect abiotic factors such as salinity, turbidity, dissolved oxygen (DO) concentration, and temperature, these flow conditions can also influence the total area and characteristics of wetted habitat accessible to fish, food resources, prey and predator interactions, distribution of invasive species, and other habitat characteristics. Flows and these related parameters also can influence fish migration patterns through and upstream of the Delta.

Conservation Measure (CM) 1 Water Facilities and Operation and *CM2 Yolo Bypass Fisheries Enhancement* are the conservation measures that are directly evaluated in this appendix, but other conservation measures, such as *CM4 Tidal Natural Communities Restoration*, indirectly affect CM1 operations through changes in the Delta landscape that require adjustments to water operations. As described in Chapter 3, *Conservation Strategy*, there are four potential operational outcomes for CM1, depending on the outcome of the decision tree process for spring outflow and Fall X2 operations. These alternative outflow conditions have the potential to cause differences in upstream conditions or in Delta flows in other seasons (i.e., summer and winter). The high outflow scenario (assuming the high outflow outcome for both spring outflow and Fall X2 operations) and the low outflow scenario (assuming the low outflow outcome for both spring outflow and Fall X2 operations) are evaluated in this appendix, in addition to the evaluated starting operations (ESO), which includes the high Fall X2 operation and the low spring outflow operation. Table 5C.0-1 contains specific descriptions of each of the scenarios evaluated. Regardless of which CM1 operational outcome is selected, the effects analysis of the Bay Delta Conservation Plan (BDCP) compared with existing biological conditions[1] shows that some daily, monthly, or water year–type patterns may shift under the BDCP to maximize benefits to fish and water supply to achieve the BDCP's goals of water supply reliability and ecosystem restoration. Overall, there would be minimal upstream changes but some substantial shifts in how water moves through the Delta. This appendix evaluates the effects on fish that result from changes in flows and flow-related parameters by comparing the BDCP with the existing biological conditions. The BDCP could affect flows and related conditions in four primary ways.

- *CM1 Water Facilities and Operation* includes the new north Delta intakes, operations of which could affect Sacramento River inflow to the Delta, Delta hydrodynamics, and outflow to the Bay.
- *CM2 Yolo Bypass Fisheries Enhancement* would improve passage in the Yolo Bypass for salmon, steelhead, and sturgeon while somewhat reducing Sacramento River flows between the Fremont Weir and the confluence of the Sacramento River and and the downstream end of the Yolo Bypass.

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[1] Existing biological conditions: this condition is the state of the environment at the time of the analysis and assumes current operations.

- *CM4 Tidal Natural Communities Restoration* includes restoration of 65,000 acres of tidal marsh that could result in changes in turbidity and tidal excursion in specific Delta locations and subregions.
- Operations of upstream reservoirs to meet downstream and Delta flow requirements could result in changes in temperatures in key spawning and egg incubation areas, changes in wetted areas that could result in redd dewatering, and changes in accessible rearing habitat.

This appendix has the components listed below.

- A description of the potential mechanisms for changes in flow and the related parameters of temperature, salinity, turbidity, and DO.
- An overview of the historical operations and management of flows in the State Water Project (SWP)/Central Valley Project (CVP) systems.
- A description of species exposure to potential changes in flows.
- A description of the methods used to predict the potential effects of changes in flows under the BDCP.
- Results of the application of these methods.
- Based on these results, a comprehensive description of the expected flow-related effect on each life stage of each covered fish species. (Population-level effects on each species are presented in Chapter 5, *Effects Analysis*.)

The methods used to assess flow effects and the various flow-related parameters are based on CALSIM and DSM2 outputs, upstream temperature models, particle tracking modeling (PTM), multiple biological models, assumed and measured locations of fish, previous studies in the Delta, Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) analyses, analyses developed by ICF International in coordination with the fish agencies, and professional judgment. The methods used reflect the best available tools and data regarding fish abundance, movement, and behavior. These methods were applied to a comparison of the BDCP scenarios with two baseline conditions (EBC1 and EBC2 [EBC = existing biological conditions]). The EBC1 scenario was analyzed under existing climate change conditions, whereas the EBC2 scenario was analyzed at two time periods in the permit term, both of which include assumed future climate change (early long-term [ELT] and late long-term [LLT]). Appendix 2.C, *Climate Change Implications and Assumptions*, provides more detailed information about climate changes assumptions, results, and analyses, while Appendix 5.A-2, *Climate Change Approach and Implications for Aquatic Species*, provides additional information about climate change effects on fish. Table 5C.0-1 describes each of the scenarios used in this effects analysis. For some methods, five water-year types (40-30-30 Sacramento River Index) were identified in CALSIM to determine the variation in flow-related effects under different flow conditions.

Table 5C.0-1 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 staring operations in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	ESO_LLT	Evaluated staring 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_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.

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

The following methods are used to evaluate flow-related effects.

- **CALSIM**: Simulates flows and storage in the SWP/CVP distribution system based on user-defined constraints and priority weights under various flow conditions and water project operations.
- **DSM2-HYDRO:** Uses CALSIM output to predict depth and velocity of flow in Delta channels.
- **DSM2-QUAL:** Uses DSM2-HYDRO output to predict water temperature, DO, and salinity in the Delta and Suisun Marsh.
- **DSM2-Fingerprinting:** Uses DSM2-HYDRO output to estimate sources of flow in Delta channels, with the source estimates being used to assess potential effects on migration cues for covered fish species such as Chinook salmon.
- **DSM2-PTM**: Uses DSM2-HYDRO and both hypothetical release sites and data from trawls to estimate the movement of larval longfin smelt that are assumed to be influenced primarily by flows.

- **MIKE 21**: Modeling software used to develop a two-dimensional hydrodynamic model that predicts water surface elevation, and average velocity at each computational grid cell in the Yolo Bypass for a given flow level. The results are used to calculate the area of suitable habitat for Sacramento splittail spawning and early rearing at various flow levels.
- **Bureau of Reclamation (Reclamation) Temperature Model:** Uses CALSIM flow and climatic model output to predict monthly water temperature in the Trinity, Feather, American, and Stanislaus River basins and upstream reservoirs.
- **Sacramento River Water Quality Model (SRWQM):** Simulates mean daily (using 6-hour meteorology) reservoir and river temperatures at key locations on the Sacramento River based on CALSIM output.
- **Reclamation Egg Mortality Model:** Uses results of water temperature modeling, Reclamation Temperature Model, and SRWQM to estimate Chinook salmon egg mortality below each major SWP and CVP reservoir.
- **SALMOD:** Estimates juvenile Chinook salmon production in the upper Sacramento River, as a result of effects of flow and temperature on juvenile rearing habitat.
- **Sacramento Ecological Flows Tool (SacEDT):** Links flow management actions to changes in the physical habitats for salmonids using daily flow; data from submodels of temperature, substrate, and meander, including the SRWQM; and studies of habitat suitability, stranding, and dewatering.
- **Delta Passage Model (DPM):** Uses results from coded wire tag (CWT) and acoustic-tag studies to estimate the proportion of Chinook salmon runs that would occur in various Delta channels and salmon survival during downstream migration.
- **Assessment of Effectiveness of Nonphysical Barriers:** Uses results of recent studies at Georgiana Slough and Old River and features of covered fish biology to assess the potential effectiveness of barriers in other Delta locations to improve migration.
- **DRERIP:** Uses results of scientific studies to establish conceptual models of the stressors and mechanisms that are thought to affect the population dynamics of various resident and migratory fish species, as well as habitat functions.
- **Winter–Spring X2-Abundance Regression:** Used to estimate relative abundance of longfin smelt in the fall based on winter–spring X2 (as an indication of outflow), using the regression coefficients from Kimmerer et al. (2009).
- **Delta Smelt Abiotic Habitat Index:** Used to estimate extent of delta smelt abiotic habitat defined by turbidity and conductivity within the Suisun Bay, Suisun Marsh, and West Delta subregions, based on Feyrer et al.'s (2011) method.
- **Yolo Bypass Fry Growth Model:** Estimates potential survival of fall-run and winter-run Chinook salmon fry to ocean fisheries based on differences in growth and survival between the Yolo Bypass and the mainstem lower Sacramento River.
- **Fall-run/Spring-run Chinook Salmon Smolt Survival:** Estimates proportional through-Delta survival of spring-run and fall-run Chinook salmon smolts as a function of Sacramento River flow, south Delta exports, and other variables, based on coefficients from Newman (2003).
- **PTM Nonlinear Regression**: Assesses through-Delta migration potential of fall-run Chinook salmon fry as expressed by regressions linking prevailing channel flows and exports to PTM

results (percentage of particles released from various Delta entry points that reach Chipps Island within 30 days).

- **Longfin Smelt Stock-Recruitment/Flow Analysis**: Assesses longfin smelt abundance as a function of a logistic hockey stick stock-recruitment relationship that is adjusted by March–May Delta outflow.
- **Reverse Flow Analysis**: Uses 15-minute DSM2-HYDRO data to assess the proportion of time that Sacramento River flow below Georgiana Slough is reversed, and the contribution of the reverse flows to Georgiana Slough.
- **Water Clarity Assessment**: Estimates sediment removal by the north Delta intakes and the potential influence of various factors such as location, wind fetch, water depth, and tidal action on water clarity within the Plan Area.
- **Wetland Bench Inundation Analysis**: Uses DSM2-HYDRO estimates to assess the proportion of days that minimum river stage exceeds certain levels at a number of wetland bench sites in the North Delta, Cache Slough, and East Delta subregions.
- **Sutter Bypass Inundation**: Assesses area of floodplain habitat inundated in the lower Sutter Bypass as a function of Sacramento River at Verona river stage, in order to assess potential Fremont Weir notch effects.

No single one of these methods could be used for all life stages of all species. As a result, it was necessary to employ these methods in combination to complete the assessment of flow-related effects. For example, the SRWQM could not be applied to San Joaquin River effects, and the DPM can be applied only to Chinook salmon smolt passage through Delta channels.

These methods were applied to each species and life stage as appropriate, and the results of the assessments are presented in Section 5C.5, *Results*.

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5C.5.4 Delta Habitat (Plan Area) Results

Attachment 5C.A CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios

Attachment 5C.B Sacramento River Ecological Flows Tool (SacEFT): Design & Guidelines (v.2.00)—ESSA Technologies Ltd., June 2010

Attachment 5C.C Water Temperature

Attachment 5C.D Water Clarity—Suspended Sediment Concentration and Turbidity

Attachment 5C.E BDCP Effects Analysis: 2D Hydrodynamic Modeling of the Fremont Weir Diversion Structure, November 2010

Attachment 5C.F Numerical Modeling in Support of Bay Delta Conservation Plan: DSM2/QUAL Nutrient Model, Modeling Nutrients and Temperature

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Acronyms and Abbreviations

ACID	Anderson-Cottonwood Irrigation District
AFRP	Anadromous Fish Restoration Program
ANN	Artificial Neural Network
BDCP	Bay Delta Conservation Plan
BiOp	biological opinion
BOD	biochemical oxygen demand
CCWD	Contra Costa Water District
CDFW	California Department of Fish and Wildlife
CDOM	colored dissolved organic material
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CM	conservation measure
cm	centimeter
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWT	coded wire tag
DCC	Delta Cross Channel
DSM2	Delta Simulation Model II
DO	dissolved oxygen
DOSS	NMFS Delta Operations for Salmonids and Sturgeon
DPM	Delta Passage Model
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
DWR	California Department of Water Resources
E/I	export/inflow
EBC	existing biological conditions
EC	electrical conductivity
ELT	early long-term
ESA	Endangered Species Act
ESU	evolutionarily significant unit
FL	fork length
FMWT	fall midwater trawl
FRWA	Freeport Regional Water Authority
ft/s	feet per second
GAM	generalized additive modeling
GCID	Glenn-Colusa Irrigation District
HSI	Habitat Suitability Index
IFIM	Instream Flow Incremental Methodology
km	kilometers
LLT	late long-term

LOWESS	locally weighted regression-scatterplot smoothing
LSZ	low salinity zone
m/s	meters per second
m^3/s	cubic meters per second
mg/L	milligrams per liter
mm	millimeters
μscm^{-1}	microSiemens per centimeter
NDD	north Delta diversions
NMFS	National Marine Fisheries Service
OMR	Old and Middle River
ppt	parts per thousand
PTM	particle tracking modeling
RBDD	Red Bluff Diversion Dam
Reclamation	Bureau of Reclamation
RM	river mile
ROA	restoration opportunity areas
RPA	Reasonable and Prudent Alternative
SacEFT	Sacramento River Ecological Flows Tool
SAV	submerged aquatic vegetation
SMSCG	Suisun Marsh Salinity Control Gates
SRWQM	Sacramento River Water Quality Model
SS	suspended sediment
SSC	suspended sediment concentration
STN	summer townet
SWAN	Simulation Waves Nearshore
SWP	State Water Project
State Water Board	State Water Resources Control Board
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
VAMP	Vernalis Adaptive Management Plan
WOMT	water operations management team
WQCP	Bay-Delta Water Quality Control Plan
WUA	weighted usable area
WY	water year
YBFR	Yolo Bypass Fry Rearing
YCI	year class strength indices
YOY	young-of-the-year

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5C.1 Overview of Flow in the Sacramento River, San Joaquin River, and Delta Systems

Fish that inhabit the Sacramento–San Joaquin River Delta (Delta) system are directly and/or indirectly affected by the flows in the Sacramento and San Joaquin Rivers and their tributaries, as well as the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) area, during all or some of their life stages (see Appendix 2.A, *Species Accounts*, for a detailed description of potential exposure of each life stage to various flow-related stressors). Currently, besides natural variation in hydrology, the primary drivers for flows in the system are reservoir operations for flood control, fish habitat needs, water supply, and upstream and in-Delta diversions. The State Water Project (SWP) and Central Valley Project (CVP) are only two of many projects that appropriate water within the Bay-Delta estuary. Each upstream reservoir (SWP or CVP) is operated with these three basic monthly operating constraints: (1) requirement for some empty storage space in the months with high potential rainfall (flood control), (2) minimum monthly reservoir releases for downstream fish habitat and water temperature conditions, and (3) downstream delivery or diversion targets for the monthly release of storage for beneficial uses by the water contractors (water supply). Habitat suitability and availability can vary based on how these flows are managed and ultimately can determine survivability of aquatic species.

The BDCP is expected to result in changes in flows primarily as a result of the change in export location (new north Delta intake) and its associated specified changes in monthly Delta operational objectives, namely, required salinity objectives, outflow objectives, export/inflow [E/I] objectives, Old and Middle River [OMR] flow objectives, and maximum exports. In addition, BDCP habitat restoration may modify hydrodynamics in the Delta. These hydrodynamic changes in turn can change salinities, concentrations of dissolved oxygen (DO), turbidity, and flows. Flow change in the Delta as a result of the BDCP, particularly in the Yolo Bypass, lower Sacramento River, and south Delta channels, can affect the migration success of fish. No substantial changes in reservoir operations are expected as a result of the BDCP, with the potential exception of Lake Oroville, where the BDCP could shift substantial releases from summer months to spring months under the high outflow scenario to contribute to the spring outflow criteria.

5C.1.1 Flow and Flow-Related Parameters

The flow-related parameters assessed in this appendix include those physical and chemical constituents that are affected by flow, which in turn can have effects on fish that can affect species survivability. Each of the following parameters has been identified as key for determining suitable habitat for aquatic species that reside in or migrate through the Delta. The operations and management of the flood control and water supply facilities that affect the Delta can be adjusted to influence each parameter. More detail regarding the potential effects and exposure of each species life stage to these parameters is provided in Table 5C.1-1 and in Appendix 2.A, *Species Accounts*.

5C.1.1.1 Dissolved Oxygen

DO is a measure of how much oxygen is available in the water column for support of aquatic species. Different species have varying tolerances of DO levels, but in general many of the fish species in the Delta require high DO levels (5–7 milligrams per liter [mg/L]). When DO levels fall, species become stressed and move toward areas of higher DO if pathways exist. Low DO levels can create passage barriers and increase species mortality.

5C.1.1.2 Salinity

The concentration of the dissolved salt in a body of water is salinity. Usually measured in parts per thousand (ppt), the salinity gradient transitioning from the ocean to a freshwater stream can vary between 0.5 ppt (fresh water) to ~32–37 ppt (sea water). Historically in the Delta, the point in the salinity gradient that has been tracked and managed is 2 ppt bottom salinity and is referred to as X2. Salinity also can affect the concentration of DO. Within the Plan Area, fresh water can support DO concentrations as high as 9 mg/L, and salt water can accommodate only up to 8 mg/L. Many fish species, at one life stage or another, have a preferred range of salinity and a range of physiological tolerance to salinity, both of which can influence species distribution.

5C.1.1.3 Temperature

Water temperature is critical in the control of chemical reactions and biological processes that can alter water chemistry and the water column’s carrying capacity for DO. Warmer water has less available DO carrying capacity. Warmer water also has increased potential for greater biological processes, including increased fish diseases and algae production, which in turn also can alter DO on a diurnal cycle that fluctuates with exposure to sunlight. Temperature is also a key factor in the mortality of aquatic species during all life stages, with egg survival and juvenile rearing being two of the phases most sensitive to temperature.

1 **Table 5C.1-1. Potential Species Presence and Exposure by Life Stage in the Subregions of the Upstream and Delta Areas, and Potential to Be Affected by Changes in Flows**

		Upstream Area						Passage and Movement			Delta Area						
Species	**Life Stage**	**Stanislaus/ Mainstem San Joaquin[1] Rivers**	**Mainstem Sacramento River**	**Feather River**	**American River**	**Trinity River**	**Clear Creek**	**Yolo Bypass**	**Stockton Deep Water Ship Channel**	**Delta and Suisun Marsh Channels**	**North Delta**	**South Delta**	**East Delta**	**West Delta**	**Suisun Marsh**	**Cache Slough**	**Yolo Bypass**
Steelhead	Egg/Embryo	▨	▨	▨	▨	☐	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Fry	▨	▨	▨	▨	☐	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Juvenile	▨	▨	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	▨	▨	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Winter-run Chinook salmon	Egg/Embryo	☐	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Fry	☐	▨	☐	☐	☐	☐	▨	☐	▨	▨	☐	☐	▨	▨	▨	▨
	Juvenile	☐	▨	☐	☐	☐	☐	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	☐	▨	☐	☐	☐	☐	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
Spring-run Chinook salmon	Egg/Embryo	☐	▨	▨	☐	☐	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Fry	☐	▨	▨	☐	☐	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Juvenile	☐	▨	▨	☐	☐	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	☐	▨	▨	☐	☐	▨	▨	☐	▨	▨	☐	☐	▨	▨	▨	▨
Fall-/late fall–run Chinook salmon	Egg/Embryo	▨	▨	▨	▨	☐	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Fry	▨	▨	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Juvenile	☐	▨	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	▨	▨	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Delta smelt	Eggs	▨	☐	☐	☐	☐	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Larva	▨	☐	☐	☐	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Juvenile	☐	☐	☐	☐	☐	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	☐	☐	☐	☐	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨
Longfin smelt	Eggs	▨	▨	☐	☐	☐	☐	☐	☐	☐	▨	☐	☐	▨	☐	▨	▨
	Larva	▨	▨	☐	☐	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Juvenile	☐	☐	☐	☐	☐	☐	☐	☐	▨	☐	▨	☐	▨	▨	☐	☐
	Adult	☐	☐	☐	☐	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨
Sacramento splittail	Egg/Embryo	▨	▨	▨	▨	☐	☐	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Larvae	▨	▨	▨	▨	☐	☐	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Juvenile	▨	▨	▨	▨	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	▨	▨	▨	▨	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
White sturgeon	Egg/Embryo	▨	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Larva	▨	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Juvenile	▨	▨	▨	☐	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	▨	▨	▨	▨	☐	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Green sturgeon	Egg/Embryo	☐	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Larva	☐	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Juvenile	☐	▨	▨	☐	☐	☐	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	Adult	☐	▨	▨	☐	☐	☐	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
Pacific lamprey	Egg/Embryo	▨	▨	▨	▨	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Ammocoete	▨	▨	▨	▨	▨	▨	▨	☐	☐	▨	▨	▨	▨	☐	▨	▨
	Adult	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
River lamprey	Egg/Embryo	▨	▨	▨	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Ammocoete	▨	▨	▨	▨	▨	☐	▨	☐	☐	▨	▨	▨	▨	☐	▨	▨
	Adult	▨	▨	▨	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

☐ = Life stage not present or unlikely to be exposed
▨ = Life stage present or has potential to be exposed

[1] Analyses in mainstem San Joaquin River were limited to Vernalis only.

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5C.1.1.4 Turbidity

Turbidity is a measure of the amount of suspended solids at any point in the Delta. Suspended solids may be sediment, algae, or other solids. In general, as water moves downstream and flow velocity decreases, heavier particles settle out, falling toward the river bottom, and turbidity is reduced. As flow velocities increase during periods of high flow, or ebb and flow of tidal cycles, sediment can re-suspend as it is agitated, and turbidity will increase. Algal blooms also can alter turbidity during periods of high biological production. Turbidity can be measured using a correlation between turbidity and total suspended solids (TSS) (which is somewhat unique for each location or situation) or a Secchi disk. The Delta flow regimes are in a constant state of flux; as velocities and depths vary with floodflows, deliveries, and tides, sediment and biological matter are regularly circulated and suspended, creating a highly turbid environment. Turbidity and its composition varies widely depending on season and location. Turbidity is highest in the winter and is mostly due to suspended sediment associated with increased runoff from storms. This sediment settles out as water moves downstream. Increases in spring and summer turbidity tend to result from increased algal productivity. There has been a general trend towards decreased turbidity in the Delta over the past four decades (B.J. Miller pers. comm.; Nobriga et al. 2008; Kimmerer 2004). Turbidity may be biologically important to delta smelt because it can provide cover from predators and provide a better contrast (background) for delta smelt to catch their prey. Turbidity may provide cover from predators for multiple other covered species. To the extent that turbidity is an index of food supply, it also correlates with basic food availability (Section 5C.4.4.6, *Turbidity* (*Water Clarity*)).

5C.1.1.5 Passage

For the purposes of this appendix, passage refers to the ability of aquatic species to migrate beyond a potential barrier. In the Delta and the tributaries, migrating adult fish species, outmigrating juveniles, and resident or rearing fishes may find barriers to free movement through Delta waterways. Not all waterways are connected at all flow levels, and nonphysical barriers (e.g., water quality constraints such as zones of low DO), engineered structures (Delta Cross Channel), or lack of accessibility (Fremont Weir operations) can inhibit passage. Passage constraints can delay or prohibit successful spawning or the ocean growth stage, or subject species to higher-mortality situations (i.e., areas of increased predation, potential entrainment into CVP/SWP facilities). Passage will be described in the context of a physical facility, or an alteration of flow that has the potential to change corridors or change the potential for fish to move through a region over the annual flow cycle.

5C.2 System Hydrology and Operations

This section includes a description of SWP/CVP operations in the Delta under State Water Resources Control Board [State Water Board] water right Decision 1485 [D-1485] and Decision 1641 [D-1641] and revised operations as a result of the 2008 U.S. Fish and Wildlife Service (USFWS) and 2009 National Marine Fisheries Service (NMFS) Biological Opinions [BiOps]). A general description of each modeling scenario evaluated in this appendix also is given.

5C.2.1 Historical Operations

Water quality and flow objectives for the Delta were established in the State Water Board's 1978 Bay-Delta Water Quality Control Plan (WQCP) and were implemented in D-1485 in 1978. In general, D-1485 mandated that SWP and CVP manage water operations to maintain minimum Delta outflow and also maintain salinity at concentrations similar to what would have existed without the projects. The D-1485 objectives for minimum Delta outflows and maximum salinity (EC) mostly varied with water-year type (i.e., runoff). These outflow and water quality objectives, along with the COA, were the primary regulatory requirements for operations of the SWP/CVP Delta exports until 1995. Fish protection at the SWP/CVP facilities was provided by the fish collection facilities (fish salvage) and upstream habitat mitigation was supported by the Four-Pumps Agreement in 1986, which mandated that entrainment losses of striped bass, Chinook salmon, and steelhead be offset or mitigated through the funding and implementation of fish mitigation projects, based on the number of fish salvaged each year.

The 1995 WQCP introduced several changes in the D-1485 objectives. These new Delta objectives included the daily location of the average 2 ppt salinity (abbreviated as X2) for February through June, which was variable (adaptive) depending on runoff conditions in the previous month. The 1995 WQCP also introduced the E/I ratio, which limited total SWP/CVP exports to a specified fraction of the combined Delta inflow. The 1995 WQCP objectives were implemented as amendments to D-1485 and in the 1999 D-1641. The Vernalis Adaptive Management Plan (VAMP) was authorized as was the implementation of the San Joaquin River minimum flow objectives during the February through June period. The D-1641 objectives for minimum outflow, maximum E/I, maximum EC at several stations in the Delta, and X2 in the months of February through June must be satisfied by the SWP and CVP Delta operations. Reservoir releases and Delta exports are the two basic methods for satisfying these Delta objectives.

The Central Valley Project Improvement Act (CVPIA) imposed additional regulations affecting CVP pumping and upstream reservoir release flows for anadromous fish protection. Further regulations have been imposed under the federal Endangered Species Act (ESA) by NMFS and USFWS to reduce the effects of the SWP and CVP operations on listed species. The Reasonable and Prudent Alternative (RPA) actions included in the recent BiOps issued by NMFS (2009) and USFWS (2008) augment the fish protection provided by the D-1641 objectives and generally impose greater pumping restrictions through limitations on the reverse OMR flow. As a result of these ESA restrictions, SWP and CVP water deliveries for a given runoff hydrology have been reduced relative to Delta operations under D-1641 or under D-1485.

5C.2.2 Bay Delta Conservation Plan Physical Aquatic Modeling

5C.2.2.1 Baseline Operations

For the effects analysis, BDCP scenarios were compared with two baseline conditions, one of which was consistent with the USFWS BiOp RPA actions (Existing Biological Conditions 2 [EBC2]), and one condition in which Component 3, Action 4 of the USFWS RPA (hereafter Fall X2 action) was not included (EBC1). Four existing biological conditions model scenarios (EBC 1, EBC2, EBC2_ELT, and EBC2_LLT) differing in operational assumptions and climate change conditions were evaluated for this analysis. Table 5C.0-1 provides a description of each as well as a description of the six model scenarios related to the BDCP. The two additional EBC2 model scenarios differ from EBC2 in climate change assumptions. The EBC2_ELT scenario incorporated early long-term (ELT) (2025) climate assumptions that included 15 centimeters (cm) of sea level rise, more variable precipitation, and warmer temperatures. The EBC2_LLT scenario incorporated late long-term (LLT) (2060) climate assumptions that included 45 cm of sea level rise, more variable precipitation than in the ELT, and warmer temperatures than in the ELT. The use of these two additional model scenarios allows for comparison of conditions without the BDCP in the future with climate change to conditions with the BDCP with climate change. The resulting analyses show those changes attributable to climate change versus those attributable to the BDCP. The EBC2 case included several other changes in the current CVP water demands in the Sacramento River basin (upstream demands). The CALSIM results from the four available existing biological conditions scenarios provide comparisons of reservoir operations (storage), release flows, Delta inflows, channel flows, exports (south Delta and north Delta), and Delta outflow, all of which have direct and indirect effects on the covered fish species.

The existing biological conditions operations simulated with the monthly CALSIM model include many of the USFWS/NMFS BiOps RPA actions at upstream reservoirs and in the Delta. However, because many of these actions include adaptive management in response to changing environmental conditions (e.g., flow, temperature, turbidity, fish sampling), the CALSIM model implementation required several approximations. In the end, the modeling provides a reasonable representation of the likely operations of the SWP and CVP reservoirs and Delta pumping, and provides a basis of comparison for various model scenarios. A technical committee, formed to determine the best methods for including the BiOp actions in the CALSIM model, concluded:

> The RPAs in the Service's BO [biological opinion] are based on physical and biological phenomena that do not lend themselves to simulations using a monthly time step. Much scientific and modeling judgment has been employed to represent the implementation of the RPAs. The group believes the logic put into CALSIM II represents the RPAs as best as possible at this time, given the scientific understanding of environmental factors enumerated in the BO and the limited historical data for some of these factors.
>
> The simulated Old and Middle River (OMR) flow conditions and CVP and SWP Delta export operations, resulting from these assumptions, are believed to be a reasonable representation of conditions expected to prevail under the RPAs over large spans of years (refer to CALSIM II modeling results for more details on simulated operations). Actual OMR flow conditions and Delta export operations will differ from simulated operations for numerous reasons, including having near real-time knowledge and/or estimates of turbidity, temperature, and fish spatial distribution that are unavailable for use in CALSIM II over a long period of record. Because these factors and others are believed to be critical for smelt entrainment risk management, the Service adopted an adaptive process in defining the RPAs. Given the relatively generalized representation of the RPAs, assumed for CALSIM II modeling, much caution is required when interpreting outputs from the model.

(Source: CH2M HILL, March 10, 2010, technical memorandum on *Confirmation of Final Assumptions for Existing and Future No Action Alternative Conditions CALSIM II and DSM2 Models*.)

The CALSIM results shown in Attachment 5C.A, *CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios*, provide the appropriate basis for comparison and evaluation of the likely flow effects resulting from the BDCP, even without inclusion of the magnitude of the outflow requirements and OMR flow restrictions that might be identified each year in the various adaptive management committees (e.g., USFWS smelt committee, NMFS Delta Operations for Salmonids and Sturgeon [DOSS]) and review processes (e.g., water operations management team [WOMT]).

5C.2.2.2 Proposed Operations

Six BDCP model scenarios were analyzed that differed in fall and spring outflow and climate change assumptions. All of the model scenarios assumed that new intake facilities in the north Delta were constructed and operational. Table 5C.0-1 provides a description of each of the BDCP model scenarios evaluated: ESO_ELT, ESO_LLT, HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT. The BDCP will include modified operations of the existing SWP and CVP Delta facilities and proposed operations for the new conveyance facilities. These operations are briefly described below.

The BDCP will modify the existing SWP and CVP Delta operations to further protect fish populations and to accommodate new Delta facilities and proposed habitat restoration.

The existing SWP and CVP Delta operations are summarized here so that the BDCP modifications to these existing operations can be identified and described. Delta operations can be simplified into two sets of rules; (1) rules controlling the maximum allowable south Delta exports and (2) rules controlling the minimum required Delta outflow. Several different objectives are used to control the allowable exports, and several more objectives are used to control the minimum required Delta outflow. The proposed BDCP north Delta intakes will require a third category of Delta rules: (3) rules governing maximum allowable north Delta diversions. The new rules governing the north Delta diversions may increase the allowable Delta exports by shifting the diversion location to the new north Delta facilities, where entrainment issues are expected to be substantially reduced compared with current operations.

5C.2.2.2.1 Maximum Allowable Export Rules

Currently, several D-1641 rules govern the maximum SWP and CVP pumping capacities. The BDCP assumes the CVP pumping capacity is 4,600 cfs, which requires use of the new Delta-Mendota Canal/California Aqueduct Intertie (DMC–CA Intertie) facility in the winter months. The BDCP assumes the existing south Delta SWP maximum daily diversion from the Clifton Court Forebay (CCF) is 6,680 cfs, with additional diversions of 1/3 of the San Joaquin River flow at Vernalis (to a maximum monthly pumping of 8,500 cfs) between December 15 and March 15 when Vernalis flow is above 1000 cfs. SWP pumping to the maximum SWP Harvey O. Banks Pumping Plant (SWP Banks) physical capacity of 10,300 cfs was assumed for the BDCP using the north Delta intakes.

The E/I ratio was introduced in the 1995 WQCP and limits the SWP and CVP combined pumping to 65% of the Delta inflow from July to January, and to 35% of the Delta inflow from February to June. The rule is applied with a 7-day moving average of inflow and a 3-day average of export pumping. The 35% is increased to 45% in February if the January runoff was low (D-1641). For the BDCP cases, the E/I ratio was assumed to apply only to south Delta exports; the north Delta intake diversions were assumed to be exempt from this E/I rule because the north Delta diverisons are controlled by the bypass flow rules. The south Delta pumping was limited by the E/I calculated with the inflow minus the north Delta diversions; this would allow slightly higher total exports during periods when Sacramento River flows are high and north Delta diversion are high. Attachment 5C.A, *CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios*, indicates that this difference in the E/I rule would allow increased total exports in June for about 30% of the years; the total exports are generally controlled by other factors.

An additional limit on exports was imposed by the 2009 NMFS BiOp with an export/San Joaquin River inflow ratio that applies in April and May. This ratio effectively limits the combined export to 1,500 cfs for San Joaquin River inflows of less than 6,000 cfs. This limit was assumed for the EBC cases, but was not included in the BDCP operations scenarios.

The USFWS and NMFS BiOps introduced new limits on the reverse (negative) OMR flow in the months of December–June of many years (adaptively managed based on turbidity and fish monitoring). For example, a minimum OMR limit of -2,000 cfs would restrict exports to about 2,000 cfs plus the Old River flow diverted from the San Joaquin River near Mossdale. The north Delta intakes would allow these OMR limits to be satisfied (and in many instances further improved) while pumping additional water from the Sacramento River. The OMR limits will vary each year with fish and turbidity conditions; however, the CALSIM modeling assumed in addition to the estimated requirements under the USFWS BiOp, a monthly OMR limit that varies with the water-year type.

The final constraints on Delta exports are related to the seasonal (monthly) water supply deliveries that are assumed for south of Delta SWP and CVP contractors. The San Luis Reservoir provides about 2 million acre-feet of seasonal storage for meeting the peak summer water demands. The San Luis Reservoir storage allows relatively high exports to continue through the fall and winter period. SWP exports include Article 21 deliveries to contractors with local storage capacity (e.g., surface reservoirs or groundwater storage) once San Luis Reservoir is filled, if there is excess delta outflow as defined under the COA. Because the BDCP will allow higher exports and fill San Luis Reservoir earlier each year, the simulated BDCP operations often included higher SWP Article 21 "bonus" deliveries, although maximum Article 21 deliveries are the same in all scenarios.

5C.2.2.2.2 Minimum Required Delta Outflow Rules

Several D-1641 objectives currently often control Delta outflow. Minimum monthly outflows are specified in D-1641 for each month, which often depend on the water-year type (i.e., runoff conditions). For example, a minimum monthly outflow of 3,000 cfs is specified in September of all years. A minimum monthly outflow of 8,000 cfs is specified in July of wet and above normal water-year types (about half of the years).

The second set of D-1641 objectives that control Delta outflow are the maximum salinity objectives specified for each month or period. For example, salinity (EC) objectives are specified at Emmaton and Jersey Point to protect agricultural diversions, and salinity (chloride) objectives are specified at the Contra Costa Water District (CCWD) Rock Slough intake (PP#1) to protect drinking water supplies. Because Delta outflow is the major factor determining salinity in the Delta channels, these salinity objectives are satisfied by increasing Delta outflow (often by reducing exports). The D-1641 salinity objectives are assumed to apply to the EBC and the BDCP cases (ELT and the LLT).

The third set of rules that control Delta outflow is the spring X2 objectives introduced in the 1995 WQCP. The location (kilometers [km] upstream of the Golden Gate Bridge) of the 2 ppt salinity (i.e., upstream edge of estuarine salinity gradient) is specified, based on the month and the (unimpaired) runoff in the previous month. This was formulated as an adaptive objective; the required outflow increased with higher runoff conditions. D-1641 specifies maximum required Delta outflows for the X2 objectives; X2 at Collinsville (81 km) can be satisfied with an outflow of 7,100 cfs, X2 at Chipps Island (74 km) can be satisfied with an outflow of 11,400 cfs and X2 at Roe Island (64 km) can be satisfied with an outflow of 29,200 cfs. The CALSIM model includes changes in the outflow-salinity relationships for the ELT and LLT cases. San Francisco Bay tidal salinity modeling (i.e., 3-D UnTRIM model) results were used to estimate the effects of assumed sea level rise and tidal restoration on the salinity gradient for the ELT and LLT. The increased salinity effects were translated into higher CALSIM required outflows needed to satisfy the EC and X2 objectives, though the D-1641 flow caps were assumed to still apply.

The 2008 USFWS BiOp included an additional outflow requirement for September and October of wet and above normal water-year types (about half the years). The Fall X2 rule requires X2 to be at downstream of Collinsville (requiring up to 7,100 cfs outflow) in above normal years and downstream of Chipps Island (requiring up to 11,400 cfs outflow) in wet years. The Fall X2 rule was included in the EBC2, EBC2_ELT, and EBC2_LLT cases, but not the EBC1 case.

As described above and in Chapter 3, *Conservation Strategy*, , the Fall X2 outflow operation is the subject of one decision tree process, while spring outflow volume is the subject of the other decision tree process. For the Fall X2 decision tree, the potential operational outcomes are D-1641 (pre-2008 BiOp) fall outflow criteria or the Fall X2 USFWS RPA. For the spring outflow decision tree, the two potential outcomes are the existing D-1641 outflow criteria for the months of March through May, or a high outflow scenario that attempts to increase spring outflow as much as possible without causing unacceptable biological effects on upstream operations. As described in Table 5C.0-1, the high outflow scenario (which includes both the Fall X2 USFWS RPA and high spring outflow) and the low outflow scenario (D-1641 fall and spring outflow) are evaluated in this effects analysis along with the evaluated starting operations, which include the Fall X2 USFWS RPA and D-1641 spring outflow criteria . All three of these operational scenarios are evaluated in the early long-term and the late long-term (ELT and LLT).

5C.2.2.2.3 Rules for North Delta Intake Diversions

The proposed north Delta intakes will operate under several parameters related to fish screen approach velocity and sweeping velocity. Some of these operational parameters could limit operations within the tidal cycle. However, only the maximum allowable north Delta diversions, using daily or monthly flows, could be incorporated into the CALSIM modeling of the BDCP scenarios (ELT and LLT) (Section 5C.4.1, *CALSIM II and DSM2 Models*).

The new operational rules vary between months and are referred to as *bypass flow rules* for the north Delta intakes. These bypass rules are designed to protect fish migrating past the intake facilities, especially during the first flow “pulse” that often coincides with a major fish movment (de Rosario et al. 2013), to reduce the upstream tidal transport of migrating fish into Georgianna Slough, and to “bypass” the majority of the Sacramento River inflow hydrograph. The north Delta intakes and the associated bypass flow rules are the major changes in Delta operations that would result from the BDCP. The proposed bypass flow rules govern the fraction of Sacramento River flow that can be diverted during a particular month (Chapter 3, *Conservation Strategy*, Table 3.4.1-2). For example, the basic bypass flow rule for the months of July through September is 5,000 cfs in all years. The minimum bypass flow rule in October and November is 7,000 cfs in all years. There may be other rules that would limit the north Delta diversion and allow a higher bypass flow, but these minimum bypass rules will govern the operations of the north Delta intakes.

The north Delta intake bypass flow rules for December through June are more complicated, with bypass flows increasing with the inflow and allowing for initial pulse flow protection. Low-level pumping of 6% of the river flow (to a maximum of 300 cfs per intake) is allowed most of the time (Freeport flow must be >5,000 cfs), but major diversions could not begin until the Sacramento River flow was greater than a specified threshold (of about 9,000 cfs to 15,000 cfs). These bypass flow rules have an effect similar to the E/I ratio—generally limiting the north Delta diversion to a fraction of the Sacramento River flow at Freeport. These monthly bypass flow rules control how much of the Delta exports are diverted from the north Delta intakes.

The bypass flow criteria are constant values of 5,000 cfs in July through September and 7,000 cfs in October and November. The allowable diversions are easily calculated and increase directly with Sacramento River flows above the bypass criteria. For example, with a Sacramento River flow at Freeport of 10,000 cfs, the allowable north Delta diversion would be 5,000 cfs in July through September and 3,000 cfs in October and November. At a Sacramento River flow of 15,000 cfs, the allowable diversion would be 10,000 cfs in July through September and 8,000 cfs in October and November. However, if the first pulse flow occurs in October or November, the pulse flow protection rules will reduce the diversions to eh low-level pumping of 6% of the river flow.

There is some ambiguity in the allowed diversions during the December–June period as the Freeport flow increases to the initial bypass flow rule threshold (i.e., 15,000 cfs for Level I, 11,000 cfs for Level II, or 9,000 cfs for Level III in December–June). The diversions would decrease if the low-level pumping was not continued once the Freeport flow increased to the threshold. For the summary description of allowable diversions, the low-level pumping was assumed to be added to the diversion allowed by the bypass flow rules. Beginning on December 1, only low-level pumping (6% of river flow to a maximum of 900 cfs) is allowed until after the initial Sacramento River at Wilkins Slough flow pulse. This low-level pumping provides protection for juvenile fish migration (e.g., winter-run Chinook salmon) that has been shown to increase during the first major storm event each year. The initial flow pulse was defined for modeling purposes to begin with the following criteria: (1) Sacramento River at Wilkins Slough flow increasing by more than 45% within a 5-day period and (2) Wilkins Slough flow greater than 12,000 cfs at the end of the 45% increase. The initial pulse period was defined for modeling purposes to end when one of the following occurs: Wilkins Slough flow decreases to the flow on first day of the 45% increase; Wilkins Slough flows decrease for 5 consecutive days; or flows at Wilkins Slough are greater than 20,000 cfs for 10 consecutive days. However, the actual operations of the north Detla intakes during the initial puse period would be based on real-time monitoring of fish movement at the upstream rotary screw traps and Sacramento River trawl stations; the adaptive operations of the north Delta intakes would be similar to the existing guidance provided by the DOSS work group.

After the initial pulse flow period, north Delta intake bypass flow rules increase with Sacramento River flow at Freeport and have three progressively lower levels. Level I bypass flow rules apply until there have been 15 days of post-pulse bypass flows above 20,000 cfs.. Level II bypass flow rules allow slightly higher diversions and apply until there have been 30 total days of bypass flows above 20,000 cfs. Level III bypass flow rules apply until the end of April. The bypass flow rules in May and June are similar, with three levels of protection, but with slightly lower bypass flow requirements. It is likely that the level I and level II criteria would apply to the first month after the initial pulse period in years with substantial runoff; north Delta diversions will be governed by the level III bypass criteria for the majority of the December–June fish protection period, if the bypass flows remain higher than 20,000 cfs for 30 days after the initial pulse period. These bypass flow criteria will greatly reduce the allowable north Delta pumping in the December–June period for Sacramento River flows of less than 15,000 cfs, which are common in dry and critical years.

The effects of the bypass flow criteria can be summarized by determining the allowable north Delta diversions for a range of Sacramento River flows at Freeport. Table 5C.2-1 shows the allowable north Delta diversions in each month for a range of Sacramento River flows at Freeport. The first two columns show the allowable diversions in the months of July through September and in the months of October and November. The next three columns (3–5) show the allowable diversions for the three levels of bypass flow criteria that are applied during the months of December through April, after the initial pulse period is ended.

For example, level III diversions in December–April would be 600 cfs for a Sacramento River flow at Freeport of 10,000 cfs; 3,000 cfs for a Sacramento River flow of 15,000 cfs; and 7,000 cfs for a Sacramento River flow of 20,000 cfs. Columns 6 through 11 show the allowable diversions with the three levels of bypass flow criteria in May and June. For example, the allowable north Delta diversions for Level III bypass rules with a Sacramento River flow at Freeport of 15,000 cfs would be 3,600 cfs in May and 4,200 cfs in June. The allowable north Delta diversions with a Sacramento River flow of 20,000 cfs would be 4,200 cfs in May and 8,200 cfs in June.

Full diversions of 9,000 cfs would be allowed in July–September with a Sacramento River flow of 14,000 cfs, would be allowed in October and November with a Sacramento River flow of 16,000 cfs. Full diversions of 9,000 cfs would be allowed in December–April for level I bypass rules with a Sacramento River flow of 31,000 cfs and for Level III bypass rules with a Sacramento River flow of about 22,000 cfs. Full diversions of 9,000 cfs would be allowed for Level III bypass rules in May with a Sacramento River flow of 22,000 cfs and in June with a Sacramento River flow of 21,000 cfs. These bypass flow rules were included in the CALSIM modeling, which included daily estimates of Sacramento River flows based on historical daily flows and adjustments in reservoir releases, to provide realistic estimates of the allowable monthly north Delta pumping.

Table 5C.2-1. Maximum Allowable North Delta Diversions (cfs) in Different Months for a Range of Sacramento River Flows at Freeport (cfs) under BDCP CM1 Post-Pulse Bypass Rules

Months	Jul–Sep	Oct–Nov	Dec–Apr			May			Jun		
Level			I	II	III	I	II	III	I	II	III
Sacramento River at Freeport Flow (cfs)											
5,000	0	0	0	0	0	0	0	0	0	0	0
6,000	1,000	0	360	360	360	360	360	360	360	360	360
7,000	2,000	0	420	420	420	420	420	420	420	420	420
8,000	3,000	1,000	480	480	480	480	480	480	480	480	480
9,000	4,000	2,000	540	540	540	540	540	540	540	540	540
10,000	5,000	3,000	600	600	600	600	600	600	600	600	700
15,000	9,000	8,000	900	1,600	3,000	900	2,000	3,600	900	2,400	4,200
20,000	9,000	9,000	1,600	4,100	7,000	2,100	5,250	7,600	2,600	6,400	8,200
25,000	9,000	9,000	5,100	8,100	9,000	6,100	9,000	9,000	6,600	9,000	9,000
30,000	9,000	9,000	8,600	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
35,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
40,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000

Notes: Level I bypass flow rules apply after the initial flow pulse period ends until after 15 days with a bypass flow of greater than 20,000 cfs. Level II bypass rules apply until a total of 30 days with bypass flow of greater than 20,000 cfs. Level III bypass rules apply for the remainder of the migrating fish protection period of December through June. Low-level pumping for December-June (up to 6% of the Freeport flow) was assumed to continue until the allowable diversions under the post-pulse bypass rules were greater than 6% of the Freeport flow.

5C.3 Species Exposure to Flow and Flow-Related Parameters

All of the covered fish species would be exposed to BDCP-related changes in flows and flow-related parameters in the Sacramento River system, the San Joaquin River system, the Delta, or a combination of these areas. Table 5C.1-1 indicates which life stages for each species would be exposed to various areas in the Study Area. The life stage presence of each species as shown in the table provides the basis for determining why certain methods and analyses are applicable to the various life stages of each species. Additional detail about the life histories and a conceptual model for each species are provided in Appendix 2.A, *Species Accounts*.

Appendix 5.C
Flow, Passage, Salinity, and Turbidity

5C.4 Methods Used

A number of methods were used to assess the potential effects on fish related to changes in flows from the BDCP. Table 5C.4-1 indicates which methods were applied for each area of interest (upstream habitat, Delta habitat, and passage/movement) and to each life stage of each species. Table 5C.4-2 provides a description of each method used and its benefits and limitations.

1 **Table 5C.4-1. Summary of Methods Used for Each Region and Species Life Stage**

Flow Parameter Change or Species Affected	Geographic Region or Life Stage	CALSIM	DSM2-HYDRO	DSM2-QUAL	DSM2-Fingerprinting	MIKE21	Sacramento Splittail Habitat Area	Reclamation Temperature Model	Sacramento River Water Quality Model	Delta Passage Model	Salmon Smolt Survival (Newman 2003)	PTM Nonlinear Regression	DRERIP	Sacramento Ecological Flows Tool	Reclamation Egg Mortality Model	SALMOD	Winter/Spring X2–Abundance Regression	Delta Smelt Abiotic Habitat Index	Yolo Bypass Fry Growth Model	Wetland Bench Inundation	Straying Rate of Adult SJR Region Fall-Run Chinook Salmon (Marston et al. 2012)	North Delta Diversion Bypass Flow Effects on Chinook Salmon Smolt Survival	Reverse Flows Analysis	Water Clarity	Sutter Bypass Inundation
Upstream Abiotic Habitat	Sacramento River and San Joaquin River	X						X	X					X	X	X									
Fish Movement (Migration, Transport, and Passage)	Sacramento River, Delta	X	X		X					X	X	X	X								X	X	X		
Delta Habitat (Plan Area)	Delta	X	X	X		X							X				X	X	X	X				X	X
Steelhead	Eggs/Embryo	X						X	X					X											
	Fry and Rearing Juveniles	X	X					X	X					X											
	Juvenile Migrants	X	X	X				X	X																
	Adults	X		X	X			X	X				X												
Winter-Run Chinook Salmon	Eggs/Embryo	X						X	X					X	X	X									
	Fry	X						X	X					X		X			X						
	Juvenile Migrants	X	X	X						X			X									X			
	Adults	X		X	X			X	X				X												
Spring-Run Chinook Salmon	Eggs/Embryo	X						X	X					X	X	X									
	Fry	X						X	X					X		X									
	Juvenile Migrants	X	X	X						X	X		X									X			
	Adults	X		X	X			X	X				X												
Fall-/Late Fall–Run Chinook Salmon	Eggs/Embryo	X						X	X					X	X	X									
	Fry	X						X	X					X		X			X						
	Juvenile Migrants	X	X	X						X	X	X	X								X	X			
	Adults	X		X	X			X	X				X												

Flow Parameter Change or Species Affected	Geographic Region or Life Stage	CALSIM	DSM2-HYDRO	DSM2-QUAL	DSM2-Fingerprinting	MIKE21	Sacramento Splittail Habitat Area	Reclamation Temperature Model	Sacramento River Water Quality Model	Delta Passage Model	Salmon Smolt Survival (Newman 2003)	PTM Nonlinear Regression	DRERIP	Sacramento Ecological Flows Tool	Reclamation Egg Mortality Model	SALMOD	Winter/Spring X2–Abundance Regression	Delta Smelt Abiotic Habitat Index	Yolo Bypass Fry Growth Model	Wetland Bench Inundation	Straying Rate of Adult SJR Region Fall-Run Chinook Salmon (Marston et al. 2012)	North Delta Diversion Bypass Flow Effects on Chinook Salmon Smolt Survival	Reverse Flows Analysis	Water Clarity	Sutter Bypass Inundation
Delta Smelt	Eggs			X																					
	Larva	X		X																					
	Juvenile	X		X														X							
	Adult			X																					
Longfin Smelt	Eggs			X																					
	Larva	X	X	X																					
	Juvenile	X		X													X								
	Adult			X																					
Sacramento Splittail	Eggs/Embryo	X				X	X	X	X																
	Fry	X				X	X	X	X																
	Juveniles	X				X	X						X												
	Adults	X				X	X	X	X				X												
White Sturgeon	Egg/embryo	X						X	X				X												
	Larva	X						X	X				X												
	Juvenile	X		X				X	X				X												
	Adult	X		X				X	X				X												
Green Sturgeon	Egg/embryo	X						X	X					X											
	Larva	X						X	X																
	Juvenile	X		X				X	X				X												
	Adult	X		X				X	X				X												
Pacific Lamprey	Eggs	X						X	X																
	Ammocoetes	X						X	X																
	Macropthalmia	X		X																					
	Adult	X		X	X																				
River Lamprey	Eggs	X						X	X																
	Ammocoetes	X						X	X																
	Macropthalmia	X		X																					
	Adult	X		X	X																				

Table 5C.4-2. Description of Methods Used and the Benefits and Limitations of Each Method

Method	Description of Method	Benefits of Method	Limitations of Method
CALSIM	The CALSIM II planning model simulates the operation of the CVP and SWP over a range of hydrologic conditions based on an assumed set of demands, regulatory requirements and climate-related factors using an 82-year record of hydrology. CALSIM II produces key outputs that include river flow volumes and diversion volumes, reservoir storage, Delta flow volumes and export volumes, Delta inflow volumes and outflow volumes, deliveries to project and nonproject users, and controls on project operations. The model operates at a monthly time step, but for the BDCP analysis daily flows on the Sacramento River were used to estimate Fremont Weir diversions and north Delta intake bypass flow requirements. These daily Sacramento River flows were estimated from the historical daily patterns adjusted to match the monthly CALSIM flows.	Based on a long, hydrologically diverse record and system-wide. Allows comparisons of changes in flows under a range of alternative operations. Used extensively to determine change in water operations and flows.	Monthly time step limits use for daily or instantaneous effects analysis; does not accurately simulate real-time operational strategies to meet temperature objectives or flood control requirements.
DSM2-HYDRO	DSM2-HYDRO estimates flow rates, velocities, and depths for the Delta for a given scenario (e.g., the BDCP or climate change). It is tidally averaged. Outputs are used to determine the effects of these hydrodynamic parameters on covered terrestrial and fish species and as inputs to other biological models. The model operates at a 15-minute time step.	Numerous output nodes throughout the Plan Area. Provides information in short time steps that can be used to assess tidal hydrodynamics. Used extensively to determine change in water operations and flows. The 16 years modeled in DSM2 represent the range of conditions found in the 82 CALSIM II years.	One-dimensional model; very data-intensive; runs for limited period (only 16 years). Open-water areas are treated as a fully mixed system, which is an oversimplification.

Method	Description of Method	Benefits of Method	Limitations of Method
DSM2-QUAL	The DSM2-QUAL module simulates fate and transport of conservative and non-conservative water quality constituents, including salts, given a flow field simulated by HYDRO. Outputs are used to estimate changes in salinity and their effects on covered species as a result of the BDCP and climate change. The model operates at a 15-minute time step.	Numerous output nodes throughout the Plan Area. Used extensively in Central Valley fishery assessments.	One-dimensional model; very data-intensive; runs for limited period (only 16 years).
DSM2-Fingerprinting	Calculates the proportion of water from different sources at specific locations in the Delta. The model operates at a 15-minute time step, although the fingerprinting outputs are monthly-averages for the 16-year period.	Allows assessment of water composition at numerous locations throughout the Plan Area. Useful for assessing changes in potential olfactory cues and attraction flows as well as water movement through the Delta.	One-dimensional model; very data-intensive; runs for limited period (only 16 years).
MIKE-21	MIKE-21 is a two-dimensional hydrodynamic model used to model steady-state inundation. Outputs of MIKE-21 are used to estimate the area of inundated habitat in the Yolo Bypass for species such as splittail and Chinook salmon. Because the model is not temporally explicit, there is no time step.	Two-dimensional model provides improved definition over one-dimensional models. Can be used to assess changes in physical habitat conditions for fish within the inundated floodplain as a function of specific flows.	The model is steady-state such that changes in flows are not modeled dynamically.
Sacramento splittail habitat area	Estimates suitable habitat area for splittail spawning and early rearing habitat in the Yolo Bypass as a function of area weighted by depth. Because this analysis is not temporally explicit, there is no time step.	Accounts for the duration of flooding required for successful spawning and rearing.	No weighting is applied across months; does not account for sources of inundation to the Yolo Bypass
Reclamation Temperature Model	The Reclamation Temperature Model is used to assess the effects of operations on water temperatures in the Feather, Stanislaus, Trinity, and American river basins, which are then used as inputs to the Reclamation Salmon Mortality Model and species-specific habitat evaluations. The model operates at a monthly time step.	Large geographic extent makes model widely spatially applicable to the ESO effects analysis area. Used extensively in Central Valley fishery assessments. Uses modified meteorological data that future climate change for ELT and LLT scenarios.	Monthly time step limits use for daily or instantaneous effects analysis; does not accurately simulate real-time reservoir operational strategies to meet temperature objectives.

Method	Description of Method	Benefits of Method	Limitations of Method
Sacramento River Water Quality Model	SRWQM is an application developed to use the HEC-5Q model to simulate mean daily (using 6-hour meterology) reservoir and river temperatures at key locations in the Sacramento River from Shasta Dam to Knights Landing. Output (temperature and flow) from the SRWQM is used as an input to a number of biological models for upstream life stages of salmonids and sturgeon. The model operates at a daily time step.	Daily time step allows more accurate simulation and can be used to assess temperature effects at a more biologically meaningful time step. Provides input to the Reclamation egg mortality and SALMOD models, as well as IOS and OBAN Used extensively in Central Valley fishery assessments. Uses modified meteorological data that incorporates future climate change for ELT and LLT scenarios.	Temporal downscaling routines have limited precision and are not always accurate. Cannot reflect real-time management decisions for coldwater pool and temperature management.
Delta Passage Model	DPM simulates migration and mortality of Chinook salmon smolts entering the Delta from the Sacramento, Mokelumne, and San Joaquin Rivers through a simplified Delta channel network, and provides quantitative estimates of relative Chinook salmon smolt survival through the Delta to Chipps Island. DPM is used to estimate through-Delta survival for winter-, spring-, fall-, and late fall–run juvenile Chinook salmon passing through the Delta, as well as estimates of salvage in the south Delta export facilities. Model inputs are DSM2-HYDRO and CALSIM data. The model operates at a daily time step.	Provides estimates of overall proportions of migrating juvenile Chinook salmon runs that are lost to entrainment, while accounting for movement down different Delta channels; allows differentiation of fall-run populations by Sacramento, San Joaquin, and Mokelumne River basins. Reach-specific survival/behavior at junctions can be post-processed to investigate specific hypotheses regarding conservation measures not included in the model.	Many of the model assumptions are based on results from large, hatchery-reared fall-run Chinook salmon that may not be representative of smaller, wild-origin fish. Model is applicable only to migrating fish and not to those rearing in the Delta. Model is mostly limited to operations-related effects on flow. Model only accounts for smolts and not other migrating juvenile life stages.
Fall-run/spring-run Chinook salmon smolt survival (based on Newman 2003)	Estimates through-Delta survival of fall-run and spring-run Chinook salmon smolts on the Sacramento River, based on the coefficients determined by Newman (2003). Model inputs are DSM2-HYDRO and DSM2-QUAL data. The model operates at a daily time step.	Based on peer-reviewed paper including many years of coded-wire tag survival studies and includes numerous covariates (Sacramento River flow, south Delta exports, water temperature, turbidity, conductivity, position of Delta Cross Channel); provides information applicable to smaller size smolts (80 mm) than DPM.	Applied only to fall-run and spring-run Chinook salmon from the Sacramento River; limited to operations-related covariates (flow and exports, plus Delta Cross Channel gate position); does not account for potential benefits of the Yolo Bypass for migrating smolts.

Method	Description of Method	Benefits of Method	Limitations of Method
Sacramento Ecological Flows Tool	Links flow management actions to changes in the physical habitats and predicts effects of habitat changes to several fish species. The model operates at a daily time step.	Incorporates flow and water temperature inputs with multiple model concepts and field and laboratory studies to predict effects on multiple performance measures for fish species; peer-reviewed model.	Limited to upper Sacramento River; limited set of focal species (steelhead, Chinook salmon, and green sturgeon); third in a sequence of models (CALSIM and SRWQM), so limitations of previous models are compounded.
SALMOD	SALMOD is a simulation model for salmonids in the Sacramento River from Keswick to Red Bluff that is used to assess the effects of flows in the Sacramento River on habitat quality and quantity and ultimately on juvenile production of all races of Chinook salmon. The model operates at a weekly time step.	Measures effects of flows and water temperatures on spawning, egg incubation, and juvenile growth in terms of smolt production. Used extensively in Central Valley fishery assessments.	Model only extends from Keswick to Red Bluff. Not all life stages are represented (e.g., outmigration, ocean dwelling, upstream migration). Only assesses effects of flow and water temperature; not reasonably accurate for small spawner numbers (<500 fish). The number of spawners for each year isdefined by the user.
Reclamation Egg Mortality Model	The Salmon Mortality Model is used to assess temperature-related proportional losses of eggs and fry for each race of Chinook salmon in the Trinity, Sacramento, Feather, American, and Stanislaus Rivers. The model operates at a daily time step and provides output on an annual time step.	Assesses effects at multiple locations within multiple rivers. Used extensively in Central Valley fishery assessments.	Limited to effects of water temperature on eggs only; daily time step requires linear interpolation between monthly temperatures to compute daily temperatures; third in a sequence of models (CALSIM and Reclamation Water Temperature Model), so limitations of previous models are compounded.
DRERIP	Used to assess importance of stressors, develop methods, and aid in qualitative assessments of covered activities in the Plan Area.	Conceptual models have been peer-reviewed and include individual fish species and habitat functions. Provides information on potential stressors and mechanisms for effects analysis.	Outputs are limited to qualitative assessments based on best professional judgment of topical experts.
Longfin Smelt Winter-Spring X2–Abundance Regression	Used to estimate relative abundance of longfin smelt in the fall based on winter-spring X2 (as an indication of outflow). Model input is from CALSIM data.	Method has been peer-reviewed and includes regressions based on observed data.	Changes in the nature of the relationship in recent years appear to have occurred as a result of factors other than outflow; method does not account for population dynamics such as stock-recruitment relationships; the specific mechanism(s) underlying the flow/abundance relationship are not clearly understood.

Method	Description of Method	Benefits of Method	Limitations of Method
Delta Smelt Abiotic Habitat Index	Used to calculate area of delta smelt abiotic habitat in fall (September–December) based on the relationship described by Feyrer et al. (2011). Model input is CALSIM data for Fall X2.	Method has been peer-reviewed and includes relationships based on observed data, and the approach has been reasonably predictive of recent indices (e.g., the strong index in 2011).	Was developed based on a portion of delta smelt fall habitat (primarily Suisun Bay, Suisun Marsh, and West Delta subregions) that does not incorporate other areas where recent occurrence has been appreciable; based on two abiotic factors; based on linked statistical models without accounting for uncertainty in each model.
Straying Rate of Adult San Joaquin River Region Fall-Run Chinook Salmon (Marston et al. 2012)	Estimates straying rate of San Joaquin River adult fall-run Chinook salmon as a function of south Delta exports and San Joaquin River inflow.	Based on peer-reviewed published work, allowing assessment of the potential biological importance of changes in the ratio of San Joaquin River flow to south Delta exports in the fall.	It is uncertain the extent to which exports or inflow or both drive the observed relationships, as models with similar explanatory ability were found for several different combinations of predictor variables.
North Delta Diversion Bypass Flow Effects on Chinook Salmon Smolt Survival	Estimates survival of Sacramento River Chinook salmon from Sacramento River-Georgiana Slough/Delta Cross Channel Divergence as a function of north Delta diversion bypass flow (based on Perry 2010), with differences across the various pulse protection flow levels; also uses the results of the analysis based on Newman (2003) for a similar purpose.	Allows more detailed examination of potential differences in survival under different bypass flow levels, to assess the relative differences between the levels.	Method only provides perspective on survival over a portion, albeit major, of potential migration pathways. Method limited to changes caused by changes in Sacramento River flow and the assumed flow-survival relationship. Method does not provide perspective on changes that could result from other conservation measures.
Reverse flows analysis	Estimates percentage of time that Sacramento River at Georgiana Slough has reverse flows and what proportion of flow enters Georgiana Slough or the Delta Cross Channel, based on 15-minute DSM2-HYDRO data. Also uses DPM results to examine proportion of Chinook salmon smolts entering Georgiana Slough and Steamboat/Sutter Sloughs.	Allows detailed examination of percentage of time that flow is reversing and what proportion of flow is entering the interior Delta through Georgiana Slough.	Results may be challenging to interpret because it is difficult to isolate differences between scenarios caused by changes in water operations (CM1) versus changes caused by tidal habitat restoration (CM4).
Yolo Bypass Fry Growth Model	Used to estimate the differences in growth of Chinook salmon fry in the Yolo Bypass compared with the mainstem lower Sacramento River. Model input is from CALSIM data.	Provides comparison of alternate migratory routes for fry in terms of growth and size-related survival.	Enhanced growth rate on Yolo Bypass modeled as a function of duration of flooding and does not floodplain is include potential benefits of productivity related to flooded area.

Method	**Description of Method**	**Benefits of Method**	**Limitations of Method**
Water Clarity	Qualitative and quantitative assessment of the potential for changes in water clarity because of factors such as sediment removal by the proposed north Delta intakes, sedimentation in restoration areas, water depth, and water velocity.	Method provides useful framework from which the influence of different potential factors affecting water clarity can be judged. Includes quantitative modeled data (CALSIM and DSM2-HYDRO) where possible.	Many uncertainties exist and a full analysis would require a suspended sediment model, currently unavailable.
Lower Sutter Bypass Inundation	Assesses potential negative effect of *CM2 Yolo Bypass Fisheries Enhancement* on Sutter Bypass inundation caused by Sacramento River backwatering. Model input is from CALSIM data.	Provides information on potential trade-off between enhanced inundation in the Yolo Bypass and less inundation in the Sutter Bypass.	Does not account for previous days of inundation in Sutter Bypass; assumes that empirically derived Verona flow-stage rating curve can be applied to CALSIM flow outputs at Verona.

CVP = Central Valley Project.
DRERIP = Delta Regional Ecosystem Restoration Implementation Plan.
PTM = particle tracking model.
Reclamation = Bureau of Reclamation.
SRWQM = Sacramento River Water Quality Model.
SWP = State Water Project.

5C.4.1 CALSIM II and DSM2 Models

The CALSIM II model was used to evaluate the performance of the SWP and CVP systems for existing or future levels of water supply development, potential future facilities, and current or alternative operational requirements. Key model output includes reservoir storage levels, river flows, water diversions, Delta exports, water deliveries, and Delta outflow. The CALSIM model was used to simulate the monthly reservoir storage and flows for the Water Year (WY) 1922–2003 period (82 years) for each EBC and BDCP scenario. Attachment 5C.A, *CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios*, describes the CALSIM and DSM2 modeling assumptions and results in more detail.

CALSIM II simulates SWP and CVP operations assuming a repeat of the historical hydrology for the Central Valley region for WY 1922–2003. Hydrology inputs to the model are generated by adjusting the historical runoff to account for an assumed static land use and infrastructure. These calculated hydrology inputs correspond to a specified “level of development” (e.g., 2005, or 2020). The model uses an optimization algorithm to calculate SWP and CVP reservoir and Delta operations on a monthly time step. Reservoir storage, releases, and Delta conditions are controlled by many different objectives, i.e., goals and constraints. The model results are governed by specified “weights” for meeting (satisfying) the various regulatory and operational priorities. The Delta outflow–salinity response is approximated with Artificial Neural Network (ANN) “internal equations.” Delta exports and outflow, along with X2 position and electrical conductivity (EC) at a few key regulatory locations, are the major model outputs of the ANN. The CALSIM II model originally was described by Draper and coauthors (2004) and documentation provided by California Department of Water Resources (DWR) (2002); CALSIM has been subjected to two peer reviews in the past 8 years (Close et al. 2003; Lund et al. 2006). Much more information on the CALSIM II model can be found at <www.modeling.water.ca.gov>.

DSM2 is a one-dimensional (with branched-channels) tidal hydrodynamic model used to simulate tidal elevations and tidal flows (velocities), water quality, and particle tracking in the Delta (Anderson and Mierzwa 2002). DSM2 was used to describe the existing conditions in the Delta and for simulations of the changes from the existing biological conditions for the BDCP (tidal restoration) and with climate change (sea level rise). The DSM2 model has three separate components: HYDRO, QUAL, and particle tracking (PTM). HYDRO simulates tidal flows, tidal velocities, and tidal elevations for the specified Delta channel geometry and tidal boundary elevations at Martinez. QUAL simulates the concentrations of conservative (i.e., no decay or growth) variables such as salinity and nonconservative (decay or growth) variables such as temperature and turbidity given the inflows and tidal flows in the Delta channels simulated by HYDRO. PTM simulates mixing and transport of neutrally buoyant (suspended) particles based on the channel geometry and tidal flows simulated by HYDRO.

5C.4.1.1 CALSIM II Inflows

Reservoir inflows and other watershed runoff are calculated from the historical measurements of river flows during 1922–2003 and assumed upstream nonproject reservoir operations and water diversions. Most of the SWP and CVP reservoirs have upstream storage projects that regulate the natural unimpaired runoff. These regulated inflows to SWP and CVP reservoirs are generally determined with separate upstream watershed and reservoir simulation models. The 82-year sequences of monthly inflow were adjusted slightly for the assumed ELT and LLT scenarios to reflect assumed changes due to climate change. The changes in the CALSIM inflows for the ELT and LLT scenarios are described in Appendix 5A.2, *Climate Change Approach and Implications for Aquatic Species*; inflow was shifted from the April–June period into the January–March period, and total runoff was slightly higher (5%) for the LLT.

5C.4.1.2 CALSIM Reservoir Operations

Reservoir inflow generally is stored, unless the end-of-month storage would exceed the monthly specified maximum storage level (volume) for flood control. The monthly minimum reservoir releases are specified and must be satisfied, and there may be downstream water supply demands for diversion along the river or in the Delta for export pumping or for required Delta outflow.

Although minimum reservoir storage volumes can be specified, the CALSIM model of the SWP and CVP operations does not use minimum storage levels to govern (limit) reservoir drawdown and carryover storage at the end of September. The water supply deliveries are adjusted according to the runoff and storage levels, and the water supply deficits (specified for dry years) are used indirectly to limit reservoir drawdown.

Upstream CVP reservoirs generally are linked to each other through balancing rules and are somewhat linked to the Delta operations. However, in many months each reservoir operates independently to fill during the winter and spring and release water for the local water supply diversions and minimum specified river flows.

The CALSIM model was used to determine what the monthly storage and flows from each upstream reservoir would be under the various modeling scenarios. These monthly storage levels and monthly flows were used to directly assess changes in aquatic habitat or indirectly as inputs to other biological models.

5C.4.1.3 CALSIM Delta Operations

The CALSIM model simulates Delta operations by comparing the Delta inflows with the Delta flow and salinity (EC) objectives to determine the required Delta outflow and the allowable Delta exports. CALSIM first meets south-of-Delta monthly demands, determines whether additional exports can be accommodated by additional upstream reservoir releases, then estimates the outflow required to satisfy the most stringent of the salinity or X2 objectives and adjusts the exports (or upstream releases) to fully satisfy the D-1641 objectives and the USFWS/NMFS BiOp actions (described in Section 5C.2.2).

The CALSIM II model uses a monthly time step to calculate reservoir storage and river flows. While monthly time steps are reasonable for long-term planning analyses of water operations, two major components of the BDCP include operations that depend on flow variability at scales less than monthly: the operation of the modified Fremont Weir and the diversion/bypass flow rules associated with the proposed north Delta intakes. In an effort to better represent the sub-monthly flow variability, particularly in early winter, a monthly to daily flow disaggregation technique was included in the CALSIM II model for the flows at the Fremont Weir (Sacramento River at Verona) and the north Delta intakes (Sacramento River at Freeport). The technique applies historical daily patterns to transform the monthly flows into daily flows. The historical daily flow was adjusted (using a ratio) to match the CALSIM monthly average flow; some smoothing was needed between months.

The proposed north Delta intakes would be operated with bypass flow rules that govern the fraction of Sacramento River flow that can be diverted during a month (described in Section 5C.2.2). Bypass rules are designed to avoid increased upstream tidal transport from downstream channels, to protect the fish migrating past the intake facilities, and to preserve the natural hydrograph. The north Delta intakes, along with the corresponding reductions in south Delta exports, and the associated bypass flow rules are the major changes in Delta operations that would result from the BDCP.

The CALSIM inflows, north Delta intake diversions, required Delta outflow, south Delta exports, and specified Delta agricultural diversions were used to calculate Delta channel flows at several locations (based on the DSM2 simulated flow splits). CALSIM monthly flows were calculated for the Sacramento River at Rio Vista, Threemile Slough, Georgiana Slough, Sutter Slough, Steamboat Slough, OMR at Bacon Island, and San Joaquin River at Stockton and at Antioch. These channel flows were used to assess changes in habitat directly or indirectly as inputs to other biological models.

5C.4.1.4 CALSIM Outflow-Salinity Relationships

There are two methods for estimating the outflow-salinity response in CALSIM. One method was introduced by CCWD in 1993 and is based on historical outflow and salinity (EC) data from several west Delta locations. The other is a generalized multiple regression method (artificial neural network [ANN]) based on the DSM2 simulations of the Delta outflow–salinity relationships at several regulatory compliance locations (Emmaton, Jersey Point, Rock Slough).

The outflow–salinity curves illustrate the basic relationships between Delta outflow and salinity distribution in the estuary upstream of Martinez (Contra Cost Water District 2010). These outflow–salinity relationships were introduced by CCWD staff (Denton 1993) using the concept of effective Delta outflow and negative exponential salinity–outflow curves (known as the *G-model* formulation). The effective Delta outflow is estimated from the daily historical outflow (DAYFLOW data file). The effective Delta outflow is similar to a moving average, with a period of about 3 months. Salinity (measured as EC) at Suisun Bay and Delta locations can be well-represented with negative exponential EC–outflow curves. These EC–outflow relationships were estimated using historical monthly average outflow and EC values during WY 1976–1991. This 16-year period often is used for Delta salinity modeling with DSM2 because it includes both dry-year and wet-year sequences.

5C.4.1.5 CALSIM Artificial Neural Network

The other method used in CALSIM to estimate the outflow required to satisfy X2 or salinity objectives is an ANN. Operation of the SWP/CVP facilities and management of Delta flows are often dependent on Delta outflow needed for compliance with D-1641 salinity objectives. An ANN statistical estimation method was developed by DWR (Sandhu et al. 1999) that attempts to mimic the flow–salinity relationships simulated with DSM2 but provides an internal calculation that can be used in the monthly CALSIM model calculations. The ANN is used to match the simulated Delta inflow and exports with the outflow needed to satisfy the monthly salinity objectives. A more detailed description of the use of ANNs in the CALSIM model is provided in Wilbur and Munévar (2001).

The ANN developed by DWR (Seneviratne and Wu 2007) statistically correlates the salinity results from a DSM2 model run to the Delta inflows, Delta exports, Delta Cross Channel (DCC) gate operations and an indicator of tidal energy. The ANN was calibrated with the DSM2 results that may represent historical or future conditions using a full circle (iterative) analysis (Seneviratne and Wu 2007). Separate ANN calibrations were used for the existing conditions and the ELT and LLT conditions (with sea level rise and tidal restoration).

The BDCP (ELT and LLT) used the ANN method for estimating Delta outflow requirements. The ANN method requires calibration whenever the outflow–salinity relationship in the Delta changes. The BDCP assumed different tidal restoration acres for the ELT and LLT timeframes. In addition, the DSM2 modeling included 15 cm of sea level rise at ELT and 45 cm of sea level rise at LLT. Each combination of restoration and sea level condition may result in different outflow–salinity relationships and therefore require a different ANN calibration (coefficients). Attachment 5C.A, *CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios*, describes the increased Delta outflow requirements that were simulated with the ANN for the ELT and LLT timeframes.

5C.4.1.6 DSM2

HYDRO was used to determine the change in flows at various locations in the Delta. The QUAL module was used to simulate source water “fingerprinting,” which calculates the fraction of the water or salinity contributed from each water source (Delta inflows) based on HYDRO outputs. The fractions of water and salt normally are tracked from the Sacramento River, San Joaquin River, Martinez boundary, eastside streams (Mokelumne and Cosumnes Rivers combined), agricultural drains (all combined), and the Yolo Bypass. For source water fingerprinting, a tracer with constant concentration is assumed for each source tracked, while keeping the concentrations at other inflows as zero. For constituent (e.g., EC) fingerprinting analysis, the concentrations of the desired constituent are specified at each tracked source, while keeping the concentrations at other inflows as zero (Anderson 2003). Particle tracking modeling (PTM) was used in the analysis of transport flows of delta smelt and as a proxy for tracking transport of DO. At a junction the path of a particle is determined randomly based on the proportion of flow. The proportion of flow determines the probability of movement into each reach. A random number based on this determined probability then determines where the particle will go. A particle that moves into an open water area, such as a reservoir, no longer retains its position information. A DSM2 open water area is considered a fully mixed reactor. The probability of a particle leaving the open water area is calculated from the fraction of the volume leaving the open water area. Particles entering exports or agricultural diversions are removed and recorded. Once particles pass the Martinez boundary, they are removed and recorded.

The general documentation and description of the DSM2 model, along with calibration results, are available at the DWR website:

<http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm>.

This page includes an online introduction to the many aspects of the DSM2 modeling system, with particular attention to the necessary inputs and data files (most of these do not change between cases). A draft tutorial document was written by DWR in 2002, which provides good background on the general methods and data requirements for modeling of the Delta and Suisun Marsh, upstream of Martinez. Most of the geometry files and boundary files (tidal elevations at Martinez, river inflows and exports, agricultural diversions, and drainage) are provided with the modeling package. The only changes between most DSM2 cases are the daily or monthly inflows and exports. However, for the ELT and LLT cases, the tidal boundary conditions and boundary EC values at Martinez were adjusted, based on 3-D modeling performed with the UnTRIM modeling (MacWilliams and Gross

2010). Increased salt exchange coefficients were assumed for the ELT and LLT cases to match the 3D results for the 15 cm (0.5 foot) and 45 cm (1.5 feet) sea level rise conditions.

The DSM2 model was recalibrated to better match recent tidal flow and EC data and to include the Liberty Island (south end of Yolo Bypass) inundation, which occurred in 1998. This report (CH2MHill 2009) was prepared to support the BDCP Delta tidal restoration evaluations and provides a very thorough review of the accuracy of modeled tidal elevations, tidal flows, and EC patterns throughout the Delta, in comparison to the very extensive measurements by the U.S. Geological Survey and DWR. This report is available at the DWR website:

> <ftp://ftp.modeling.water.ca.gov/pub/delta/DSM2_Users_Group/BDCP/DSM2_Recalibration_102709_doc.pdf>.

DSM2 modeling was used to determine the changes in Delta tidal hydrodynamics and salinity caused by the tidal restoration (RMA 2010) and operational changes for the BDCP. Six DSM2 simulations for 1976–1991 (16-year period) were conducted also to evaluate the likely (combined) effects of future sea level rise on Delta tidal flows and salinity. The EBC2_ELT and ESO_ELT cases assumed 6 inches of sea level rise, and the EBC2_LLT and ESO_LLT cases assumed 18 inches of sea level rise. The BDCP was simulated only for the ELT and LLT periods. Two existing baselines were simulated with (EBC2) and without (EBC1) the Fall X2 requirements of the 2009 USFWS BiOp.

The DSM2 model inputs and geometry files were adjusted for each of these six cases. The new intakes were added to the Sacramento River upstream of Sutter Slough; the additional areas of tidal habitat were added to appropriate locations for the ESO_ELT (25,000 acres) and the ESO_LLT (65,000 acres) cases. Some of the existing gates and barriers were modified for the BDCP cases. The BDCP simulations assumed that the Suisun Marsh Salinity Control Gates (SMSCG) on Montezuma Slough would remain open all year long to allow full connection with tidal restoration areas in Suisun Marsh (this had a salinity effect in the fall months of some years when the gates were operated in the existing biological conditions cases). The south Delta agricultural barriers (water level control weirs) were not installed for the BDCP cases to enhance tidal flows in the proposed south Delta restoration areas.

Many of the DSM2 results for the six BDCP cases are summarized and described in Attachment 5C.A., Section 5C.A.6, *Hydrodynamic and Salinity Modeling—Results*, describes the simulated changes in tidal flows caused by the combination of tidal restoration and sea level rise for the ELT (6 inches) and LLT (18 inches) timeframes. Some shifts in the channel flow diversions (e.g., Sutter, Steamboat, Georgiana, and Threemile Sloughs; DCC) were simulated for the combination of sea level rise and tidal restoration. These shifts in the tidal patterns were greatest for the LLT timeframe with 65,000 acres of tidal restoration and 18 inches of sea level rise.

Section 5C.A.6 describes the changes in the simulated salinity (EC) patterns within the Delta. Delta outflow is the major control on salinity (EC); because Delta outflow was slightly different for each of the DSM2 cases, the salinity (EC) was also slightly different. The analysis of the salinity patterns focused on the shifts in the relationships between the effective Delta outflow and the salinity at selected Delta locations (i.e., EC monitoring stations). Because the CALSIM model estimates the relationship between Delta outflow and EC (using ANN) in order to calculate the required Delta outflow to satisfy the monthly X2 and EC objectives, the comparison of the CALSIM EC and the DSM2 EC values at these Delta locations is also important.

Section 5C.A.7 describes the DSM2 "source tracking," which refers to the fraction of water at a Delta location that originated from each Delta inflow (e.g., San Joaquin River, eastside streams, Yolo Bypass, Sacramento, and Martinez). This tracking of inflows and the tidal movement and mixing within the Delta channels provides the logical basis for describing water quality patterns (e.g., seawater intrusion) and also for understanding the movement of water and small drifting organisms (e.g., plankton, larvae) and the Delta channel pathways for migrating fish.

Section 5C.A.8 describes the DSM2 particle tracking results. Because the PTM methods (when and where to inject tracking particles, where and for how long to track the movement and fate of tracking particles) are determined by the model user, the methods used for the BDCP evaluations are described in this section. The PTM results have been found to depend on the general flow patterns. Kimmerer and Nobriga (2008) found that the percentage of tracking particles entrained at the SWP and CVP south Delta pumping plants could be described with "logistical" (S-shape curve) relationships with the overall Delta E/I ratio as the independent variable.

The PTM results were used in the evaluation of estuarine fish movement and survival (See Appendix 5.B, *Entrainment*, and below).

5C.4.2 Upstream Habitat Methods

5C.4.2.1 Salmonids

The geographic distribution and seasonal timing of spawning, rearing, and emigration vary among Central Valley steelhead and winter-, spring-, fall-, and late fall–runs of Chinook salmon (see Appendix 2.A, *Species Accounts*). These differences determined the river and stream reaches and months for which habitat conditions were analyzed for each salmonid species and race and their life stages. Habitat conditions were analyzed only for streams that potentially will be affected by BDCP.

For Central Valley steelhead, the upstream habitat effects analysis for the Sacramento River system focused on habitat conditions in the mainstem Sacramento River, Feather River, American River, and Clear Creek. The effects analysis for the San Joaquin River system focused on conditions in the Stanislaus River and the mainstem San Joaquin River downstream of the Stanislaus River confluence. The effects analysis also analyzed potential effects on Klamath Mountain Province steelhead habitat in the Trinity River.

For Sacramento River winter-run Chinook salmon, the upstream habitat effects analysis considered only habitat conditions in the mainstem Sacramento River because the upper Sacramento River is the only known spawning location for Sacramento River winter-run salmon.

For Central Valley spring-run Chinook salmon, the upstream habitat effects analysis for the Sacramento River system addressed habitat conditions in the mainstem Sacramento River, Feather River, and Clear Creek only. Although spring-run Chinook salmon are known to spawn in several other tributaries to the upper Sacramento River, including Butte, Deer, and Mill Creeks, BDCP operations would not affect instream flows or other habitat conditions in these tributaries. In recent years, an effort has begun to reestablish a naturally reproducing, self-sustaining population of spring-run Chinook salmon on the San Joaquin River. Operations under the BDCP are not expected to affect Millerton Reservoir or releases from Friant Dam to the lower San Joaquin River. Therefore, no changes in habitat conditions are expected in the upper reaches of the river, where adult holding and spawning and juvenile rearing would occur. As a result, only habitat conditions in the mainstem river downstream of the confluence with the Stanislaus River, where downstream migration of juveniles and upstream migration of adults would take place, were analyzed. The effects analysis also evaluated habitat conditions for the Upper Klamath and Trinity Rivers Chinook salmon evolutionarily significant unit (ESU) in the Trinity River.

For Central Valley fall-run/late fall–run Chinook salmon, the upstream habitat effects analysis for the Sacramento River system focused on habitat conditions in the mainstem Sacramento River, Feather River, American River, and Clear Creek, although the analysis for the late fall–run considered only habitat in the mainstem Sacramento River. The effects analysis for the San Joaquin River system considered only conditions in the Stanislaus River and the mainstem San Joaquin River downstream of the Stanislaus River confluence. BDCP operations are not expected to affect habitat conditions in the Tuolumne, Merced, Mokelumne, or Cosumnes River, and therefore they were not analyzed. The effects analysis also evaluated habitat conditions in the Trinity River for the Upper Klamath and Trinity Rivers Chinook salmon ESU.

5C.4.2.1.1 Egg/Alevin

Survival of eggs and alevins (salmonid embryos that still have a yolk sac and remain in the spawning gravel after hatching and before emergence) are affected by water temperatures and flow changes that result in redd dewatering. Changes in instream flows and water temperature during spawning and egg incubation and fluctuations in instream flows that result in redd dewatering are the primary impact mechanisms included in the effects assessment as described below.

Assumed active spawning and egg incubation periods for each species or race are listed below.

- Steelhead: January through June.
- Winter-run Chinook salmon: June through October.
- Spring-run Chinook salmon: October through January.
- Fall-run Chinook salmon: September through March.
- Late fall–run Chinook salmon: December through June.

Water Temperature

Water temperature in the upstream spawning and egg incubation habitats for steelhead and salmon is influenced by a number of factors. The primary factors are reservoir storage and coldwater pool within the reservoir, instream flow releases to the river, and seasonal atmospheric conditions. The level of water storage in a reservoir has a strong effect on the volume of cold water (coldwater pool) in the reservoir and, therefore, the temperature of water released during the summer and early fall. The summer and early fall are the times of year when river temperatures are most likely to rise above tolerance thresholds for steelhead and salmon. The effects analysis includes a summary of the May and September storage in each major upstream reservoir in combination with a frequency of exceedance analysis for May and September storage. Instream flows were characterized based on results of CALSIM II hydrologic modeling and presented as both instream flows by month and water year and monthly frequency of exceedance plots to allow examination of the entire range of simulation results for each of the effects analysis conditions examined.

Water temperatures in stream reaches used by steelhead and salmon for spawning were simulated using two separate temperature models. Daily average temperatures in the mainstem Sacramento River in the reach downstream of Keswick Dam were estimated using the Sacramento River Water Quality Model (SRWQM) with post-processed CALSIM II flow data. The SRWQM is used in the effects analysis to predict the effects of reservoir operations on water temperatures in the Sacramento River and Shasta and Keswick Reservoirs. Water temperatures in the Trinity, Feather, American, and Stanislaus Rivers were estimated using the Bureau of Reclamation (Reclamation) Temperature Model. Description of both models, as well as the post-processing procedures used to estimate daily flows from the CALSIM II model output for SRWQM input, is provided below. Note that changes in reservoir storage and instream flows also were used in the upstream effects analysis for approximate estimates of potential changes in water temperature conditions where temperature data were not available (e.g., Clear Creek).

The SRWQM was developed using the HEC-5Q model to simulate mean daily (using 6-hour meteorology) reservoir and river temperatures at key locations on the Sacramento River. The time step of the model is daily, and it provides water temperature each day for the 82-year hydrologic period (WY 1922–2003) used in CALSIM II. The model has been used in the previous SWP and CVP system operational performance evaluation (Bureau of Reclamation 2008). Monthly flows from CALSIM II are used as input into the SRWQM after being temporally downsized to convert them to daily average flows for HEC-5Q input. The conversions are based on the 1921 through 1994 daily historical record for these aggregated inflows.

- Trinity River above Lewiston.
- Sacramento River above Keswick.
- Incremental inflow between Keswick and Bend Bridge (7-day trailing average for inflows below Butte City).

Each of the total monthly inflows specified by CALSIM II is scaled proportionally to one of these three historical records. Reservoir inflows are proportioned as defined above. Outflows and diversions are smoothed for a better transition at the end of the month without regard for reservoir volume constraints or downstream minimum flows. As flows are redistributed within the month, the minimum flow constraint at Keswick, Red Bluff, and Knights Landing may be violated. In such cases, operation modifications are required for daily flow simulation to satisfy minimum flow requirements. A utility program is included in SRWQM to convert the monthly CALSIM II flows and releases into daily operations. A more detailed description of SRWQM and the temporal downscaling process is included in an RMA calibration report (RMA 2003).

For more information on the SRWQM, see Appendix H of Reclamation's 2008 *Biological Assessment on the Continued Long-term Operations of the Central Valley Project and the State Water Project*:

<www.usbr.gov/mp/cvo/OCAP/sep08_docs/Appendix_H.pdf>.

The Reclamation Temperature Model is used in the effects analysis to predict the effects of reservoir operations on water temperatures in the Trinity, Feather, American, and Stanislaus River basins and upstream reservoirs. The model is a reservoir and stream temperature model that simulates monthly reservoir and stream temperatures used for evaluating the effects of SWP/CVP project operations on mean monthly water temperatures in the basin based on hydrologic and climatic input data. It has been applied to past SWP and CVP system operational performance evaluations (Bureau of Reclamation 1994, 2004, 2008).

The model uses CALSIM II output to simulate mean monthly vertical temperature profiles and release temperatures for seven major reservoirs (Trinity, Whiskeytown, Shasta, Oroville, Folsom, New Melones, and Tulloch); four downstream regulating reservoirs (Lewiston, Keswick, Goodwin and Natoma); and five main river systems (Sacramento, Trinity, Feather, American, and Stanislaus), although the model was not applied to the Sacramento River in the effects analysis because the SRWQM was deemed superior because of its daily time step.

For more information on the Reclamation Temperature Model, see Appendix H of Reclamation's 2008 Biological Assessment at:

<www.usbr.gov/mp/cvo/OCAP/sep08_docs/Appendix_H.pdf>.

The temperature data simulated using the SRWQM and Reclamation Temperature Model were used to evaluate effects of potential exposure to seasonally elevated water temperatures on steelhead and salmon egg incubation and hatching success. Several different procedures were used for these evaluations.

- Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different between BDCP scenarios in ELT and LLT and four baselines (EBC1, EBC2, EBC2_ELT, and EBC2_LLT). In addition, the exceedances of several water temperature thresholds as requested by NMFS during the BDCP planning and evaluation process (Table 5C.4-3) were compared among model scenarios. For each location in the Sacramento River, we first calculated the number of days per month on which water temperatures would exceed threshold water temperatures by 0.5°F exceedance increments between 0.5°F and 5°F by scenario for the entire 82-year modeling period. Next, a level of concern, provided by NMFS, for the combined number of days per month on which the temperature threshold was exceeded by one, two, or three degrees (Table 5C.4-4), was determined for each month of the 82-year period. The highest level of concern for each year was then determined for each model scenario and compared between pairs of model scenarios. In addition, the cumulative number of degree-days by month and water year type was calculated for each temperature threshold and compared between pairs of model scenarios.

  For each location in the Feather and American rivers (Table 5C.4-3), the percent of months over the 82-year modeling period that exceeded the NMFS threshold by 1°F to 5°F in 1°F increments were determined for each month within the specificed period and compared between pairs of model scenarios. In addition, the difference in water temperature relative to the threshold for each month of the period during the 82-year modeling period are first presented by scenario. For all years in which temperatures would exceed the threshold, the cumulative number of degree-months by water year type for each month of the period was calculated and compared between pairs of model scenarios.

Table 5C.4-3. Maximum Water Temperature Criteria for Covered Salmonids and Sturgeon Provided by NMFS and Used in the BDCP Effects Analysis

Location	Period	Maximum Water Temperature (°F)	Purpose
Upper Sacramento River			
Bend Bridge	May–Sep	56	Winter- and spring-run spawning and egg incubation
		63	Green sturgeon spawning and egg incubation
Red Bluff	Oct–Apr	56	Spring-, fall-, and late fall–run spawning and egg incubation
Hamilton City	Mar–Jun	61 (optimal), 68 (lethal)	White sturgeon spawning and egg incubation
Feather River			
Robinson Riffle (RM 61.6)	Sep–Apr	56	Spring-run and steelhead spawning and incubation
	May–Aug	63	Spring-run and steelhead rearing
Gridley Bridge	Oct–Apr	56	Fall- and late fall–run spawning and steelhead rearing
	May–Sep	64	Green sturgeon spawning, incubation, and rearing
American River			
Watt Avenue Bridge	May–Oct	65	Juvenile steelhead rearing
	Nov–Apr	56	Fall-run and steelhead spawning and incubation

Table 5C.4-4. Number of Days per Month Required to Trigger Each Level of Concern for Water Temperature Exceedances in the Sacramento River for Covered Salmonids and Sturgeon Provided by NMFS and Used in the BDCP Effects Analysis

Exceedance above Water Temperature Threshold (°F)	Level of Concern			
	None	Yellow	Orange	Red
1	0–9 days	≥10–14 days	≥ 15–19 days	≥20 days
2	0–4 days	5–9 days	10–14 days	≥15 days
3	0 days	1–4 days	5–9 days	≥10 days

- Egg mortality in the mainstem Sacramento River for each race of Chinook salmon was estimated for each model scenario using the Reclamation Egg Mortality Model. This model estimates proportional salmon mortality for prespawned eggs, fertilized eggs, and preemergent fry of all Chinook salmon races in the Trinity, Sacramento, Feather, American, and Stanislaus rivers based on water temperature output from the SRWQM for the Sacramento River and the Reclamation Temperature Model for other rivers. Monthly monthly flow and temperature data were used for the Trinity, Feather, American, and Stanislaus rivers. Although monthly flow and temperature data were available for the Sacramento River, daily SRWQM flow and temperature data were used. Using daily SRWQM data provides a lower estimate of egg mortality than does using monthly CALSIM data in the Sacramento River, although it is unknown how close either model is to estimating actual egg mortality in the river. In general, Reclamation considers the daily model to be better at approximating egg mortality (Hannon pers. comm.). As a result, the daily model was used for the Sacramento River for the current analysis. The Reclamation Egg Mortality

Model operates at a daily time step and provides output on an annual time step. The model uses temperature exposure mortality criteria for the three life stages, spawning distribution data, and output from the river temperature models to estimate percentages of egg and fry losses of a given brood of eggs for each run of Chinook salmon. For more information on the Reclamation Salmon Mortality Model, see Appendix L of Reclamation's 2008 Biological Assessment at:

<www.usbr.gov/mp/cvo/OCAP/sep08_docs/Appendix_L.pdf>.

- Indices of spawning and egg incubation habitat suitability relying on water temperature and flow estimates were computed for steelhead and all races of Chinook salmon using the Sacramento River Ecological Flows Tool (SacEFT). The SacEFT system is a database-centered software system for linking flow management actions to changes in the physical habitats for the species of interest. The model uses daily temperature and flow outputs from the SRWQM. SacEFT employs a set of functional relationships to generate habitat-centered performance measures for the species of interest that change in response to flow-management scenarios. SacEFT operates on a daily time step. For more information on SacEFT, see Attachment 5C.B, *Sacramento River Ecological Flows Tool (SacEFT): Design & Guidelines (v.2.00)*.

- SALMOD was used to compare egg mortality for each race of salmon due to water temperature and flows on the mainstem Sacramento River from Keswick to Red Bluff Diversion Dam (RBDD) in the reach where spawning and egg incubation occur, for the different BDCP model scenarios. An index of egg mortality was calculated for each year in the Chinook salmon spawning area. SALMOD uses the Instream Flow Incremental Methodology (IFIM), which is a decision-making process with five components: hydrology, geomorphology, biology, water quality (including temperature), and connectivity; and it estimates juvenile salmonid production in fresh water as a function of habitat availability. The primary assumption of the model is that egg and fish mortality is directly proportional to spatially and temporally variable habitat limitations, such as water temperature limits, which themselves are functions of the timing and quantity of flow and meteorological variables, such as air temperature. SALMOD is a spatially explicit model that characterizes habitat value and carrying capacity using the hydraulic and thermal properties of individual habitat units. Inputs to SALMOD include CALSIM flows, water temperature from SRWQM, spawning distribution based on aerial surveys, spawning timing depending on salmon race, and the number of spawners provided by the user (e.g., recent average escapement). The primary output is juvenile salmon production for each race of salmon in the Sacramento River. For more information on SALMOD, see Appendix P of Reclamation's 2008 Biological Assessment at:

<www.usbr.gov/mp/cvo/OCAP/sep08_docs/Appendix_P.pdf>.

Instream Flows and Redd Dewatering

To assess the effects of instream flows on spawning habitat conditions, information was compiled from CALSIM modeling on instream flows under each model scenario during the spawning and egg incubation periods used in the assessments for steelhead and the four races of Chinook salmon. The instream flows were compared among scenarios based on monthly flows by water year as well as based on frequency of exceedance analyses. The analysis also examined variation in instream flows each month over the entire 82-year simulation to assess differences among months and years. In addition, the exceedances of several flow thresholds established by NMFS (2009, in prep.) and in the Feather River using a recent document provided by NMFS during the BDCP planning process (National Marine Fisheries Service 2012) were compared among model scenarios.

Redd dewatering occurs when streamflows decrease after fish have spawned. The greater the change in flow after spawning, the greater the proportion of redds that are dewatered (U.S. Fish and Wildlife Service 2006). The proportion of Chinook salmon eggs dewatered on the Sacramento River following a flow decrease is provided by USFWS (2006), which used a two-dimensional hydraulic and habitat model (RIVER2D) to simulate the percentage of redds dewatered across eight Chinook spawning areas from Keswick Dam to Battle Creek (Figure 5C.4-1).

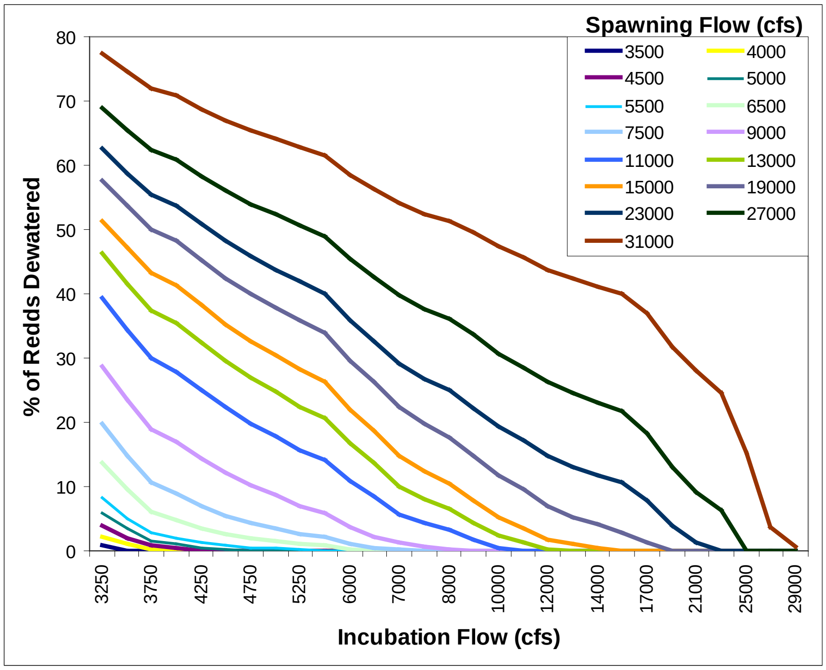

Figure 5C.4-1. Percent of Winter-Run Chinook Redds Dewatered as a Function of the Difference between Spawning Flow and Incubation Flow

SacEFT and SALMOD also were used to analyze flow effects, including redd dewatering. Daily average flows post-processed from CALSIM II were input into SacEFT and SALMOD to evaluate egg mortality resulting from redd dewatering. SacEFT assesses effects of flows on redd dewatering for steelhead and all races of Chinook salmon in the Sacramento River only. SALMOD assesses effects of flows on redd dewatering for all races of Chinook salmon in the Sacramento River only.

There is currently no model like SacEFT or SALMOD that can incorporate flows to determine the risk of redd dewatering for other Central Valley rivers and no monthly to daily conversion was attempted. Instead, the frequency and magnitude of monthly flow reductions that potentially would result in redd dewatering were estimated using CALSIM flow outputs in these rivers. “Spawning” was assumed to occur during the first month of the spawning period of each race of salmon or steelhead. Subsequent months during the spawning period were assumed to be the “incubatin period” for this analysis. Results of monthly CALSIM flows were used to determine the magnitude of flow reduction that would occur each month during the incubation period compared to the “spawning period.” The index of risk for redd dewatering is based on the greatest percentage change (reduction) in flows in any month during the “incubation period” when compared to the “spawning period.”

5C.4.2.1.2 Fry and Upstream Juveniles

Fry and rearing juveniles were assumed to be present upstream for each species or race as follows.

- Steelhead: Year-round
- Winter-run Chinook salmon: July through April
- Spring-run Chinook salmon: October through August
- Fall-run Chinook salmon: December through May
- Late fall–run Chinook salmon: October through February

Fry and Juvenile Upstream Rearing Habitat

After emergence, Chinook fry seek nearshore habitats with cover (cobble, woody debris, riparian vegetation) and food sources, including aquatic and terrestrial invertebrates (National Marine Fisheries Service 2009). Cover functions as a refuge from both high-flow velocities and predators (National Marine Fisheries Service 2009). Shallow water rearing habitats are likely more productive than the main river channels, supporting higher growth rates, partially because of higher prey consumption rates, and favorable environmental temperatures. This has been observed previously in shallow inundated floodplains (Sommer et al. 2001).

The effects of BDCP water operations on upstream rearing habitat were analyzed by assessing flow-related habitat suitability indices developed through the IFIM (Mark Gard unpublished data) using both SALMOD and SacEFT modeling. The models quantify changes to the extent of suitable rearing habitat using results of CALSIM II hydrologic modeling (e.g., monthly summary of instream flows over 82 years of hydrologic record, monthly frequency of exceedance analyses by water-year type). Results of simulation modeling of instream flows were compiled each month over the 82-year period of hydrologic simulation, as well as frequency of exceedance analyses monthly by water-year type, to examine potential changes in habitat conditions for rearing habitat.

Indices of weighted usable area (the product of the physical habitat area based on instream flows and the weighting factor for habitat suitability for juvenile salmon or steelhead rearing) were used as a basis for assessing the quantity and value of habitat changes in upstream rearing areas as a function of flow that would be expected to occur under each model scenario. For fry, results of instream flow studies conducted on both the upper reaches of the Sacramento River (Keswick Dam to RBDD) and Feather River are available to assess the relationship between instream flow and fry rearing habitat (expressed as weighted usable area). These relationships were used in combination with results of daily estimates of instream flows during the fry rearing stage to assess changes in habitat under each model scenario.

Based on SALMOD and SacEFT modeling results and weighted usable area estimates of rearing habitat for each model scenario, comparative indices of predicted changes in rearing habitat value and availability were developed. Specifically, these included the following:

- Using SALMOD to compare fry and juvenile mortality of all races of Chinook salmon due to habitat limitation on the mainstem Sacramento River from Keswick to RBDD.
- Using results of the SacEFT model to assess changes in fry and juvenile rearing habitat for all races of Chinook salmon and steelhead in the upper Sacramento River under different model scenarios. The relative contribution of habitat-related mortality and habitat conditions to

Chinook fry and juveniles was assessed based on a comparison of results among model scenarios.

Depending on the presence of steelhead and spring-run and fall-/late fall–run fry, results of information on instream flows in the Feather River, American River, Trinity River, Stanislaus River, and Clear Creek were used to assess potential differences in juvenile rearing habitat.

Water Temperature

Many of the water temperature analyses used for evaluating effects of the BDCP model scenarios on steelhead and salmon fry are similar to those previously described for the egg/alevin stage.

The SRWQM was used to estimate daily water temperatures in the upper Sacramento River, and the Reclamation Temperature Model was used to estimate monthly temperatures in reaches of the Feather, American, Trinity, and Stanislaus Rivers where fry rearing occurs. Reservoir storage (May and September) and instream flow data also were used to assess fry rearing conditions on the Feather, Trinity, andAmerican Rivers and Clear Creek.

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. In addition, the exceedances of several water temperature thresholds as requested by NMFS were calculated and reported as described in Section 5C.4.2.1.1.

SALMOD was used to compare Chinook salmon fry production on the mainstem Sacramento River from Keswick to RBDD. The model was also used to assess the contribution of temperature-related stress and mortality relative to and in combination with other sources of fry mortality for each model scenario.

SacEFT was used to assess changes in steelhead and Chinook salmon rearing habitat conditions based on water temperature and flows.

Stranding

Chinook fry typically select low-velocity shallow channel margins for rearing and, hence, are vulnerable to stranding when flows and water surface recede quickly and trap the fry in isolated channels and pools located along channel margins and in seasonally inundated floodplain habitat. Steelhead and spring-run Chinook salmon juveniles are relatively strong swimmers, but stranding mortality on inundated river channel margins and floodplains is still a concern.

Stranding risk for salmon and steelhead in the Sacramento River was estimated by SacEFT. Stranding risk in other rivers was assessed using monthly CALSIM II estimates of flows in each river, although flow-related habitat parameters (velocities, depths, and areal extent of inundation) are not available from the model. Therefore, best professional judgment was used to assess the magnitude of effect of flow changes on potential stranding risk for steelhead and each Chinook salmonrace.

5C.4.2.1.3 Adult

This section briefly describes the methods used to assess effects on adults that are immigrating, spawning, and emigrating (steelhead kelts only).

Immigration, spawning, and emigration were assumed to occur for each species or race as follows.

- Steelhead: June through March (adult upstream migration); January through April (kelt migration)
- Winter-run Chinook salmon: December through August
- Spring-run Chinook salmon:March through September
- Fall-run Chinook salmon:July through January
- Late fall–run Chinook salmon: December through April

Water Temperature

Using flow and temperature data simulated from CALSIM II, SRWQM, and the Reclamation Temperature Model, mean water temperatures in the Sacramento, Feather, American, Stanislaus, and Trinity Rivers and Clear Creek were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. Because water temperatures in all rivers under the BDCP would not be meaningfully different from water temperatures under EBC2, no further water temperature analyses were necessary.

5C.4.2.2 Splittail

Splittail spawning and rearing of larvae and young juveniles in channel margin and side-channel habitat upstream of the Delta are likely to be especially important during dry years, when flows are too low to inundate the floodplains. Splittail have been observed in the Sacramento River as far as the Red Bluff Diversion Dam, in the Feather River almost to the Thermalito Afterbay outlet, and in the American River as far upstream as a couple of miles beyond the Watt Avenue Bridge (Sommer et al. 2007). Their presence upstream is limited to February through June for spawning, egg incubation, and larval and juvenile rearing. Due to high overlap among all lifestages during this period, this analysis combines all lifestages together.

Spawning and Rearing Habitat

Inundated floodplain habitat is the most important habitat for splittail spawning and rearing because splittail population dynamics are largely driven by floodplain spawning in wet years, when this habitat is most available. Splittail spawning and larval and juvenile rearing also occur in channel margin and side-channel habitat upstream of the Delta. These habitats are likely to be especially important during dry years, when flows are too low to inundate the floodplains (Sommer et al. 2007). Backwater location was the only habitat factor that rearing splittail were found to select in upstream locations (Feyrer et al. 2005).

Side-channel habitats are affected by changes in flow because greater flows cause more side channel inundation, thereby increasing availability of such habitat, and because rapid reductions in flow dewater the habitats, potentially stranding splittail eggs and rearing larvae. Effects of the BDCP on flows in years with low flows are expected to be most important to the splittail population because in years of high flows, when most production comes from floodplain habitats, the upstream side-channel habitats contribute relatively little production. Simulated flows in representaqtive locations in each river were used to investigate the potential effects of BDCP operations on side channel habitat availability. This analysis was limited to flows during February through June because these are the most important months for splittail spawning and larval and juvenile rearing and the months in which splittail are most likely to be upstream.

Water Temperature

Changes in flow and other factors potentially affect water temperatures in splittail upstream spawning and rearing habitat. Feyrer et al. (2005) found no evidence that temperature was an important factor in habitat selection for rearing splittail in their upstream habitats. However, mean monthly water temperatures were examined in representative locations in each river during February through June. Because water temperatures in these rivers under the BDCP would not be meaningfully different from water temperatures under EBC2, no further water temperature analyses were necessary.

5C.4.2.3 Sturgeon

5C.4.2.3.1 Egg/Embryo

Water Temperature

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. In addition, the exceedances of several water temperature thresholds as requested by NMFS were calculated and reported as described in Section 5C.4.2.1.1. The SacEFT model, described in Section 5C.4.2.1.1, *Egg/Alevin*, was used to investigate Sacramento River temperature exceedances for temperature tolerances of green sturgeon eggs under the different BDCP scenarios. For green sturgeon, the model was applied to Sacramento River reaches downstream of Red Bluff during spawning periods and used 63 degrees Fahrenheit (°F) (17 degrees Celsius [°C]) for the upper temperature threshold below which there would be no adverse effects, and 68°F (20°C) as a maximum(lethal) threshold for embryos (Cech et al. 2000). Temperatures exceeding 68°F in the model scenarios were considered lethal to green sturgeon eggs.

5C.4.2.3.2 Larvae

Water Temperature

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. In addition, the exceedances of several water temperature thresholds as requested by NMFS were calculated and reported as described in Section 5C.4.2.1.1.

5C.4.2.3.3 Juvenile

Because juvenile sturgeon are classified in this analysis as those migrating downstream, the flow analysis for juveniles is described in Section 5C.5.3.

Water Temperature

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. In addition, the exceedances of several water temperature thresholds as requested by NMFS were calculated and reported as described in Section 5C.4.2.1.1.

5C.4.2.3.4 Adult

Water Temperature

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios.

Spawning Habitat

Gard (1996) developed a suitability index for Sacramento white sturgeon spawning habitat that indicated that white sturgeon are limited to spawning in deep, fast areas with large substrates. This index identified waters with velocities of 3.9–19.95 feet per second (ft/s) as suitable, with velocities of 5–12.5 ft/s as ideal. Further, water depths greater than 6 feet were suitable, while those greater than 10 feet were ideal; habitats with snags and gravel were considered suitable, while those that included cobble, boulder, and bedrock were ideal. The effects analysis did not develop a habitat suitability index (HSI) for white sturgeon spawning habitat specifically but reviewed the habitat factors independently to determine whether and how they would be altered by BDCP operations.

There are no weighted usable area curves available for green sturgeon spawning habitat, and because of differences in spawning habitat preferences, white sturgeon cannot be used as a suitability index surrogate.

Seasonal Flows

White sturgeon studies abroad have indicated that only 1–3% of fingerlings released from captive rearing survived to adulthood (Marti 1979, as cited in Moberg and Doroshov 1992). Although to a local population one adult fish has greater reproductive value than one embryo, habitat-scale effects would not affect a single individual alone, but have the potential to affect multiple individuals within and between year classes and age classes. As a result, the potential effects of future changes in flow were also analyzed for each sturgeon life stage. This approach allows the analysis to determine which, if any, age classes potentially would be affected by possible BDCP–related changes to a given habitat parameter, such as flow.

April and May are indentified by Israel and coauthors (2009) as peak periods for white sturgeon eggs and embryos in Bay-Delta rivers. However, as prespawn adults occur throughout the winter and there may be some potential early spawning, the analytical period was expanded to include February and March. As a result, CALSIM was used to investigate potential changes in flows from February to May in suitable white sturgeon spawning reaches. In the Sacramento River these locations included Verona and Wilkins Slough (surrogate for Grimes); for the Feather River the confluence with the Sacramento River and at Thermalito were investigated; for the San Joaquin River the flows at Vernalis.

As sturgeon recruitment is correlated to flow (Kohlhorst et al. 1991; Beamesderfer and Farr 1997; Fish 2010), the most successful spawning generally occurs in wet and above-normal water years (Israel et al. 2009). As a result, the analysis of the potential flow changes from the BDCP on white sturgeon eggs and embryos focused on these wet and above-normal years in habitats believed to be used by these life stages (although high spring flow conditions commonly occurred in drier year types prior to the construction and operation of major Central Valley dams). However, reviews of CALSIM exceedance plots and average monthly flows for all water-year types were included in this investigation to determine whether there were anticipated changes related to the BDCP or climate change under suboptimal water years. White sturgeon spawning is much more common in the

Sacramento River system, although the San Joaquin River appears to support white sturgeon reproduction and, therefore, is included in this analysis. Therefore, exceedance plots were used as a tool to investigate at these locations at what probabilities differentiation between modeled scenarios occurs.

Gard (1996) developed a suitability index for Sacramento River white sturgeon spawning habitat. Velocity was one of the parameters of this index, and velocities of 3.9–19.95 ft/s were identified as suitable, and velocities of 5–12.5 ft/s as ideal. Parsley et al. (1993) found that white sturgeon spawning and egg incubation in the Columbia River occurred in the swiftest available waters (mean water column velocity 0.8–2.8 meters per second (m/s) [2.6–9.2 ft/s]). However, in order to convert the flow data from CALSIM to velocity, channel contour descriptions for each appropriate CALSIM node, including depth and width for each flow level, were required. These parameters were not available to convert modeled flow results to velocity. Therefore, CALSIM flow outputs, rather than velocity, were investigated to determine BDCP–related flow effects on habitats used by sturgeon. Although regionally comprehensive, the CALSIM model does not include nodes at every location throughout the Bay-Delta. As a result, where literature may indicate suitable habitat conditions at a specific location, a surrogate location was needed to relate this to available nodes modeled in CALSIM.

5C.4.2.4 Lamprey

For the purposes of this effects analysis, the following assumptions were made based on existing literature and communication with experts regarding the spatial and temporal patterns of the life stages of Pacific and river lamprey.

- Adults spawn in the upper Sacramento, Trinity, Feather, American, and Stanislaus Rivers during the months of January through August (Pacific lamprey) or February through June (river lamprey), although there is temporal variation among locations (Beamish 1980; Moyle 2002; Hannon and Deason 2007; Streif 2007; Luzier et al. 2009).
- Eggs for both species incubate for 18–49 days, depending on water temperature (Brumo 2006) during roughly the same period and in the same locations as the adults spawn.
- Ammocoetes rear in approximately the same locations for 5–7 years (Pacific lamprey) or 3–5 years (river lamprey), although in more silty backwaters than redd locations (Moyle 2002).
- After 5–7 years (Pacific lamprey) or 3–5 years (river lamprey), ammocoetes migrate downstream but do not yet feed parasitically. Pacific lamprey emigration generally is associated with large flow pulses in winter months (December through June) (U.S. Fish and Wildlife Service unpublished data), but can extend through June (Beamish 1980). River lamprey generally emigrate from May through July (Beamish 1980).
- Both species become macropthalmia once they reach the Delta, where they may reside for a very short period. Macropthalmia do not feed parasitically in the Delta but, once the esophagus is fully formed, will move into the ocean to feed. The marine phase for Pacific lamprey lasts up to 3–4 years, while that for river lamprey lasts only 3–4 months (Moyle 2002).
- Adults migrate upstream to spawn between January and July (Pacific lamprey) or between September and May (river lamprey) and usually die shortly afterward (Beamish 1980; Moyle 2002).

5C.4.2.4.1 Egg/Embryo

Water Temperature

Water temperature results from the SRWQM and the Reclamation Temperature Model were used to assess the exceedances of water temperatures under all model scenarios in the upper Sacramento, Trinity, Feather, American, and Stanislaus Rivers. These temperature models are described above in Section 5C.4.2.1.1, *Egg/Alevin*. Pacific lamprey were observed to spawn in the American River between January and May with a peak in April (Hannon and Deason 2007). Streif (2007) and Luzier and coauthors (2009) indicate that spawning occurs during March through July, but this is likely for more northern populations of Pacific lamprey. To be inclusive, the analysis examined the period of January through August. Because Pacific lamprey eggs hatch in 18–49 days, depending on water temperature (Brumo 2006), eggs are assumed to be present during roughly the same period. River lamprey generally spawn between February and June (Beamish 1980; Moyle 2002), and the range for egg incubation period is assumed to be the same as that for Pacific lamprey (18–49 days).

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. Because water temperatures in all rivers under the BDCP would not be meaningfully different from water temperatures under EBC2, no further water temperature analyses were necessary.

Redd Dewatering

Because of limited information on spawning locations and timing in the rivers in the Sacramento and San Joaquin watersheds, it was assumed that a month-over-month reduction in flow rate using CALSIM II output of >50% during the period of redd preference would constitute an adverse effect that would mimic dewatering of lamprey redds. Although there is no information available to determine whether this value is suitable, it was applied to all model scenarios equally as a surrogate for flow reductions in the rivers. As such, there is high uncertainty that these values represent actual redd dewatering events, and results should be treated as rough estimates of flow fluctuations under each model scenario. The analysis was conducted assuming a presence of Pacific lamprey redds during January through August and river lamprey redds from February through June.

Locations for each river used in this analysis were based on available literature, personal conversations with agency experts, and spatial limitations of the CALSIM II model as follows.

- Sacramento River: Keswick and Red Bluff.
- Feather River: Thermalito.
- American River: Nimbus and at the confluence with the Sacramento River.
- Stanislaus River: at the confluence with San Joaquin River.
- Trinity River: downstream of Lewiston.

For this analysis, the number of months in which flows decreased by at least 50% from the previous month was calculated for each model scenario in all rivers and locations where lamprey are thought to spawn. Small-scale spawning location suitability characteristics (e.g., depth, velocity, substrate) of Pacific or river lamprey are not adequately described to employ a more formal analysis such as a weighted usable area analysis. Therefore, the change in month-over-month flows is used as a surrogate for a more formal analysis, and a month-over-month flow reduction of 50% was chosen as a best professional estimate of flow conditions in which redd dewatering is expected to occur, but does not estimate empirically derived redd dewatering events.

5C.4.2.4.2 Ammocoete

Water Temperature

Water temperatures in each river were compared to determine whether mean monthly temperatures by water-year type were different among BDCP scenarios. Because water temperatures in all rivers under the BDCP would not be meaningfully different from water temperatures under EBC2, no further water temperature analyses were necessary.

Stranding

Because ammocoetes are relatively immobile in the sediments for 5–7 years (Pacific lamprey) or 3–5 years (river lamprey), there is the potential for stranding events to occur as a result of rapid fluctuations in flows. The analysis of ammocoete stranding was conducted by analyzing a range of month-over-month flow reductions in the Sacramento, Trinity, Feather, American, and Stanislaus Rivers. Predicted flows from CALSIM II were used as inputs for the analysis. The range of flow reductions was 50–90% (in 5% increments) and included the range in which model scenarios were distinguishable and indistinguishable from one another. A cohort of ammocoetes was assumed to be born every month during their spawning period (January through July for Pacific lamprey, February through June for river lamprey) and spend 7 years (Pacific lamprey) or 5 years (river lamprey) rearing upstream. Therefore, a cohort was considered stranded if at least one month-over-month flow reduction was greater than the flow reduction at any time during the period.

There is no information available to determine whether this range is suitable as a surrogate of stranding and, therefore, there is high uncertainty regarding whether it includes the range of a sizable stranding event. Results should be treated as rough estimates of flow fluctuations under each model scenario that lead to dewatering of previously wetted areas, resulting in stranding of Pacific lamprey ammocoetes.

CALSIM II nodes used in the analysis as approximate ammocoete locations were the same as those identified in Section 5C.5.2.3.1, *Redd Dewatering*.

5C.4.3 Passage, Movement, and Migration Methods

5C.4.3.1 Migration of Adult Anadromous Covered Fish Species

5C.4.3.1.1 Attraction and Upstream Migration Flows

The BDCP may change flow magnitude in various tributaries with SWP/CVP reservoirs and the relative proportions of water reaching the Delta that originates from the Sacramento or San Joaquin River watersheds, with the potential effect of reducing attraction of upstream migrating adult anadromous fishes that may be cueing on scent from the natal river and sources along the way (Williams 2006).

Water-Source Fingerprinting (DSM2-QUAL)

Upstream migrating adult salmonids may home to natal spawning grounds based on cues such as odor (Williams 2006). A recent study indicates that Pacific lamprey adults do not exhibit specific homing behavior to exact spawning locations when passing upstream to spawn (Hatch and Whiteaker 2009). However, lamprey still may be attracted to natal spawning grounds through chemical attraction in water originating from rivers in which ammocoetes are present, as has been hypothesized for sea lamprey (Li et al. 1995), although this has not been confirmed *in situ* (Luzier et al. 2009). If true, a major decision that must be made by returning lamprey adults at the confluence of the Sacramento and San Joaquin Rivers is whether to enter the San Joaquin or Sacramento watershed. Water source–fingerprinting output from DSM2-QUAL was used to assess the relative contribution of water from the Sacramento and San Joaquin Rivers near their confluence for each model scenario. This analysis was conducted for adult steelhead, winter-run Chinook salmon, spring-run Chinook salmon, fall-run Chinook salmon, late fall–run Chinook salmon, Pacific lamprey, and river lamprey during assumed upstream spawning migration periods.

Flow Assessment (CALSIM)

Potential changes in the magnitude of attraction and upstream migration flows were based on CALSIM results using a comparison of mean monthlyflows by water-year type over the 82-year period of hydrologic simulation. This was conducted for flows on the mainstem Sacramento River, San Joaquin River, and the major tributaries in the Study Area based on the assumed occurrence of the species (See Appendix 2.A, *Species Accounts*). The potential effect on migrating anadromous adult covered fish species of estimated changes in attraction flows from the Study Area watersheds was assessed on the basis of the percentage changes in flows.

In addition to fingerprinting analyses described above, effects of the BDCP on adult salmonid immigration was determined by comparing CALSIM monthly flows among model scenarios in the Sacramento River at Rio Vista during the migration period of each race of Chinook salmon and steelhead.

Upstream adult white sturgeon movements to spawn are triggered by photoperiod, increases in river flow, and preferred temperature range (Israel et al. 2009). Kohlhorst et al. (1991) and Schaffter (1997) concluded that elevated flows provide cues stimulating upstream prespawn adult migration. In addition to providing cues, higher flows increase the ability to pass any migrational barriers to spawning habitat. Flows throughout the Bay-Delta region, including the reduction of seasonal peak flows, have been affected by a number of factors, including dams and diversions (Israel et al. 2009). The reduction of both peak and elevated seasonal flows reduces the migrational cues available for prespawn adult sturgeon. Schaffter (1997) identified a potential threshold of 5,300 cfs (150 cubic meters per second [m^3/s]) in the Sacramento River at Colusa (Wilkins Slough used as a surrogate for this analysis) as a potential flow threshold. To investigate the potential flow-related effects of the project on sturgeon, CALSIM flow outputs of seasonal attraction flows were analyzed to detect differences in flow rates during the attraction (November through May) and upstream migration (mid-February and late May) periods in the Sacramento River in and below known spawning grounds (between Knights Landing and several kilometers upstream of Colusa). In addition, the Israel and coauthors (2009) review of late-winter, early-spring flows upstream of Verona indicated that flows that attracted adult sturgeon and resulted in successful spawning events ranged from 6,356 cfs (180 m^3/s) and 12,360 cfs (350 m^3/s). Therefore, a CALSIM review of when these conditions would occur during February through May under the modeled scenarios also was completed. As California Department of Fish and Wildlife (CDFW) creel surveys indicate that white sturgeon may be using portions of the San Joaquin system for spawning (California Department of Fish and Game 2002), attraction flows also were investigated at Vernalis during this same period.

Israel and Klimley (2008) identified February through July as peak periods of occurrence in the Bay-Delta for green sturgeon prespawn adults. However, as green sturgeon tagging studies indicate that prespawning upstream movement of reproductively mature adults occurs during the winter and spring months (Emmett et al. 1991; Beamesderfer and Webb 2002; Lindley et al. 2008; Heublein et al. 2009), to detect whether there were any changes in flows that may attract these prespawn adults into the estuary, the analysis also investigated flows during November through January. Upstream movements to spawn apparently are triggered by photoperiod, increases in river flow, and preferred temperature range (Israel and Klimley 2008). Higher flows provide the necessary migration cues and increase the ability to pass any impediments to spawning habitat. As a result, the analysis of potential effects on adult green sturgeon attraction flows investigates potential changes in November through July flows for each water-year type in the Sacramento River at Keswick, Verona, and downstream at Rio Vista and in the Feather River at Thermalito and the confluence with the Sacramento River.

In addition to the fingerprinting analysis described above for lampreys, seasonal flows farther upstream in the watersheds were used to evaluate the effects of the BDCP on relative contribution to flows of tributaries upstream of the Delta. No fingerprinting tools are available for this analysis, although an evaluation of flow rates from CALSIM outputs along the likely migration pathways of Pacific lamprey provides estimates of how the BDCP would affect adult attraction flows. Five locations were chosen at which to evaluate flow rates during January through June (Moyle 2002): Sacramento River upstream of Red Bluff, Feather River at the confluence, the American River at the confluence, San Joaquin River at Vernalis, and Stanislaus at the confluence. Higher flows during this period are assumed to provide better attraction flows. The effects of BDCP water operations on attraction flows for river lamprey adults were assessed using the same methods as the analysis of effects on Pacific lamprey, although migration timing differed between species. Although river lamprey adult migration timing in California is unknown, adults migrate upstream in the Columbia River watershed during fall months (Moyle 2002). Therefore, this analysis assumed this migration period of September through November for river lamprey in the Delta.

Straying Rate of Adult San Joaquin River Region Fall-Run Chinook Salmon (Marston et al. 2012)

Olfactory cues and attraction flows are important in determining homing of adult Chinook salmon to natal tributaries (Marston et al. 2012). Straying rates of adult fall-run Chinook salmon from the San Joaquin River region— the southern tributaries of the San Joaquin River including the Stanislaus, Tuolumne, and Merced Rivers—into tributaries of the Sacramento River region were estimated by Marston et al. (2012) under the assumption that in-river releases of coded-wire-tagged Merced River hatchery fall-run Chinook salmon juveniles would allow inferences to be made of wild-origin Chinook straying rates from these tributaries. Estimated annual straying rates for fish released at inland locations upstream of the Delta averaged 18% and ranged from 0% to more than 70%; straying rates were even greater for fish released in the Delta and Bay. These straying rates are appreciably higher than straying rates estimated by the same authors for Chinook salmon released as juvenile in the Sacramento River upstream of the Delta (0.1%). Marston et al. (2012) compared various statistical models to explain straying rate as a function of various flow terms hypothesized to be relevant during the San Joaquin River region fall-run Chinook salmon adult upstream migration period, including San Joaquin River mean base flows and pulse flows, south Delta exports, Old and Middle River flows, the ratio of exports to San Joaquin River pulse flows, as well as the potential impacts from the south Delta barrier operations. The analyses suggested that models including exports and pulse flow, either as a ratio, or as separate terms, appear to explain as much or more of the variability in stray rate as models with other hydrological variables (e.g., Old and Middle River flows). Overall, Marston et al. (2012: 14) concluded the following from their analysis:

> In conclusion, since the biology of salmon indicates that a model including San Joaquin River flow is biologically necessary (salmon navigate based upon juvenile river imprinting), we must include San Joaquin River flow in a management model. There are several ways to link flow and exports to stray rates. Whether or not to include either co-variate (flow and exports), and how, depends entirely upon the objective. If the objective is explanation, then a model that includes both flow and exports independent of one another is warranted ... Alternatively, if the goal is pure prediction, then a model that has flow alone… is acceptable given that flow is the only variable associated with San Joaquin River salmon stray rates at a statistically significant level. However, since we cannot say with statistical certainty whether flow or exports is the primary determinant influencing San Joaquin River salmon stray rates, exports can also be included in the management model in the form of an E:I ratio.

The present effects analysis of the BDCP used Equation 2 of Marston et al. (2012: 14) to estimate potential changes in straying rate of San Joaquin River region fall-run Chinook salmon adults as a function of south Delta combined exports to San Joaquin River inflow ratio (E:I):

$$Straying\ Rate = \frac{1}{1+\ e^{-\left(-3.25+2.41\ln\left(\frac{Export\ Pulse\ Flow}{SJR\ Pulse\ Flow}\right)\right)-(0.64Age3)-(1.01Age4)}}$$

Where *Straying Rate* is the percentage of San Joaquin River region fall-run Chinook salmon adults that stray to the Sacramento River region; *San Joaquin River Pulse Flow* is the highest 10-day average San Joaquin River flow at Vernalis (cfs) during October-November; *Export Pulse Flow* is the average south Delta exports during the October–November San Joaquin River pulse flow period; and *Age3* and *Age4* are indicators of fish age, so that *Age3* = 1 if calculating the straying rate for Age 3 adults and *Age3* = 0 otherwise, for example. Note that setting *Age3* and *Age4* equal to zero results in estimation of straying rate for Age-2 adults. Equation 2 of Marston et al. (2012) was used instead of Equation 1 because it provides a convenient way to estimate straying rate as a function of export to inflow.

CALSIM modeling data were used to provide flow and export inputs to the equation above. CALSIM provides monthly average flow (base flow, sensu Marston et al. 2012) and export data, whereas the above equation requires flow and exports during pulse periods, and so conversions from the monthly-average CALSIM base flows (or exports) to pulse flows (or exports) were developed from flow and export data provided by Marston et al. (2012: Table 7 of their Methods Appendix). The conversion relationships developed from Marston et al.'s (2012) San Joaquin River flow data and export data are shown in Figure 5C.4-2 and Figure 5C.4-3. Note that these conversions were developed from Marston et al.'s (2012) appendix and were not published in their paper. These conversions were applied to the CALSIM modeling data. Note also that Marston et al. (2012) included Contra Costa Water District diversions at Rock Slough and Old River in their definition of south Delta exports; estimates of these diversions were not included in this effects analysis because modeling estimates from CALSIM were not available. Given that historic Contra Costa diversions were small in relation to the SWP/CVP south Delta export facilities, i.e., 1–2%, omission of Contra Costa diversions is unlikely to affect the results very much.

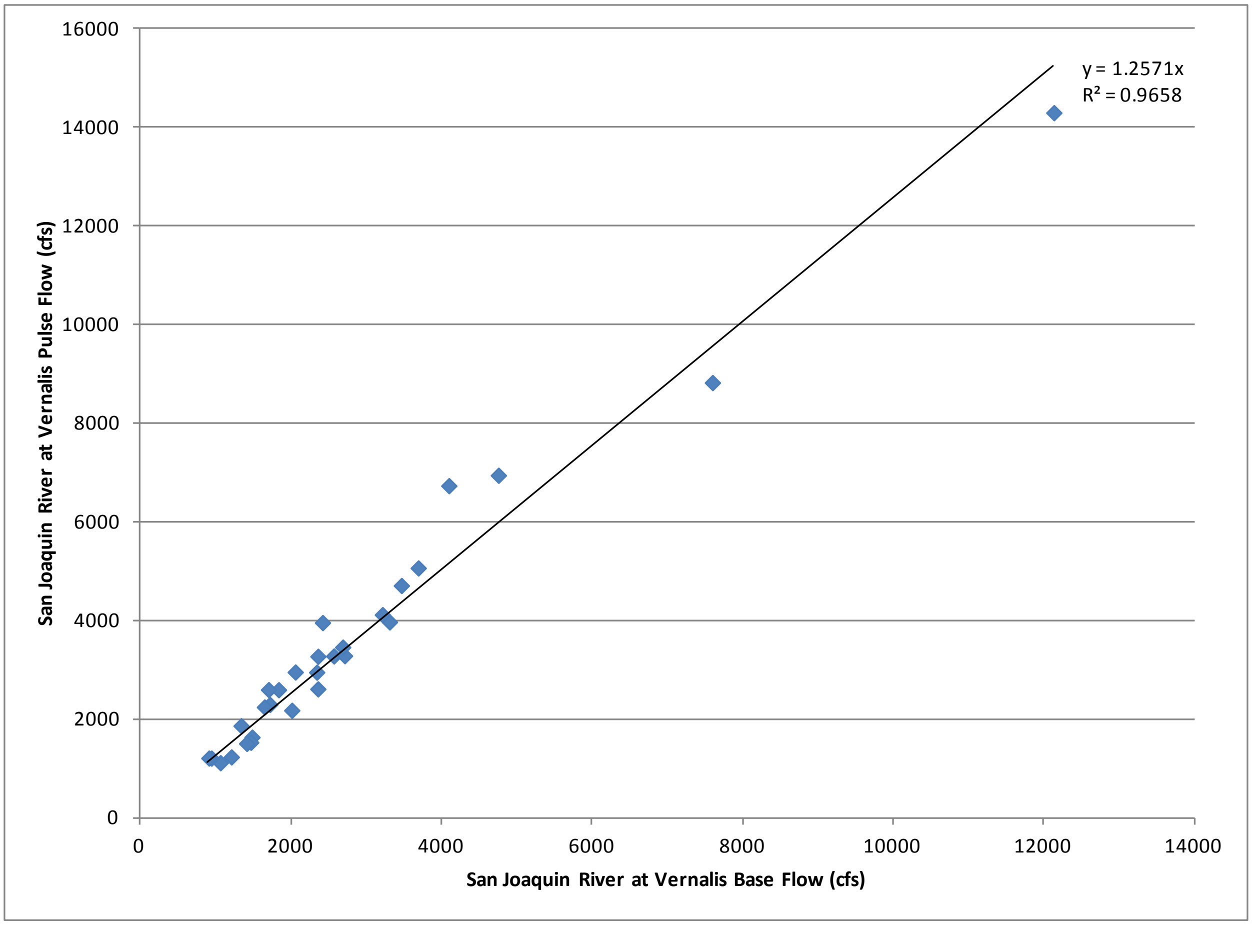

Figure 5C.4-2. Relationship between San Joaquin River at Vernalis 10-Day Average Highest October–November Pulse Flow and Average October–November Base Flow (cfs)

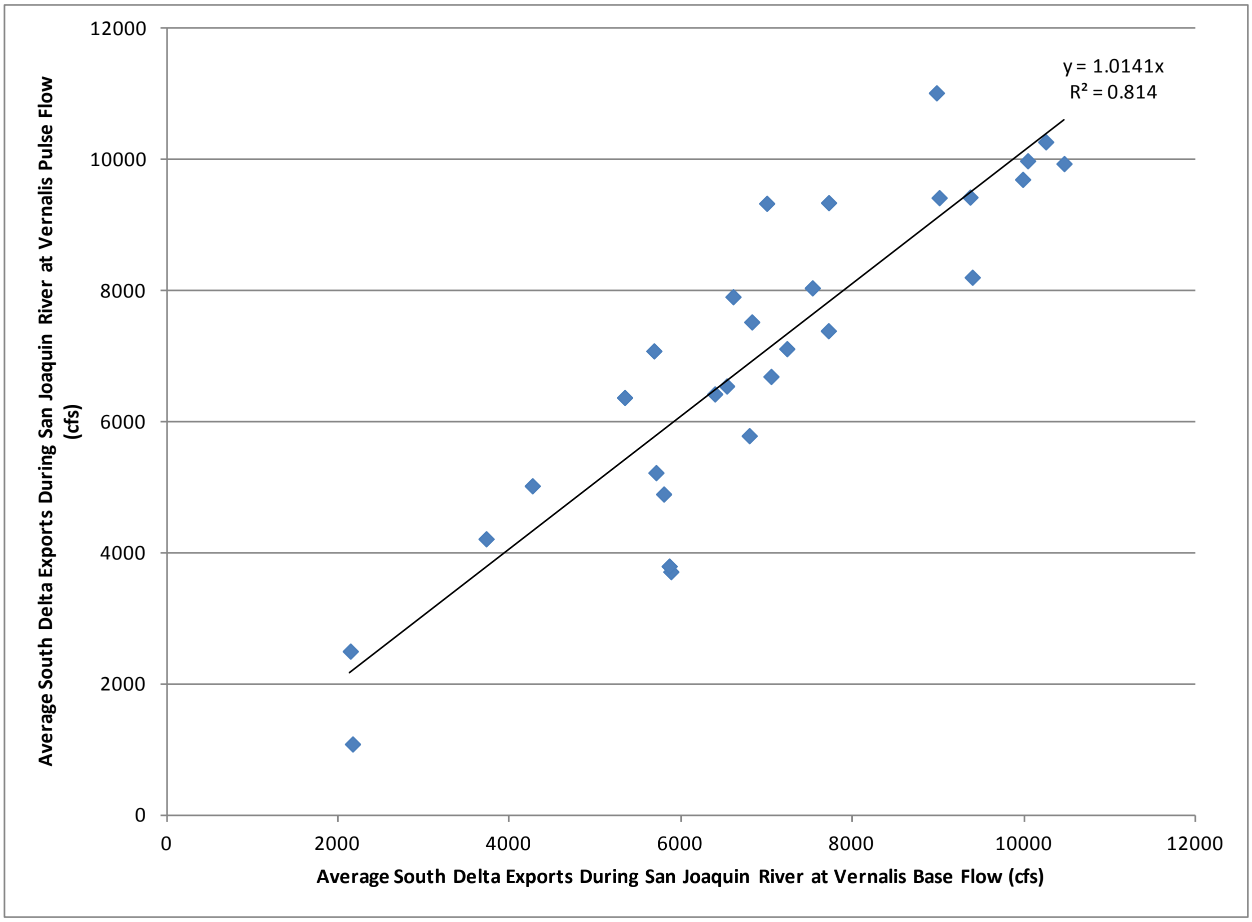

Figure 5C.4-3. Relationship between South Delta Exports During San Joaquin River at Vernalis 10-Day Average Highest October–November Pulse Flow and Average October–November South Delta Exports During Base Flow Period (cfs)

Annual estimates of straying for each scenario (EBC1, EBC2, etc.) were calculated as weighted annual averages of three annual age-specific straying rate estimates, with age-specific weights based on an assumed ratio of 32% age 2: 55% age 3: 13% age 4 from the preliminary fall-run Chinook salmon age distribution provided by California Department of Fish and Game (2005). The relationship of south Delta E:I to age-specific percentage straying rate of San Joaquin River region adult fall-run Chinook salmon as estimated from the equation above is illustrated for the range of E:I values examined by Marston et al. (2012) in Figure 5C.4-4. Straying rates increase as E:I increases, and younger fish stray more than older fish (although note that there is some uncertainty related to this, as other studies do not show this pattern, as reviewed by Marston et al. [2012]): there is very little straying with less exports than San Joaquin River inflow (i.e., E:I less than 1), whereas high levels of exports (E:I ~4–6) result in more than 50% of adults straying, and the highest E:I observed by Marston et al. (2012) is predicted to result in nearly 80% of 2-year-olds straying and nearly 60% of 4-year-olds straying, with 3-year-olds intermediate to these values.

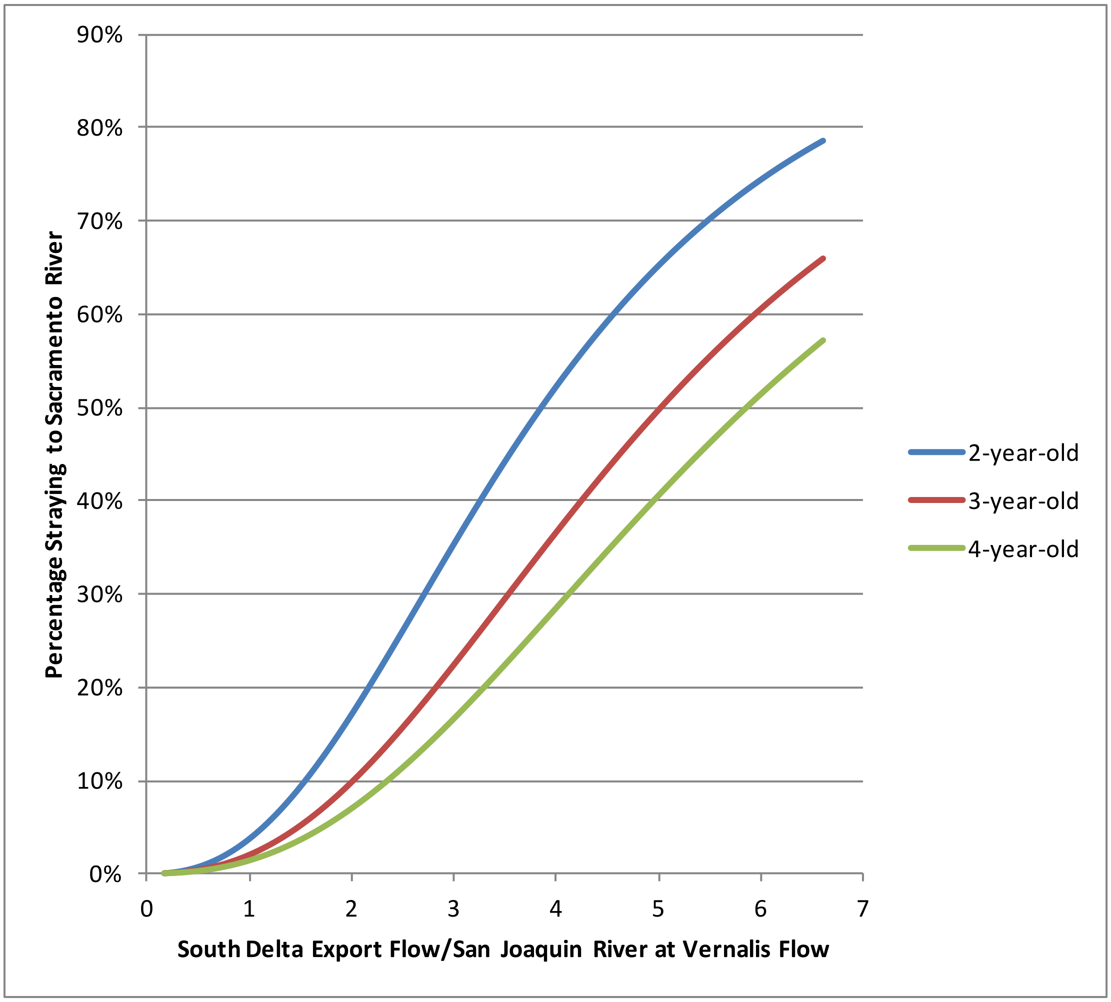

Figure 5C.4-4. Age-Specific Straying Rate of Adult San Joaquin River Region Fall-Run Chinook Salmon as a Function of the Ratio of October–November Average South Delta Export Flow to San Joaquin River Flow at Vernalis

5C.4.3.1.2 Passage Impediments

Fremont Weir Adult Passage (*CM2 Yolo Bypass Fisheries Enhancement*)

The main passage impediment for adult migrating anadromous fish in the Sacramento River, downstream of the Shasta/Keswick Dam complex, is the Fremont Weir when the Yolo Bypass is flooded but water is no longer spilling over the weir. *CM2 Yolo Bypass Fisheries Enhancement* proposes a notch in the Fremont Weir to allow diversions from the Sacramento River at lower flows (more frequent inundation) and the construction of effective adult ladders or ramps at the Sacramento and Fremont Weirs (improved passage). Upstream adult migrating anadromous fish that may be affected by CM2 include steelhead, Chinook salmon, white and green sturgeon, and Pacific and river lamprey. Relative to existing biological conditions, the main potential effects of CM2 on upstream adult migrating anadromous fish are listed here.

- Improved passage at Fremont Weir through installation of improved fish ladders or ramps at new notch and longer inundation period.

- Increased attraction into the Yolo Bypass as more Sacramento River flow is diverted through the new notch, is not expected to measurably affect survival, as long as passage past Fremont Weir is improved.

Records of Fish Rescued at Fremont Weir

Existing records of fish rescued at Fremont Weir were assembled from reports by CDFW (California Department of Fish and Game undated) and Healey and Vincik (2011) in order to provide context for the number of fish stranded at Fremont Weir under existing biological conditions that may benefit from improved passage.

DRERIP Evaluation of Fremont Weir and Yolo Bypass Inundation

The 2009 Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) evaluation of Fremont Weir and Yolo Bypass inundation (previously referred to as Water Operations Conservation Measure 2) was used to assess the potential positive and negative outcomes from changing fish passage at Fremont Weir. As with all DRERIP evaluations, the outcomes were rated on a scale of 1–4 for magnitude of the effect on the population and certainty of the outcome (4 being the greatest effect on the population or highest certainty).

Low Dissolved Oxygen (*CM14 Stockton Deep Water Ship Channel Dissolved Oxygen Levels*)

The main passage impediment for adults in the lower San Joaquin River is the result of depressed DO concentrations in the Stockton Deep Water Ship Channel. CM14 is designed to ensure that sufficient DO concentrations are maintained in the lower San Joaquin River to provide adequate water quality conditions to allow adult anadromous fish the ability to migrate freely through the area to upstream spawning habitat. This is achieved with an oxygen diffuser. Recent results from a DWR oxygen diffuser demonstration project in the Stockton Deep Water Ship Channel were used to assess the effectiveness of the conservation measure (California Department of Water Resources 2010; Herr 2010).

Nonphysical Fish Barriers (CM16)

Nonphysical fish barriers proposed for various locations in the Delta (e.g., head of Old River and Georgiana Slough–Sacramento River divergence) under *CM16 Nonphysical Fish Barriers* to deter juvenile salmonids from entering the interior Delta have the potential to impede passage of adult anadromous fish that are moving upstream through these locations. Results of the previous in-Delta deterrence study at Georgiana Slough were reviewed to assess effectiveness of proposed barriers for juvenile Chinook salmon. In addition, a qualitative analysis of the potential impeding effects of such barriers was conducted that evaluated the relative position of the barriers in relation to species' position in the water column and the hearing and escape abilities of the species in relation to the acoustic deterrent provided by the barriers.

Suisun Marsh Salinity Control Gate Modifications

An analysis of modifications to the SMSCG and the gates' effects on upstream migrating adult anadromous fish was conducted using best professional judgment.

5C.4.3.1.3 Downstream Kelt Migration (Steelhead)

In a manner similar to that described above for attraction and upstream migration flows, CALSIM flow outputs were assessed for differences between BDCP and existing biological conditions during the kelt migration period in the various tributaries in which steelhead are known to occur.

5C.4.3.2 Downstream Migration of Juvenile Anadromous Covered Fish Species

5C.4.3.2.1 Flow Assessment (CALSIM)

To assess flow effects on migration survival for juvenile anadromous fish species, monthly flows by water-year type over the 82-year hydrologic period, based on results of CALSIM II modeling during the downstream migration periods, were compiled and compared between existing biological conditions and BDCP scenarios. Frequency-of-exceedance analyses were used, by month and water-year type, to characterize instream flows during migration for each river system at the CALSIM locations, and months used for the flow summaries are detailed in Table 5C.4-5. Higher flows generally are assumed to result in increased survival for juvenile anadromous covered fish species. Many studies have found a positive relationship between juvenile Chinook salmon migration rate and flow in the Columbia River Basin (Raymond 1968; Berggren and Filardo 1993). As migration speed increases, survival is also thought to increase, due primarily to decreased cumulative predation losses. For example, the findings of Kjelson and Brandes (1989) and Williams and Mathews (1995) both show a logarithmic survival-flow relationship for juvenile Chinook salmon outmigrants. Newman (2003) and Newman and Rice (2002) also used a logarithmic relationship between smolt survival and flow for Chinook salmon smolts migrating through the Delta. Flow-survival relationships are discussed further in the description of the Delta Passage Model (DPM). Seasonal inundation of the Yolo Bypass has the potential to benefit juvenile salmonids by providing an alternative migration route around the Delta while also providing productive rearing habitat. However, flows entering the Yolo Bypass also mean reduced flows through the Sacramento River downstream to the confluence between Cache Slough and the Sacramento River. The effects of these tradeoffs for Chinook salmon smolts were captured using the DPM. For juvenile steelhead, results of CALSIM II modeling to assess daily average flows passing into the Yolo Bypass and corresponding flows in the mainstem Sacramento River at Freeport were assessed and compared under existing biological conditions and the BDCP operations.

Downstream migration of larval white sturgeon is assisted by higher flows, although it is unclear whether elevated flows may increase recruitment to less suitable rearing habitat (Israel et al. 2009). Fish (2010) found that the five highest year class indices for white sturgeon occurred during the five highest spring outflows at Chipps Island. However, the CALSIM model for analyzing BDCP–related effects did not include a CALSIM node at Chipps Island, and although tightly correlated, expressed gaps in the outflow regime that make it difficult to specify necessary spring outflow for white sturgeon recruitment. As a result, this analysis relied on the 1995 USFWS Anadromous Fish Restoration Program (AFRP) Plan, indicating that flows of 31,000 cfs at Verona and 17,700 cfs at Grimes (Wilkins Slough used as surrogate) from February to June are ideal for adult access, spawning habitat conditions, and downstream larval transport during wet and above-normal years, when sturgeon recruitment is greatest. Israel and coauthors (2009) indicated that spring flows are important for downstream migrating larval white sturgeon in the Sacramento River. February to May CALSIM flow outputs were reviewed at Verona and Wilkins Slough for all water-year types. In addition, an analysis was conducted for each model scenario to determine the percentage of months during wet and above-normal water years in which mean monthly Delta outflow exceeds 15,000 cfs, 20,000 cfs, and 25,000 cfs during April and May per AFRP guidance for green and white sturgeon (U.S. Fish and Wildlife Service 1995). The objective for this AFRP guidance was to increase sturgeon production by providing adequate Delta outflow in wet and above normal water years. The analysis also calculated average April–May outflow and analyzed the exceedance above these thresholds for each model scenario.

Potentially, migrating juvenile white sturgeon benefit from increased river flows for downstream migration rates and increased passage around low-flow barriers. Because the investigation of BDCP–related effects on flows with respect to larval occurrence previously reviewed changes to February through May flows (as described above), the investigation of flow effects on juveniles included June through October flows. An investigation of CALSIM flows during these months for each water-year type was completed to estimate what flow changes the juvenile life stage may encounter in the rivers immediately prior to their year-round occurrence in the bays and Delta.

Flow relationships have been examined for white sturgeon (Kohlhorst et al. 1991) but not for green sturgeon (Israel and Klimley 2008). Because of different seasonal occurrences of the two species, flow thresholds for white sturgeon would not apply to green sturgeon. Endogenously feeding green sturgeon larvae migrate downstream during May through October in the upper and middle rivers (Israel and Klimley 2008; National Marine Fisheries Service 2009). The flow analysis of BDCP effects on green sturgeon larvae occurring in the upper Sacramento and Feather Rivers during April through July was similar to that provided for eggs and embryos developing in this habitat. As a result, the larval analysis section addresses periods of larval occurrence in those portions of the river (September and October) not addressed previously for egg/embryo life stages (March through August). Further analysis was conducted to investigate the flows in the middle and lower Sacramento River during periods of downstream migrating YOY juvenile green sturgeon. CALSIM locations selected for the analysis of this portion of the Sacramento River included Wilkins Slough and Verona. Israel and Klimley (2008) indicate that the timing of this downstream migration, notably for YOY green sturgeon, is from August through March. As some larger juveniles may occur in this portion of the river in April, May, and June (National Marine Fisheries Service 2009), an additional review was completed of this period. In the absence of flow-threshold criteria during this downstream migration, the analysis focuses on the percent change in flow during this period. Reduced flows during this period may result in biological effects on this life stage, including downstream migration delays. The analysis grouped months with considerable (more than 5%) increases or decreases in flow under the BDCP scenarios compared to existing biological conditions and then investigated whether there were climate-related effects, or trends in water-year type, affecting these differences in flows. A separate review of April through June was conducted to determine potential effects on slightly older juveniles.

The effects of BDCP water operations on seasonal migration flows for Pacific lamprey macropthalmia were assessed using CALSIM II flow output. Specifically, flow rates along the likely migration pathways of Pacific lamprey during the likely migration period (December through June) were examined to predict how the BDCP may affect migration flows for outmigrating macropthalmia (Beamish 1980). It was assumed for this analysis that river lamprey macropthalmia migrate downstream at approximately the same time as Pacific lamprey macropthalmia.

Table 5C.4-5. CALSIM Locations Used to Assess Changes in Monthly Flows during Downstream Migration of Juvenile Anadromous Covered Fish Species

	Sacramento River (RM 194 to Keswick)		Sacramento River (North Delta to RM 143)			West Delta	North Delta		North Delta	South Delta	South Delta	West Delta	Feather River						South Delta
Species	**Keswick**	**Red Bluff Diversion Dam**	**Wilkins Slough**	**Verona**	**Yolo Bypass**	**Rio Vista**	**Freeport**	**Sutter/Steamboat Sloughs**	**Georgiana Slough/ Delta Cross Channel**	**Old and Middle Rivers**	**SWP/CVP Exports**	**Delta Outflows**	**Feather River at Thermalito**	**Feather River at Sacramento River Confluence**	**American River at Sacramento River Confluence**	**Clear Creek**	**Trinity River**	**Stanislaus River at Confluence**	**San Joaquin River at Vernalis**
Steelhead		Oct–May			Oct–May	Oct–May	Oct–May	Oct–May	Oct–May	Oct–May		Oct–May		Oct–May	Oct–May	Oct–May	Oct–May	Oct–May	Oct–May
Winter-run Chinook salmon		Sept–Apr				Sept–Apr		Sept–Apr	Sept–Apr	Sept–Apr	Sept–Apr	Sept–Apr							
Spring-run Chinook salmon		Dec–May				Dec–May		Nov–Apr	Nov–Apr	Nov–Apr	Nov–Apr	Nov–Apr		Oct–May		Oct–May	Feb–Oct		Dec–May
Fall-/late fall–run Chinook salmon		Nov–Sep				Nov–Sep		Nov–Sep	Nov–Sep	Nov–Sep	Nov–Sep	Nov–Sep		Feb–May	Feb–May	Feb–May	Feb–May	Feb–May	Feb–May
White sturgeon			Mar–Jun (Larva)	Mar–Jun (Larva); Jun–Sep (Juvenile)								Mar–Jun		Mar–Jun					
Green sturgeon	Apr–Oct (Larva)	Apr–Oct (Larva)	Apr–Oct (Larva); Aug–Jun (Juvenile)	Apr–Oct (Larva); Aug–Jun (Juvenile)									Apr–Oct (Larva)	Apr–Oct (Larva)					
Pacific lamprey		Dec–June		Dec–June										Dec–June	Dec–June			Dec–June	Dec–June
River lamprey		Dec–Jul		Dec–Jul										Dec–Jul	Dec–Jul			Dec–Jul	Dec–Jul

5C.4.3.2.2 Juvenile Chinook Salmon Smolt through-Delta Survival (Delta Passage Model)

Introduction

The DPM simulates migration of Chinook salmon smolts entering the Delta from the Sacramento River, Mokelumne River, and San Joaquin River and estimates survival to Chipps Island. The DPM uses available time-series data and values taken from empirical studies or other sources to parameterize model relationships and inform uncertainty, thereby using the greatest amount of data available to dynamically simulate responses of smolt survival to changes in water management. Although the DPM is based primarily on studies of winter-run Chinook salmon smolt surrogates (late fall–run Chinook salmon), it is applied here for winter-run, spring-run, fall-run, and late fall–run Chinook salmon by adjusting emigration timing and assuming that all migrating Chinook salmon smolts will respond similarly to Delta conditions. The DPM results presented here reflect the current version of the model, which continues to be reviewed and refined, and for which a sensitivity analysis is underway to examine various aspects of uncertainty related to the model's inputs and parameters.

Although studies have shown considerable variation in emigrant size, with Central Valley Chinook salmon migrating as fry, parr, or smolts (Brandes and McLain 2001; Williams 2001), the DPM relies predominantly on data from acoustic-tagging studies of large (>140 mm) smolts, and therefore should be applied very cautiously to pre-smolt migrants. Salmon juveniles less than 80 mm are more likely to exhibit rearing behavior in the Delta (Moyle 2002) and thus likely will be represented poorly by the DPM. It has been assumed that the downstream emigration of fry, when spawning grounds are well upstream, is probably a dispersal mechanism that helps distribute fry among suitable rearing habitats. However, even when rearing habitat does not appear to be a limiting factor, downstream movement of fry still may be observed, suggesting that fry emigration is a viable alternative life-history strategy (Healy 1980; Healey and Jordan 1982; Miller et al. 2010). Unfortunately, survival data are lacking for small (fry-sized) juvenile emigrants because of the difficulty of tagging such small individuals. Therefore, the DPM should be viewed as a <u>smolt survival model only</u>, with its survival relationships generally having been derived from larger smolts (>140 mm), with the fate of pre-smolt emigrants not incorporated into model results.

The DPM has undergone substantial revisions based on comments received through the preliminary proposal anadromous team meetings and in particular through feedback received during a workshop held on August 24, 2010, a 2-day workshop held June 23–24, 2011, and various meetings of a workgroup consisting of agency biologists and consultants. This effects analysis uses the most recent version of the DPM as of August 2013[1]. The DPM is viewed as a simulation framework that can be changed as more data or new hypotheses regarding smolt migration and survival become available. The results presented in Section 5C.5 are based on these revisions.

Survival and abundance estimates generated by the DPM are not intended to predict future outcomes. Instead, the DPM provides a simulation tool that compares the effects of different water

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[1] Details of the model are provided below. This version of the model includes the latest Yolo Bypass survival data from the UC Davis Biotelemetry laboratory, as well as corrections to the flow-survival functions in reaches Sac1 and Sac2, and a correction to the function used to calculate the proportion of fish entering the Yolo Bypass at Fremont Weir. The latter two issues were identified during review of the previous draft of the BDCP effects analysis from March 2013.

management options on smolt migration survival, with accompanying estimates of uncertainty. The DPM was used to evaluate overall through-Delta survival and migration pathway use/survival for the EBC1, EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, ESO_LLT, HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT scenarios. Note that the DPM is a tool to compare different scenarios and is not intended to predict actual through-Delta survival under current or future conditions. In keeping with other methods found in the BDCP Effects Analysis, it is possible that underlying relationships (e.g., flow-survival) that are used to inform the DPM will change in the future; there is an assumption of stationarity of these basic relationships to allow scenarios to be compared for the current analysis, recognizing that it may be necessary to re-examine the relationships as new information becomes available.

Model Overview

The DPM is based on a detailed accounting of migratory pathways and reach-specific mortality as Chinook salmon smolts travel through a simplified network of reaches and junctions (Figure 5C.4-5). The biological functionality of the DPM is based on the foundation provided by Perry et al. (2010) as well as other acoustic tagging–based studies (San Joaquin River Group Authority 2008, 2010; Holbrook et al. 2009) and coded wire tag (CWT)–based studies (Newman and Brandes 2010; Newman 2008). Uncertainty is explicitly modeled in the DPM by incorporating environmental stochasticity and estimation error whenever available.

The major model functions in the DPM are as follows.

1. Delta Entry Timing, which models the temporal distribution of smolts entering the Delta for each race of Chinook salmon.
2. Fish Behavior at Junctions, which models fish movement as they approach river junctions.
3. Migration Speed, which models reach-specific smolt migration speed and travel time.
4. Route-Specific Survival, which models route-specific survival response to non-flow factors.
5. Flow-Dependent Survival, which models reach-specific survival response to flow.
6. Export-Dependent Survival, which models survival response to water export levels in the Interior Delta reach (see Table 5C.4-6 for reach description).

Functional relationships are described in detail in the *Model Functions* section below. Postprocessing of the model's main outputs was undertaken to inform various aspects of the BDCP effects analysis, as described below in *Postprocessing of Model Outputs for BDCP Effects Analysis*.

Model Time Step

The DPM operates on a daily time step using simulated daily average flows and Delta exports as model inputs. The DPM does not attempt to represent sub-daily flows or diel salmon smolt behavior in response to the interaction of tides, flows, and specific channel features. The DPM is intended to represent the net outcome of migration and mortality occurring over days, not three-dimensional movements occurring over minutes or hours (e.g., Blake and Horn 2003).

Spatial Framework

The DPM is composed of eight reaches and four junctions (Figure 5C.4-5; Table 5C.4-6) selected to represent primary salmonid migration corridors where high-quality data were available for fish and hydrodynamics. For simplification, Sutter Slough and Steamboat Slough are combined as the reach

SS; and Georgiana Slough, the Delta Cross Channel (DCC), and the forks of the Mokelumne River to which the DCC leads are combined as Geo/DCC. The Geo/DCC reach can be entered by Mokelumne River fall-run Chinook salmon at the head of the South and North Forks of the Mokelumne River or by Sacramento runs through the combined junction of Georgiana Slough and DCC (Junction C). The Interior Delta reach can be entered from three different pathways: Geo/DCC, San Joaquin River via Old River Junction (Junction D), and Old River via Junction D. Because of the lack of data informing specific routes through the Interior Delta, or tributary-specific survival, the entire Interior Delta region is treated as a single model reach. The four distributary junctions (channel splits) depicted in the DPM are (A) Sacramento River at Fremont Weir (head of Yolo Bypass), (B) Sacramento River at head of Sutter and Steamboat Sloughs, (C) Sacramento River at the combined junction with Georgiana Slough and DCC, and (D) San Joaquin River at the head of Old River (Figure 5C.4-5, Table 5C.4-6).

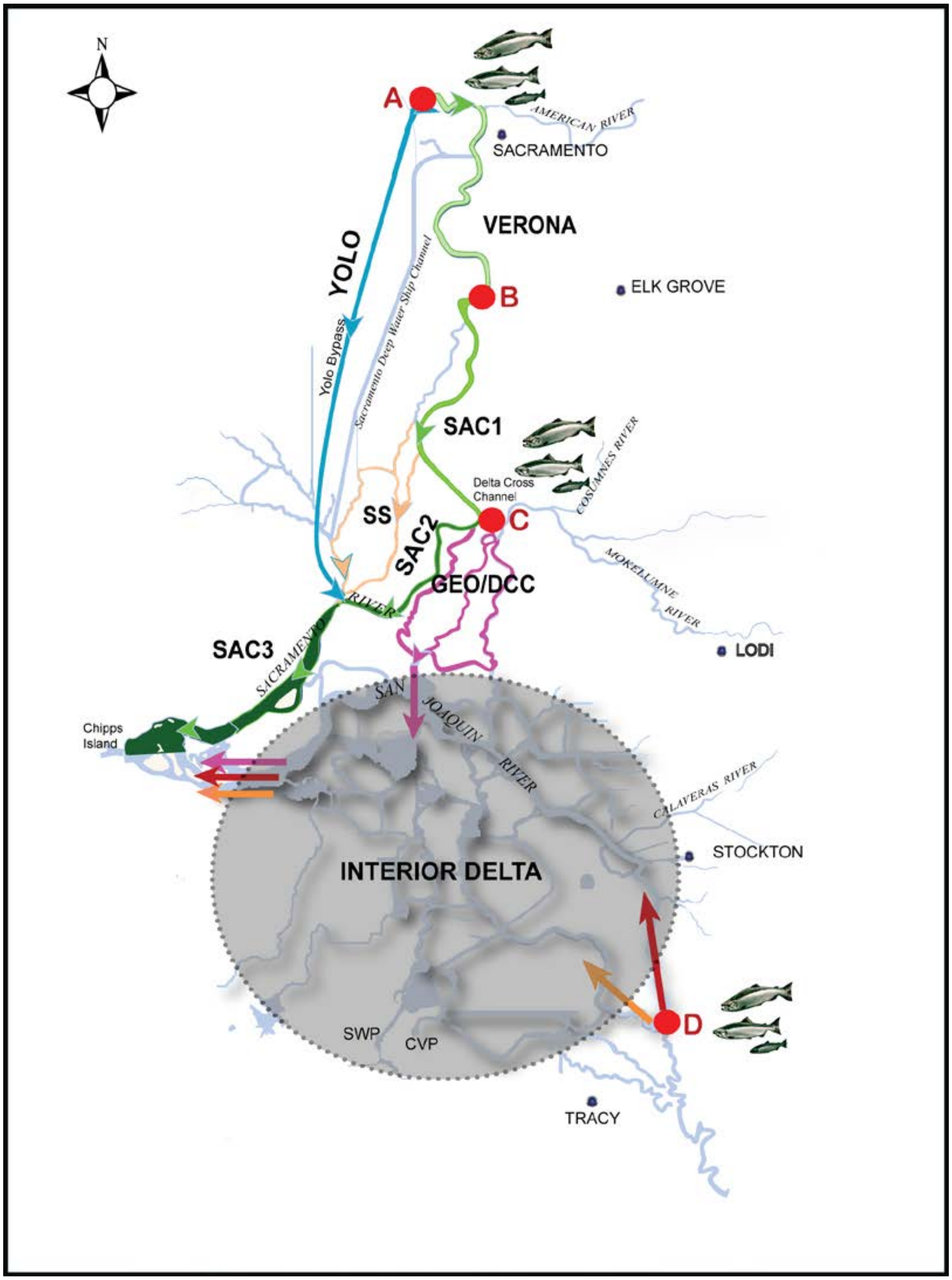
Table 5C.4-6. Description of Modeled Reaches and Junctions in the Delta Passage Model

Reach/ Junction	Description	Reach Length (km)
Sac1	Sacramento River from Freeport to junction with Sutter/Steamboat Sloughs	19.33
Sac2	Sacramento River from Sutter/Steamboat Sloughs junction to junction with Delta Cross Channel/Georgiana Slough	10.78
Sac3	Sacramento River from Delta Cross Channel junction to Rio Vista, California	22.37
Sac4	Sacramento River from Rio Vista, California to Chipps Island	23.98
Yolo	Yolo Bypass from entrance at Fremont Weir to Rio Vista, California	NA[a]
Verona	Fremont Weir to Freeport	57
SS	Combined reach of Sutter Slough and Steamboat Slough ending at Rio Vista, California	26.72
Geo/DCC	Combined reach of Georgiana Slough, Delta Cross Channel, and South and North Forks of the Mokelumne River ending at confluence with the San Joaquin River in the Interior Delta	25.59
Interior Delta	Begins at end of reach Geo/DCC, San Joaquin River via Junction D, or Old River via Junction D, and ends at Chipps Island	NA[b]
A	Junction of the Yolo Bypass[c] and the Sacramento River	NA
B	Combined junction of Sutter Slough and Steamboat Slough with the Sacramento River	NA
C	Combined junction of the Delta Cross Channel and Georgiana Slough with the Sacramento River	NA
D	Junction of the Old River with the San Joaquin River	NA

[a] Reach length for Yolo Bypass is undefined because reach length currently is not used to calculate Yolo Bypass speed and ultimate travel time.

[b] Reach length for the Interior Delta is undefined because salmon can take multiple pathways. Also, timing through the Interior Delta does not affect Delta survival because there are no Delta reaches located downstream of the Interior Delta.

[c] Flow into the Yolo Bypass is primarily via the Fremont Weir but flow via Sacramento Weir is also included.



Bold headings label modeled reaches, and red circles indicate model junctions. Salmonid icons indicate locations where smolts enter the Delta in the DPM (note that the Yolo Bypass entry point has been truncated for clarity and that the recently added Verona reach [Fremont Weir to Freeport] is not depicted in this figure). Smolts enter the Interior Delta from the Geo/DCC reach or from Junction D via Old River or San Joaquin River. Because of the lack of data informing specific routes through the Interior Delta, and tributary-specific survival, the entire Interior Delta region is treated as a single model reach but survival varies within the Interior Delta depending upon whether they enter from the Mokelumne River, the San Joaquin River or Old River.

Figure 5C.4-5. Map of the Sacramento–San Joaquin River Delta Showing the Modeled Reaches and Junctions of the Delta Applied in the Delta Passage Model

Flow Input Data

Water movement through the Delta generally as input to the DPM is derived from daily (tidally averaged) flow output produced by the hydrology module of the Delta Simulation Model II (DSM2-HYDRO; <http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/>). Although DSM2 does provide daily data for south Delta exports, these data exhibit little intramonth variation and reflect the origin of the calculations, i.e., the hydrologic simulation tool CALSIM II (Ferreira 2005). The nodes in the DSM2-HYDRO and CALSIM II models that were used to provide flow for specific reaches in the DPM are shown in Table 5C.4-7. Technical details for DSM2-HYDRO and CALSIM II models are described in Attachment 5C.A, *CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios*. DSM2 flow data output for each of the six scenarios was used to inform the daily conditions experienced by migrating salmonids in the model.

Table 5C.4-7. Delta Passage Model Reaches and Associated Output Locations from DSM2-HYDRO and CALSIM II Models

DPM Reach or Model Component	DSM2 Output Locations	CALSIM Node
Sac1	rsac155	
Sac2	rsac128	
Sac3	rsac123	
Sac4	rsac101	
Yolo		d160[a]+d166a[a]
Verona		C160[a]
SS	slsbt011	
Geo/DCC	dcc+georg_sl	
South Delta Export Flow	Clifton Court Forebay + Delta Mendota Canal	
Interior Delta via San Joaquin River	rsan058	
San Joaquin River flow at Head of Old River	rsan112	
Interior Delta via Old River	rold074	
Sacramento River flow at Fremont Weir (Notch[b] spills)		C129[a]

[a] Disaggregated into daily data based on historical patterns.

[b] "Notch" refers to the proposed notching of the Fremont Weir under *CM2 Yolo Bypass Fisheries Enhancement*.

In order to capture the effect of changed flows within the Sac1 reach being altered by the BDCP's proposed north Delta intakes before the start of the Sac2 reach and the junction with reach SS, a modification was applied to the flows in reach Sac1. The modification reflected the location of the proposed intakes (intake 2 = RM 41, intake 3 = RM 39.5, and intake 5 = RM 37). The weighted average distance of the three intakes from the start of Sac1 (i.e., RM 47) is 56% of the length downstream from the start of Sac1. Flows in Sac1 were then modified as follows:

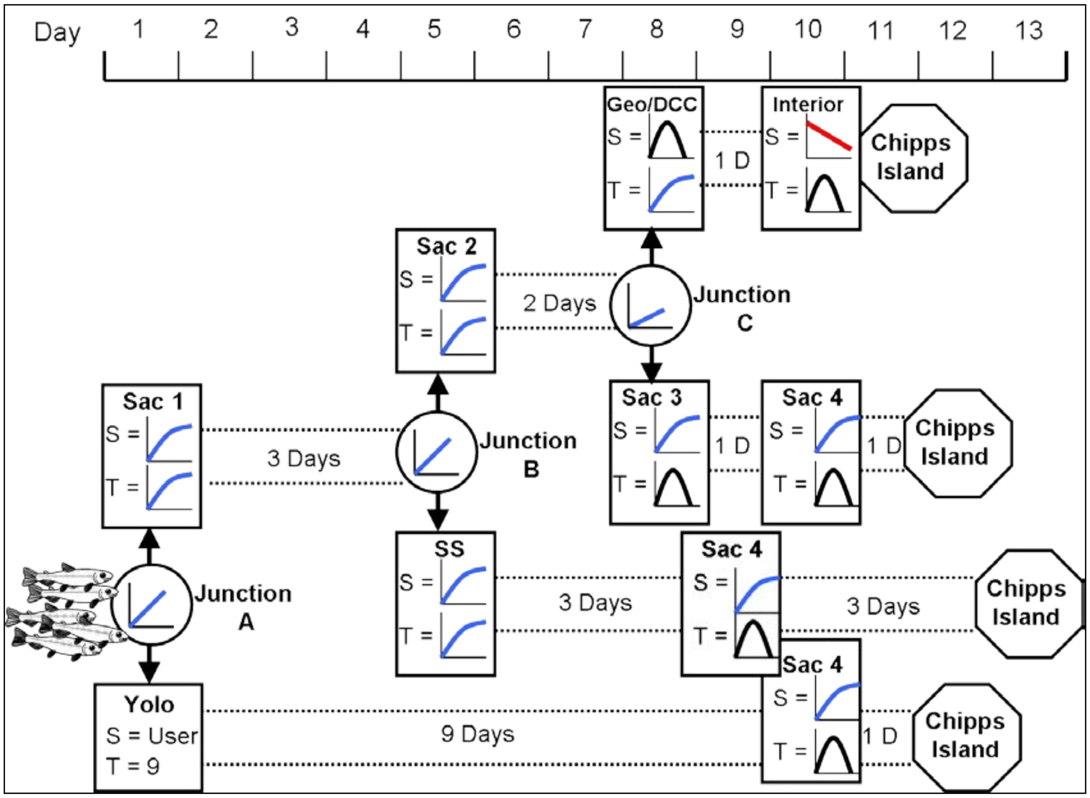
> Modified Sac1 flows = 0.56 × flows into Sac1 + 0.44 × flows at bottom of Sac1
>
> where flows into Sac1 are represented by DSM2 outputs from RSAC155 (Freeport) and flows at bottom of Sac1 are represented by DSM2 outputs from 418_mid (Sacramento River upstream of Sutter/Steamboat Sloughs and downstream of the north Delta intakes).

An illustrative hypothetical example of the computations for flows into Sac1 is for flows into Sac1 of 10,000 cfs, of which 2,000 cfs is diverted by the three north Delta intakes and therefore 8,000 cfs remains at the bottom of Sac1:

> Modified Sac1 flows = 0.56 × 10,000 cfs + 0.44 × 8,000 cfs = 9,120 cfs.

Illustrative Example

To help illustrate the series of operations performed by the DPM, Figure 5C.4-6 depicts the migration of a single daily cohort of smolts entering from the Sacramento River and migrating through the DPM. It is important to remember that cohorts of differing numbers of smolts are entering the Delta each day during the migration period of each salmon run. As fish encounter junctions in the Delta, they are routed down one of two paths dependent on the proportion of flow entering each downstream reach. In some cases (Junctions A and B) fish movement is directly proportional with flow movement, while at other junctions (Junction C) fish movement, although linear, is not directly proportional with flow movement. As fish enter Delta reaches, their reach survival and migration speed (and therefore migration time) are calculated on the day they enter the reach. All subsequent days that the fish are migrating through a given reach, they are not exposed to mortality, nor is their migration speed adjusted. For reaches where data were available to inform a relationship with flow, reach survival and migration speed are calculated as a function of the flow during the initial day of reach entry. Likewise, where data were available to inform a relationship with Delta exports (Interior Delta), reach survival is calculated as a function of exports as fish enter the reach. Because portions of a single cohort of fish migrate through different routes in the Delta, portions of the cohort will experience differing overall survival rates, differing migration rates, and differing arrival times at Chipps Island. See *Model Functions* section below for detailed descriptions of DPM functional relationships.



Day of the model run is indicated at the top of the diagram. Circles indicate Delta junctions, where the proportion of fish moving to each downstream reach is calculated, and rectangles indicate Delta reaches. The shape of the relationship for each reach-specific survival (S), reach-specific migration speed (T), and proportional fish movement at junctions is depicted. Relationships that are influenced by flow (x variable) are blue, relationships influenced by exports are red, and relationships that are calculated from a probability distribution (and not influenced by flow or exports) are black. Dotted lines indicate migration time through the previous reach, and the Chipps Island icons indicate when fish from each route exited the Delta. Note that this diagram does not incorporate the recently added Verona reach, which occurs between Junction A and reach Sac1. Note also that travel time for reach Yolo is sampled from a uniform distribution of 4-28 days (i.e., the fixed 9-day travel migration speed depicted here was subsequently changed).

Figure 5C.4-6. Conceptual Diagram Depicting the "Migration" of a Single Daily Cohort of Smolts Entering from the Sacramento River and Migrating through the Delta Passage Model

Model Functions

Delta Entry Timing

Recent sampling data on Delta entry timing of emigrating juvenile smolts for six Central Valley Chinook salmon runs were used to inform the daily proportion of juveniles entering the Delta for each run (Table 5C.4-8). Because the DPM models the survival of smolt-sized juvenile salmon, pre-smolts were removed from catch data before creating entry timing distributions. The lower 95th percentile of the range of salmon fork lengths visually identified as smolts by the USFWS in Sacramento trawls was used to determine the lower length cutoff for smolts. A lower fork length cutoff of 70 mm for smolts was applied, and all catch data of fish smaller than 70 mm were eliminated. To isolate wild production, all fish identified as having an adipose-fin clip (hatchery production) were eliminated, recognizing that most of the fall-run hatchery fish released upstream of Sacramento are not marked. Daily catch data for each brood year were divided by total annual catch to determine the daily proportion of smolts entering the Delta for each brood year. Sampling was not conducted daily at most stations and catch was not expanded for fish caught but not measured. Finally, the daily proportions for all brood years were plotted for each race, and a normal distribution was visually approximated to obtain the daily proportion of smolts entering the DPM for each run (Figure 5C.4-7). Because a bi-modal distribution appeared evident for winter-run entry timing, a generic probability density function was fit to the winter-run daily proportion data using the package "sm" in R software (R Core Team 2012). The R fitting procedure estimated the best-fit probability distribution of the daily proportion of fish entering the DPM for winter-run. A sensitivity analysis of this assumption currently is being undertaken and will be included in the final BDCP.

Table 5C.4-8. Sampling Gear Used to Create Juvenile Delta Entry Timing Distributions for Each Central Valley Run of Chinook Salmon

Chinook Salmon Run	Gear	Agency	Brood Years
Sacramento River Winter Run	Trawls at Sacramento	USFWS	1995–2009
Sacramento River Spring Run	Trawls at Sacramento	USFWS	1995–2005
Sacramento River Fall Run	Trawls at Sacramento	USFWS	1995–2005
Sacramento River Late Fall Run	Trawls at Sacramento	USFWS	1995–2005
Mokelumne River Fall Run	Rotary Screw Trap at Woodbridge	EBMUD	2001–2007
San Joaquin River Fall Run	Kodiak Trawl at Mossdale	CDFW	1996–2009
Agencies that conducted sampling are listed: USFWS = U.S. Fish and Wildlife Service, EBMUD = East Bay Municipal District, and CDFW = California Department of Fish and Wildlife.			

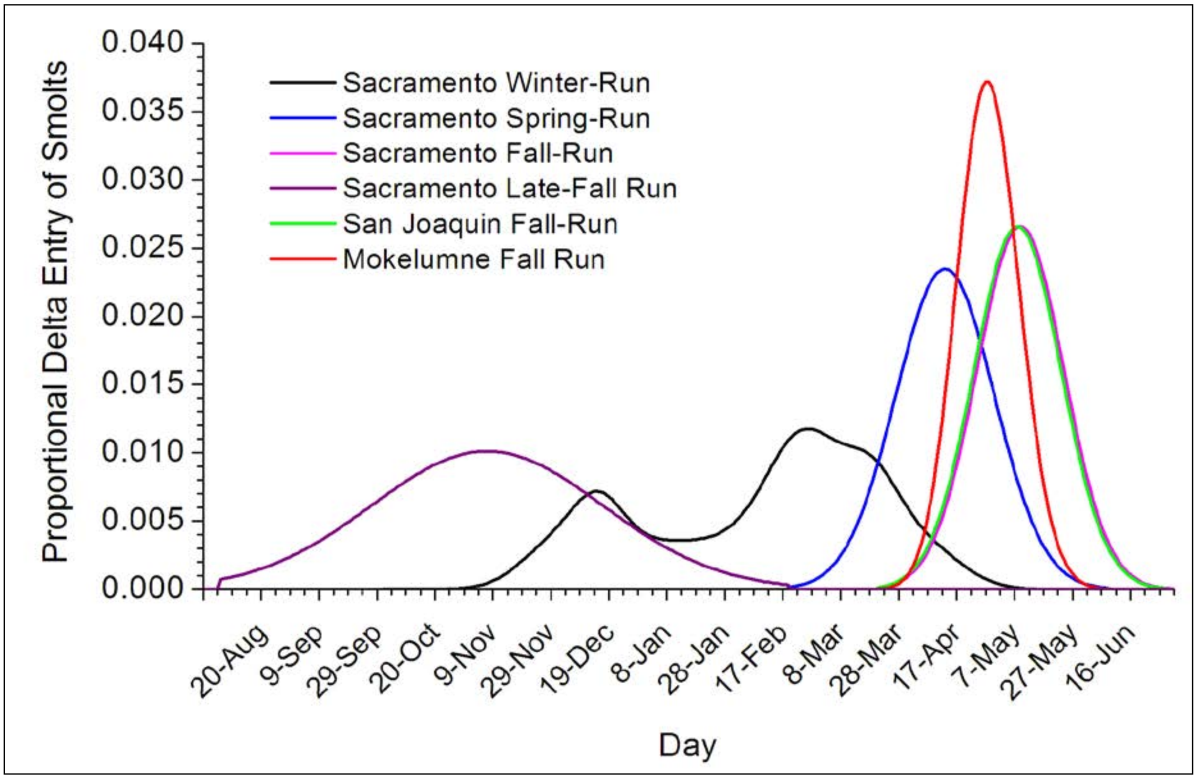


Figure 5C.4-7. Delta Entry Distributions for Chinook Salmon Smolts Applied in the Delta Passage Model for Sacramento River Winter-Run, Sacramento River Spring-Run, Sacramento River Fall-Run, Sacramento River Late Fall–Run, San Joaquin River Fall-Run, and Mokelumne River Fall-Run Chinook Salmon

Migration Speed

The DPM assumes a net daily movement of smolts in the downstream direction. The rate of smolt movement in the DPM affects the timing of arrival at Delta junctions and reaches, which can affect route selection and survival as flow conditions or water project operations change.

Smolt movement in all reaches except Yolo Bypass and the Interior Delta is a function of reach-specific length and migration speed as observed from acoustic-tagging results. Reach-specific length (kilometers [km]) (Table 5C.4-6) is divided by reach migration speed (km/day) the day smolts enter the reach to calculate the number of days smolts will take to travel through the reach.

For north Delta reaches Verona, Sac1, Sac2, SS, and Geo/DCC, mean migration speed through the reach is predicted as a function of flow. Many studies have found a positive relationship between juvenile Chinook salmon migration rate and flow in the Columbia River Basin (Raymond 1968; Berggren and Filardo 1993; Schreck et al. 1994), with Berggren and Filardo (1993) finding a logarithmic relationship for Snake River yearling Chinook salmon. Ordinary least squares regression was used to test for a logarithmic relationship between reach-specific migration speed (km/day) and average daily reach-specific flow (cubic meters per second [m^3/sec]) for the first day smolts entered a particular reach for reaches where acoustic-tagging data was available (Sac1, Sac2, Sac3, Sac4, Geo/DCC, and SS):

$$Speed = \beta_0 \ln(flow) + \beta_1;$$

Where β_0 is the slope parameter and β_1 is the intercept.

Individual smolt reach-specific travel times were calculated from detection histories of releases of acoustically-tagged smolts conducted in December and January for three consecutive winters (2006/2007, 2007/2008, and 2008/2009) (Perry 2010). Reach-specific migration speed (km/day) for each smolt was calculated by dividing reach length by travel days (Table 5C.4-9). Flow data was queried from the DWR's California Data Exchange website (<http://cdec.water.ca.gov/>).

Table 5C.4-9. Reach-Specific Migration Speed and Sample Size of Acoustically-Tagged Smolts Released during December and January for Three Consecutive Winters (2006/2007, 2007/2008, and 2008/2009)

Reach	Gauging Station ID	Release Dates	Sample Size	Speed (km/day)			
				Avg	Min	Max	SD
Sac1	FPT	12/05/06–12/06/06, 1/17/07–1/18/07, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	452	13.32	0.54	41.04	9.29
Sac2	SDC	1/17/07–1/18/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	294	9.29	0.34	10.78	3.09
Sac3	GES	12/05/06–12/06/06, 1/17/07–1/18/07, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	102	9.24	0.37	22.37	7.33
Sac4	GES[a]	12/05/06–12/06/06, 1/17/07–1/18/07, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	62	8.60	0.36	23.98	6.79
Geo/DCC	GSS	12/05/06–12/06/06, 1/17/07–1/18/07, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	86	14.20	0.34	25.59	8.66
SS	FPT-SDC[b]	12/05/06–12/06/06, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	30	9.41	0.56	26.72	7.42

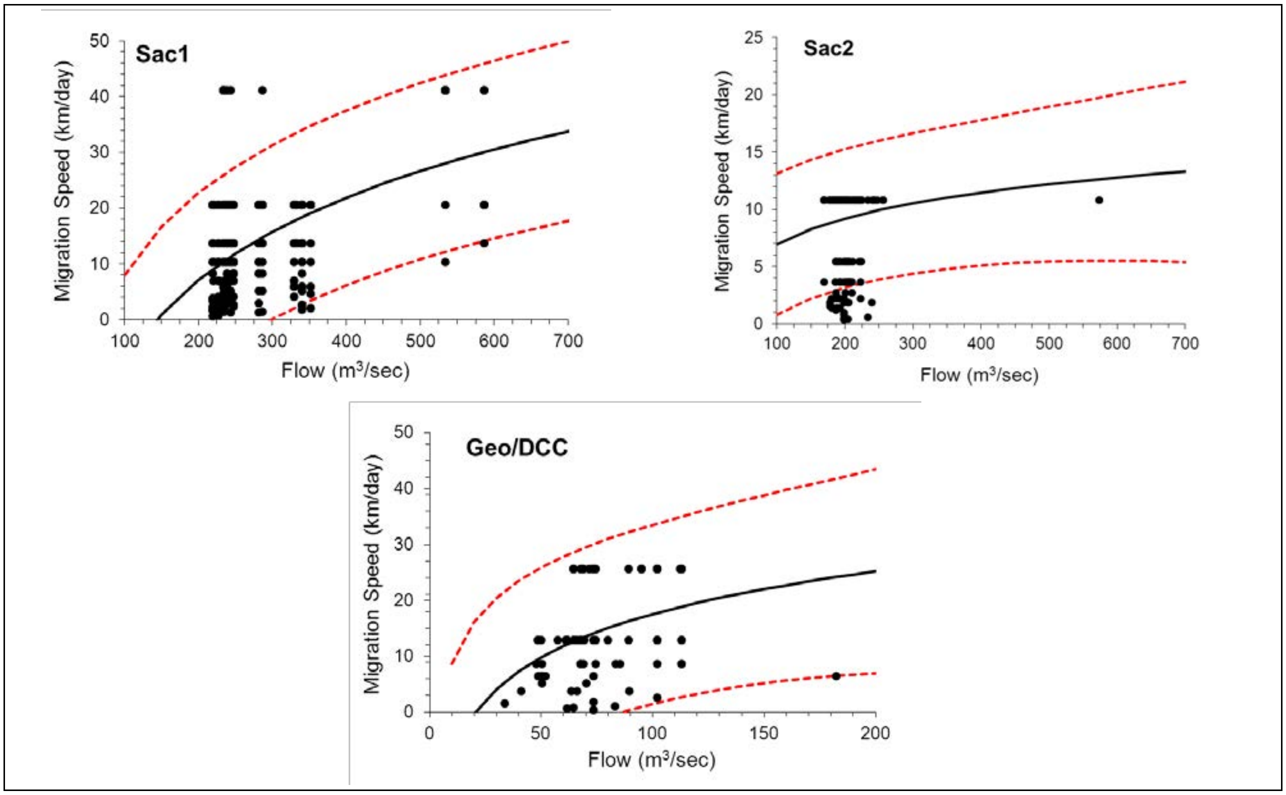
[a] Sac3 flow is used for Sac4 because no flow gauging station is available for Sac4.

[b] SS flow is calculated by subtracting Sac2 flow (SDC) from Sac1 flow (FPT).

Migration speed was significantly related to flow for reaches Sac1 (df = 450, F = 164.36, P < 0.001), Sac2 (df = 292, F = 4.17, P = 0.042), and Geo/DCC (df = 84, F = 13.74, P <0.001). Migration speed increased as flow increased for all three reaches (Table 5C.4-10, Figure 5C.4-8). Therefore, for reaches Sac1, Sac2, and Geo/DCC, the regression coefficients shown in Table 5C.4-10 are used to calculate the expected average migration rate given the input flow for the reach and the associated standard error of the regressions is used to inform a normal probability distribution that is sampled from the day smolts enter the reach to determine their migration speed throughout the reach. The minimum migration speed for each reach is set at the minimum reach-specific migration speed observed from the acoustic-tagging data (Table 5C.4-10). The flow-migration rate relationship that was used for Sac1 also was applied for the Verona reach.

Table 5C.4-10. Sample Size and Slope (β_0) and Intercept (β_1) Parameter Estimates with Associated Standard Error (in Parenthesis) for the Relationship between Migration Speed and Flow for Reaches Sac1, Sac2, and Geo/DCC

Reach	N	β_0	β_1
Sac1	452	21.34 (1.66)	-105.98 (9.31)
Sac2	294	3.25 (1.59)	-8.00 (8.46)
Geo/DCC	86	11.08 (2.99)	-33.52 (12.90)



Circles are observed migration speeds of acoustically-tagged smolts from acoustic-tagging studies from Perry (2010), solid lines are predicted mean reach survival curves, and dotted lines are 95% prediction intervals used to inform uncertainty.

Figure 5C.4-8. Reach-Specific Migration Speed (km/day) as a Function of Flow (m^3/sec) Applied in Reaches Sac1, Sac2, and Geo/DCC

No significant relationship between migration speed and flow was found for reaches Sac3 (df = 100, F = 1.13, P =0.29), Sac4 (df = 60, F = 0.33, P = 0.57), and SS (df = 28, F = 0.86, P = 0.36). Therefore, for these reaches the observed mean migration speed and associated standard deviation (Table 5C.4-9) is used to inform a normal probability distribution that is sampled from the day smolts enter the reach to determine their migration speed throughout the reach. As applied for reaches Sac1, Sac2, and Geo/DCC, the minimum migration speed for reaches Sac3, Sac4, and SS is set at the minimum reach-specific migration speed observed from the acoustic-tagging data (Table 5C.4-9).

Yolo Bypass travel time data from Sommer et al. (2005) for acoustic-tagged, fry-sized (mean size = 57 mm fork length [FL]) Chinook salmon were used to inform travel time through the Yolo Bypass in the DPM. Because the DPM models the migration and survival of smolt-sized juveniles, the range of the shortest travel times observed across all three years (1998–2000) by Sommer et al. (2005) was used to inform the bounds of a uniform distribution of travel times (range = 4–28 days), on the assumption that smolts would spend less time rearing, and would travel faster than fry. On the day smolts enter the Yolo Bypass, their travel time through the reach is calculated by sampling from this uniform distribution of travel times.

The travel time of smolts migrating through the Interior Delta in the DPM is informed by observed mean travel time (7.95 days) and associated standard deviation (6.74) from North Delta acoustic-tagging studies (Perry 2010). However, the timing of smolt passage through the Interior Delta does not affect Delta survival because there are no Delta reaches located downstream of the Interior Delta.

Fish Behavior at Junctions (Channel Splits)

Perry and coauthors (2010) found that acoustically-tagged smolts arriving at Delta junctions exhibited inconsistent movement patterns in relation to the flow being diverted. For Junction A (entry into the Yolo Bypass at Fremont Weir), the following relationships were used.

- For all Fremont Weir spills under EBC scenarios and for Fremont Weir spills greater than 6,000 cfs for ESO scenarios (i.e., flows greater than the upper limit of flows through the notch proposed under *CM2 Yolo Bypass Fisheries Enhancement*): Proportion of smolts entering Yolo Bypass = Fremont Weir spill[2] / (Fremont Weir spill + Sacramento River at Verona flows).
- For Fremont Weir spills up to 6,000 cfs for ESO scenarios (i.e., flows through the notch proposed under *CM2 Yolo Bypass Fisheries Enhancement*): Proportion of smolts entering Yolo Bypass = Fremont Weir spill / Sacramento River at Wilkins Slough flows).

As noted above in *Flow Input Data*, the flow data informing Yolo Bypass entry were obtained by disaggregating CALSIM estimates using historical daily patterns of variability because DSM2 does not provide daily flow data for these locations.

For Junction B (Sacramento River-Sutter/Steamboat Sloughs), Perry and coauthors (2010) found that smolts consistently entered downstream reaches in proportion to the flow being diverted. Therefore, smolts arriving at Junction B in the model move proportionally with flow. Similarly, with data lacking to inform the nature of the relationship, a proportional relationship between flow and fish movement for Junction D (San Joaquin River–Old River) also was applied. Note that the operation of the Head of Old River gate proposed under the BDCP is accounted for in the DSM2 flow input data (i.e., with a closed gate, relatively more flow [and therefore smolts] remains in the San Joaquin River).

For Junction C (Sacramento River–Georgiana Slough/DCC), Perry (2010) found a linear, nonproportional relationship between flow and fish movement. His relationship for Junction C was applied in the DPM:

$$y = 0.22 + 0.47x;$$

where y is the proportion of fish diverted into Geo/DCC and x is the proportion of flow diverted into Geo/DCC (Figure 5C.4-9).

In the DPM, this linear function is applied to predict the daily proportion of fish movement into Geo/DCC as a function of the proportion of flow into Geo/DCC.

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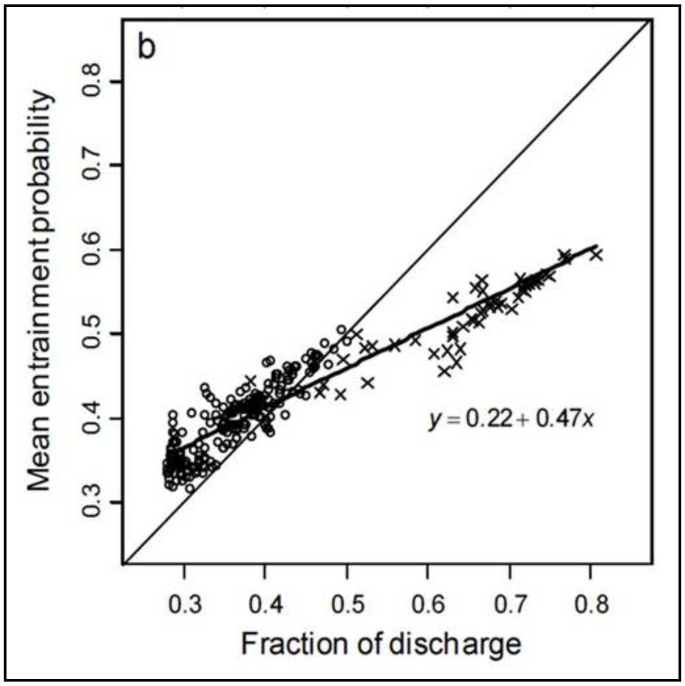
[2] As noted in Table C.4-5, Yolo Bypass flow includes spill from both Fremont Weir and Sacramento Weir. The DPM simplifies the occasional entry of fish via Sacramento Weir by adding Sacramento Weir spill to Fremont Weir spill.



Circles Depict DCC Gates Closed, Crosses Depict DCC Gates Open.

Figure 5C.4-9. Figure from Perry (2010) Depicting the Mean Entrainment Probability (Proportion of Fish Being Diverted into Reach Geo/DCC) as a Function of Fraction of Discharge (Proportion of Flow Entering Reach Geo/DCC)

Route-Specific Survival

Survival through a given route (individual reach or several reaches combined) is calculated and applied the first day smolts enter the reach. For reaches where literature showed support for reach-level responses to environmental variables, survival is influenced by flow (Sac1, Sac2, Sac3 and Sac4 combined, SS and Sac 4 combined, Interior Delta via San Joaquin River, and Interior Delta via Old River) or south Delta water exports (Interior Delta via Geo/DCC). For these reaches, daily flow or exports occurring the day of reach entry are used to predict reach survival during the entire migration period through the reach (Table 5C.4-11). For all other reaches (Geo/DCC and Yolo), reach survival is assumed to be unaffected by Delta conditions and is informed by means and standard deviations of survival from acoustic-tagging studies.

Table 5C.4-11. Route-Specific Survival and Parameters Defining Functional Relationships or Probability Distributions for Each Chinook Salmon Run and Methods Section Where Relationship is Described

Route	Chinook Salmon Run	Survival[a]	Methods Section Description
Verona	All Sacramento runs	0.931 (0.02)	This section
Sac1	All Sacramento runs	Function of flow	Flow-Dependent Survival
Sac2	All Sacramento runs	Function of flow	Flow-Dependent Survival
Sac3 and Sac4 combined	All Sacramento runs	Function of flow	Flow-Dependent Survival
Yolo	All Sacramento runs	Various	This section
Sac4 via Yolo[b]	All Sacramento runs	0.698 (0.153)	This section
SS and Sac4 combined	All Sacramento runs	Function of flow	Flow-Dependent Survival
Geo/DCC	Mokelumne fall-run	0.407 (0.209)	This section
	All Sacramento runs	0.65 (0.126)	This section
Interior Delta	All Sacramento runs	Function of exports	Export-Dependent Survival
	San Joaquin fall-run via Old River	Function of flow	Flow-Dependent Survival
	San Joaquin fall-run via San Joaquin River	Function of flow	Flow-Dependent Survival

[a] For routes where survival is uninfluenced by Delta conditions, mean survival and associated standard deviation (in parentheses) observed during acoustic-tagging studies (Michel 2010; Perry 2010) are used to define a normal probability distribution that is sampled from the day smolts enter a reach to calculate reach survival.

[b] Although flow influences survival of fish migrating through the combined routes of SS–Sac4 and Sac3–Sac4, flow does not influence Sac4 survival for fish arriving from Yolo.

For reaches Geo/DCC, Yolo, and Sac4 via Yolo, no empirical data were available to support a relationship between survival and Delta flow conditions (channel flow, exports). Therefore, for these reaches mean reach survival is used along with reach-specific standard deviation to define a normal probability distribution that is sampled from when smolts enter the reach to determine reach survival (Table 5C.4-11).

Mean reach survival and associated standard deviation for Geo/DCC are informed by survival data from smolt acoustic-tagging studies from Perry (2010). Separate acoustic-study survival data are applied for smolts migrating through Geo/DCC via the Sacramento River (Sacramento River runs) or Mokelumne River (Mokelumne River fall-run) (Table 5C.4-12). Smolts migrating down the Sacramento River during the acoustic-tagging studies could enter the DCC or Georgiana Slough when the DCC was open (December releases), therefore, group survivals for both routes are used to inform the mean survival and associated standard deviation for the Geo/DCC reach for Sacramento River runs. For Mokelumne River fall-run, only the DCC route group survivals are used to inform Geo/DCC survival because Mokelumne River fish are not exposed to Georgiana Slough.

Smolt survival data for the Yolo Bypass were obtained from the UC Davis Biotelemetry Laboratory (M. Rowlands pers. comm.). These data included survival estimates for five reaches from release near the head of the bypass to the base of the bypass. The means (and standard errors) of these estimates defined normal probability distributions from which daily value for the DPM were drawn, and were as follows: reach 1 (release site): 1.00; reach 2 (release site to I-80): 0.96 (SE = 0.059); reach 3 (I-80 to screw trap): 0.96 (0.064); reach 4 (screw trap to base of Toe Drain): 0.94 (0.107); reach 5 (base of Toe Drain to base of Bypass): 0.88 (0.064). Fish leaving the Yolo reach in the model then entered Sac4 and were subject to survival at the rate shown in Table 5C.4-11.

Mean survival and associated standard deviation for the Verona reach between Fremont Weir and Yolo Bypass were derived from the 2007–2009 acoustic-tag study reported by Michel (2010), who did not find a flow-survival relationship for that reach.

Table 5C.4-12. Individual Release-Group Survival Estimates, Release Dates, Data Sources, and Associated Calculations Used to Inform Reach-Specific Mean Survivals and Standard Deviations Used in the Delta Passage Model for Reaches Where Survival Is Uninfluenced by Delta Conditions

DPM Reach	Survival	Release Dates	Survival Calculation	Mean	Standard Deviation
Geo/DCC via Mokelumne River	0.648	12/05/06	$S_{C1}*S_{C2}$	0.407	0.209
	0.286	12/04/07–12/06/07	S_{C1}		
	0.286	11/31/08–12/06/08	S_{C1}		
Geo/DCC via Sacramento River	0.648	12/05/06	S_{D1}	0.559	0.194
	0.600	12/04/07–12/06/07	$S_{D1,SAC}*S_{D2}$		
	0.762	1/15/08–1/17/08	$S_{D1,SAC}*S_{D2}$		
	0.774	11/31/08–12/06/08	$S_{D1,SAC}*S_{D2}$		
	0.467	1/13/08–1/19/09	$S_{D1,SAC}*S_{D2}$		
	0.648	12/05/06	$S_{C1}* S_{C2}$		
	0.286	12/04/07–12/06/07	S_{C1}		
	0.286	11/31/08–12/06/08	S_{C1}		
Sac4 via Yolo	0.714	12/5/2006	$S_{A6}*S_{A7}$	0.698	0.153
	0.858	1/17/2007	$S_{A6}*S_{A7}$		
	0.548	12/4/07-12/6/07	$S_{A7}*S_{A8}$		
	0.488	1/15/08-1/17/08	$S_{A7}*S_{A8}$		
	0.731	11/31/08-12/06/08	$S_{A7}*S_{A8}$		
	0.851	1/13/09-1/19/09	$S_{A7}*S_{A8}$		

Source: Perry 2010.

Flow-Dependent Survival

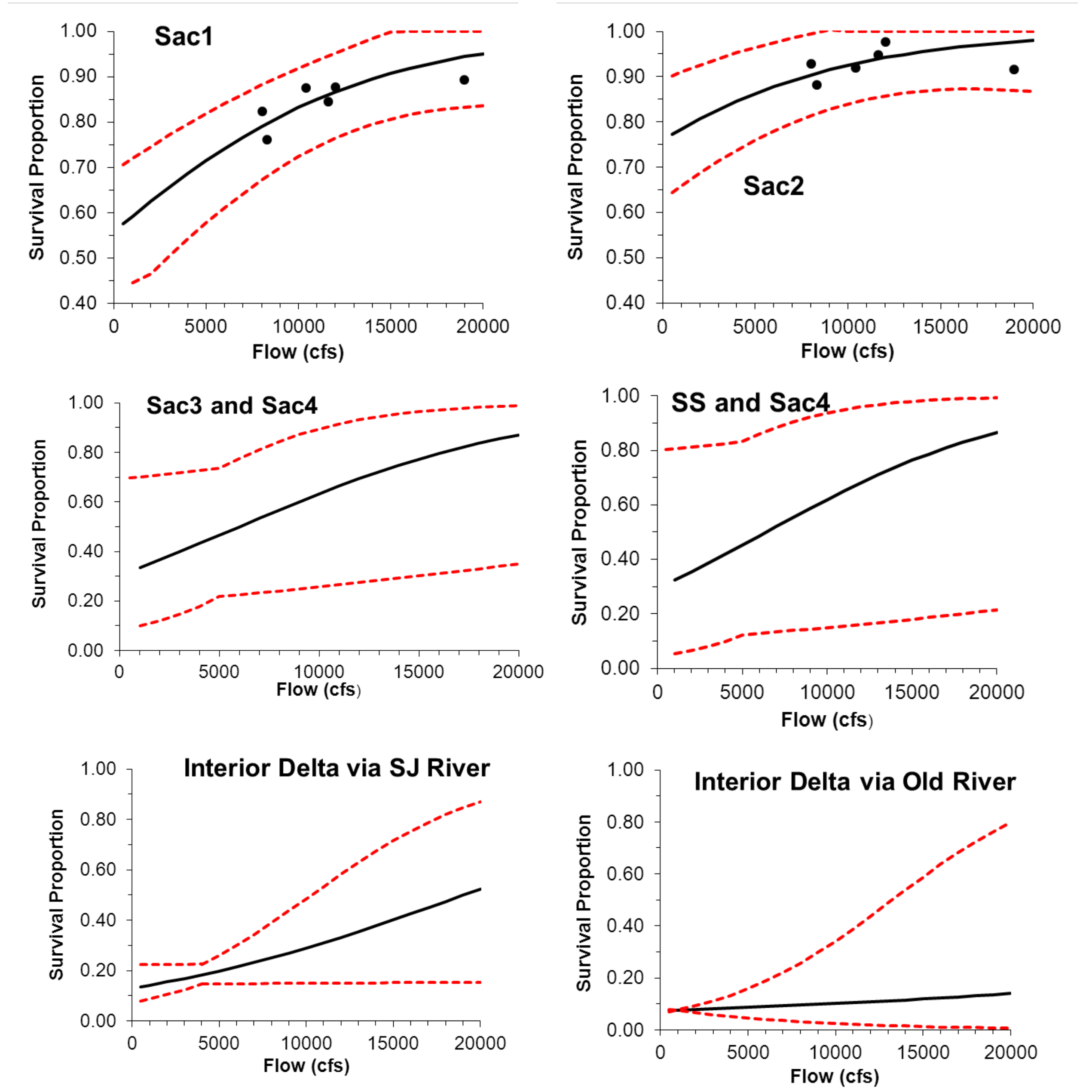
For reaches Sac1, Sac2, Sac3 and Sac4 combined, SS and Sac4 combined, Interior Delta via San Joaquin River, and Interior Delta via Old River, flow values on the day of route entry are used to predict route survival (Figure 5C.4-10). Perry (2010) evaluated the relationship between survival among acoustically-tagged Sacramento River smolts and Sacramento River flow measured below Georgiana Slough (DPM reach Sac3) and found a significant relationship between survival and flow during the migration period for smolts that migrated through Sutter and Steamboat Sloughs to Chipps Island (Sutter and Steamboat route; SS and Sac4 combined) and smolts that migrated from the junction with Georgiana Slough to Chipps Island (Sacramento River route; Sac3 and Sac4 combined). Therefore, for route Sac3 and Sac4 combined and route SS and Sac4 combined, the logit survival function from Perry (2010) was used to predict mean reach survival (S) from reach flow ($flow$):

$$S = \frac{e^{(\beta_0 + \beta_1 flow)}}{1 + e^{(\beta_0 + \beta_1 flow)}}$$

where β_0 (SS and Sac4 = -0.175, Sac3 and Sac4 = -0.121) is the reach coefficient and β_1 (0.26) is the flow coefficient, and $flow$ is average Sacramento River flow in reach Sac3 during the experiment standardized to a mean of 0 and standard deviation of 1.

Perry (2010) estimated the global flow coefficient for the Sutter Steamboat route and Sacramento River route as 0.52. For the Sac3 and Sac4 combined route and the SS and Sac4 combined route, mean survival and associated standard error predicted from each flow-survival relationship is used to inform a normal probability distribution that is sampled from the day smolts enter the route to determine their route survival.

With a flow-survival relationship appearing evident for group survival data of acoustically-tagged smolts in reaches Sac1 and Sac2, Perry's (2010) relationship was applied to Sac1 and Sac2 while adjusting for the mean reach-specific survivals for Sac1 and Sac2 observed during the acoustic-tagging studies (Figure 5C.4-10; Table 5C.4-13). The flow coefficient was held constant at 0.52 and the residual sum of squares of the logit model was minimized about the observed Sac1 and Sac2 group survivals, respectively, while varying the reach coefficient. The resulting reach coefficients for Sac1 and Sac2 were 1.27 and 2.16, respectively. Mean survival and associated standard error predicted from the flow-survival relationship is used to inform a normal probability distribution that is sampled from the day smolts enter the reach to determining Sac1 and Sac2 reach survival.



For Sac1, Sac2, Sac3, and Sac4, circles are observed group survivals from acoustic-tagging studies from Perry (2010). Raw data are not available from Newman (2010) for Interior Delta via San Joaquin River and Interior Delta via Old River from Newman (2010). Solid lines are predicted mean route survival curves, and dotted lines are 95% confidence bands used to inform uncertainty.

Figure 5C.4-10. Route Survival as a Function of Flow Applied in Reaches Sac1, Sac2, Sac3 and Sac4 combined, SS and Sac4 combined, Interior Delta via the San Joaquin River, and Interior Delta via Old River

Table 5C.4-13. Group Survival Estimates of Acoustically-Tagged Chinook Salmon Smolts from Perry (2010) and Associated Calculations Used to Inform Flow-Dependent Survival Relationships for Reaches Sac1 and Sac2

DPM Reach	Survival	Release Dates	Source	Survival Calculation
Sac1	0.844	12/5/06	Perry 2010	$S_{A1}*S_{A2}$
Sac1	0.876	1/17/07	Perry 2010	$S_{A1}*S_{A2}$
Sac1	0.874	12/4/07-12/6/07	Perry 2010	$S_{A1}*S_{A2}$
Sac1	0.892	1/15/08-1/17/08	Perry 2010	$S_{A1}*S_{A2}$
Sac1	0.822	11/31/08-12/06/08	Perry 2010	$S_{A1}*S_{A2}$
Sac1	0.760	1/13/09-1/19/09	Perry 2010	$S_{A1}*S_{A2}$
Sac2	0.947	12/5/06	Perry 2010	S_{A3}
Sac2	0.976	1/17/07	Perry 2010	S_{A3}
Sac2	0.919	12/4/07-12/6/07	Perry 2010	S_{A3}
Sac2	0.915	1/15/08-1/17/08	Perry 2010	S_{A3}
Sac2	0.928	11/31/08-12/06/08	Perry 2010	S_{A3}
Sac2	0.881	1/13/09-1/19/09	Perry 2010	S_{A3}

For smolts originating in the San Joaquin River that migrate through the Interior Delta via San Joaquin River or Old River, survival is modeled as a function of flow and exports as modeled by Newman (2010).

$$S_{SJ,OR} = \frac{e^{(\beta_0+\beta_1 flow+\beta_2 \exp orts)}}{1+e^{(\beta_0+\beta_1 flow+\beta_2 \exp orts)}}$$

> Where $S_{SJ,\,OR}$ is survival through the Interior Delta via the San Joaquin River or Old River, *flow* is average San Joaquin River flow downstream of the head of Old River or flow in Old River during the coded-wire tagging study standardized to a mean of 0 and standard deviation of 1, and *exports* is the combined export flow from the state and federal facilities in the south Delta during the study.

Exports are standardized as described for flow. Uncertainty in these parameters is accounted for by using model-averaged estimates for the intercept, flow coefficient and export coefficient (Table 5C.4-14; Figure 5C.4-10). The model-averaged estimates and their standard deviations are used to define a normal probability distribution that is resampled each day in the model. San Joaquin River flows downstream of the head of Old River that were modeled by Newman (2010) ranged from -49 cfs to 10,756 cfs, with a median of 3,180 cfs. Exports modeled by Newman (2010) ranged from 805 cfs to 10,295 cfs, with a median of 2,238 cfs.

Table 5C.4-14. Model Averaged Parameter Estimates and Standard Deviations Used to Describe Survival through the Interior Delta via the San Joaquin River and Old River Routes

Parameter	San Joaquin Route	Old River Route
Intercept	-1.577 (0.275)	-2.297 (0.537)
Flow	0.376 (0.289)	0.166 (0.524)
Exports	0.291 (0.290)	0.279 (0.363)

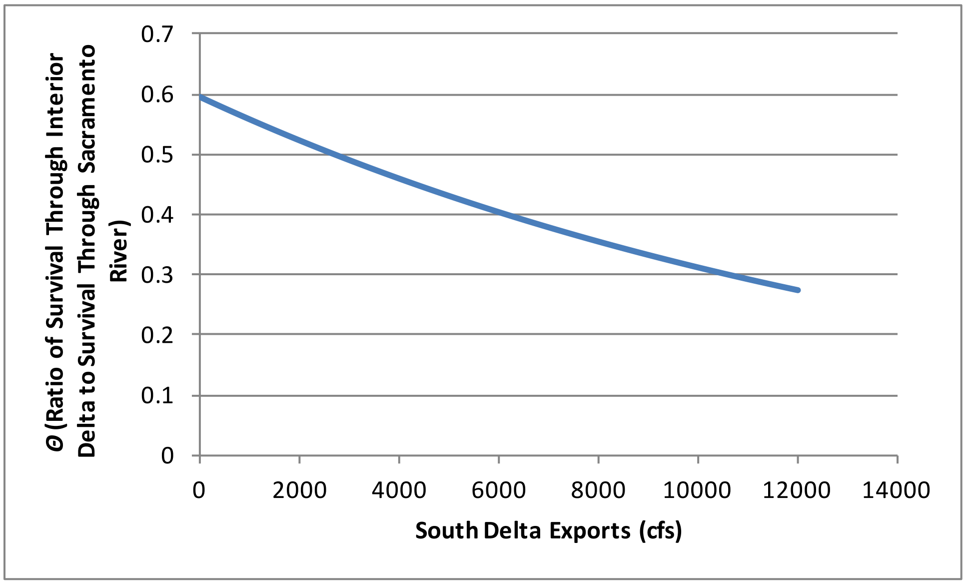
Export-Dependent Survival

As migratory juvenile salmon enter the Interior Delta from Geo/DCC for Sacramento races or Mokelumne River fall-run Chinook salmon, they transition to an area strongly influenced by tides and where south Delta water exports may influence survival. The export–survival relationship described by Newman and Brandes (2010) was applied as follows:

$$\theta = 0.5948 * e^{(-0.000065*Total\_Exports)};$$

where θ is the ratio of survival between coded wire tagged smolts released into Georgiana Slough and smolts released into the Sacramento River and Total_Exports is the flow of water (cfs) pumped from the Delta from the State and Federal facilities.

θ is a ratio and ranges from just under 0.6 at zero south Delta exports to ~0.27 at 12,000-cfs south Delta exports (Figure 5C.4-11).



Source: Newman and Brandes 2010

Figure 5C.4-11. Relationship between θ (Ratio of Survival through the Interior Delta to Survival through Sacramento River) and South Delta Export Flows

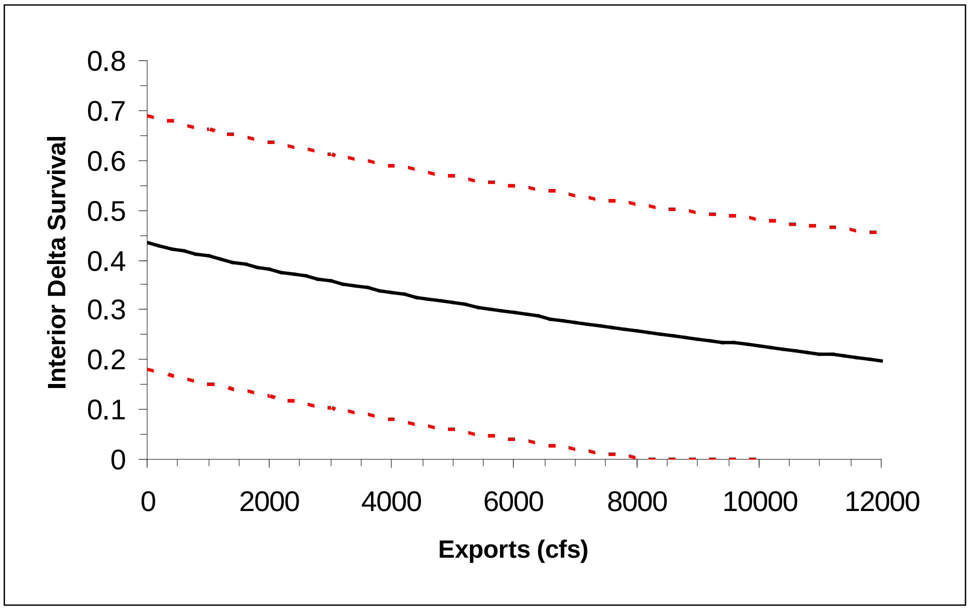
θ was converted from a ratio into a value of survival through the Interior Delta using the equation:

$$S_{ID} = \frac{\theta}{S_{Geo/DCC}} * (S_{Sac3} * S_{Sac4});$$

where S_{ID} is survival through the Interior Delta, θ is the ratio of survival between Georgiana Slough and Sacramento River smolt releases, $S_{Geo/DCC}$ is the survival of smolts in the Georgiana Slough/Delta Cross Channel reach, $S_{Sac3} * S_{Sac4}$ is the combined survival in reaches Sac 3 and Sac 4 (Figure 5C.4-12)[3].

Uncertainty is represented in this relationship by using the estimated value of θ and the standard error of the equation to define a normal distribution bounded by the 95% prediction interval of the model that is then re-sampled each day to determine the value of θ.

The export-dependent survival relationship for San Joaquin-origin fish was described above in the section on *Flow-Dependent Survival*.



Survival values in reaches Sac3, Sac4, and Geo/DCC were held at mean values observed during acoustic-tag studies (Perry 2010) to depict export effect on Interior Delta survival in this plot. Dashed lines are 95% prediction bands used to inform uncertainty in the relationship.

Figure 5C.4-12. Interior Delta Survival as a Function of Delta Exports (Newman and Brandes 2010) as Applied for Sacramento Races of Chinook Salmon Smolts Migrating through the Interior Delta via Reach Geo/DCC

5C.4.1.1.2 Postprocessing of Model Outputs for BDCP Effects Analysis

Pathway-Specific Migration and Survival

To facilitate the interpretation of overall DPM survival results in the BDCP effects analysis, summaries of the percentage of smolts taking different migration pathways and the percentage survival down those pathways was calculated for each scenario in each water year (1976–1991)

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[3] Note that the Mokelumne River fall-run does not occur in the Sacramento River but daily survival values in Sac3/Sac4 are calculated in order to inform interior Delta survival for this run according to the equation above; the Sac3/Sac4 daily survival values for this run are used solely for this purpose. Although daily survivals in Sac3/Sac4 are used to calculate Sacramento River survival for Sacramento River runs (winter-run, spring-run, Sacramento fall-run, and late fall–run), the combined Sac3/Sac4 survival used to calculate Sacramento River survival would be slightly different than that used to calculate interior Delta survival because of the travel time required for smolts to reach the interior Delta via Geo/DCC.

using the average proportion of smolts surviving in each reach and the average proportion of fish entering the various junctions. For the Sacramento River-origin smolts there are four migration pathways represented in the DPM:

- Chipps Island via Yolo Bypass (Yolo → Sac4)
    - Percentage of smolts taking Yolo pathway = Proportion entering Yolo Bypass at Fremont Weir * 100%
    - Percentage survival down Yolo pathway = (Survival in Yolo) * (survival in Sac4) * 100%
- Chipps Island via mainstem Sacramento River (Verona → Sac1 → Sac2 → Sac3 → Sac4)
    - Percentage of smolts taking mainstem Sacramento River pathway = (1 - proportion entering Yolo Bypass)*(1 - proportion entering Sutter or Steamboat Sloughs)*(1 - proportion entering Georgiana Slough or Delta Cross Channel)*100%
    - Percentage survival of smolts down mainstem Sacramento River pathway = (Survival in Verona)*(Survival in Sac1)*(Survival in Sac2)*(Survival in combined Sac3 & Sac4)*100%
- Chipps Island via Sutter & Steamboat Sloughs (Verona → Sac1 → SS → Sac4)
    - Percentage of smolts taking Sutter & Steamboat Sloughs pathway = (1 - proportion entering Yolo Bypass)*(Proportion entering Sutter or Steamboat Sloughs)*100%
    - Percentage survival of smolts down Sutter & Steamboat Sloughs pathway = (Survival in Verona)*(Survival in Sac1)*(Survival in combined SS and Sac4)* 100%
- Chipps Island via Georgiana Slough & Delta Cross Channel pathway (Verona → Sac1 → Sac2 → Geo/DCC → Interior Delta)
    - Percentage of smolts taking Georgiana Slough & Delta Cross Channel pathway = (1 - proportion entering Yolo Bypass)*(1 - proportion entering Sutter or Steamboat Sloughs)*(Proportion entering Georgiana Slough & Delta Cross Channel)*100%
    - Percentage survival of smolts down Georgiana Slough & Delta Cross Channel pathway = (Survival in Verona)*(Survival in Sac1)*(Survival in Sac2)*(Survival in Geo/DCC)*(Survival in Interior Delta)*100%

For the San Joaquin River-origin smolts the DPM has two migration pathways to Chipps Island through the Interior Delta, i.e., via the San Joaquin River and via Old River. The division of smolts into the two migration pathways was based on the junction split at the Head of Old River discussed above in *Fish Behavior at Junctions (Channel Splits)* and the calculation of survival of smolts down each pathway was based on outputs derived from the model coefficients in Table 5C.4-14 of the *Flow-Dependent Survival* section above. Mokelumne River smolts have only one possible migration pathway to Chipps Island in the DPM (Geo/DCC → Interior Delta), so only survival in each of the two reaches along their pathway was reported along with overall survival.

Hypothesized Effects of Nonphysical Barriers and Predation at the North Delta Intakes

Two additional analyses were conducted for Sacramento River-origin smolts to inform other potential effects of the BDCP on through-Delta survival. These analyses were conducted for the ESO scenarios and were compared to the results from the EBC scenarios and the results from the ESO scenarios using the ‘default’ model structure described above.

CM21 Nonphysical Fish Barriers proposes to install and test nonphysical fish barriers to deter downstream migrating juvenile salmonids away from migration pathways with relatively poor survival. The implementation of a physical barrier (operable gate) at the Head of Old River under *CM1 Water Facilities and Operation* leaves the Sacramento River-Georgiana Slough channel split as the main location that a nonphysical barrier would seem most appropriate. The potential effect of the implementation of a nonphysical barrier at the Sacramento River-Georgiana Slough channel split under the ESO scenarios was assessed by multiplying the average proportion of Sacramento River-origin smolts entering Geo/DCC by 0.33, i.e., it was assumed that a nonphysical barrier would deter two-thirds of fish from entering Georgiana Slough[4]. This value was based on the first year (2011) of testing a combined acoustic, bubble, and strobe light nonphysical barrier at the Sacramento River River-Georgiana Slough channel split (California Department of Water Resources 2012). This study found that an average of 22.1% of acoustically-tagged smolts approaching the Sacramento River-Georgiana Slough channel split entered Georgiana Slough with the nonphysical barrier turned off and 7.4% of smolts entered Georgiana Slough with the nonphysical barrier turned on. The results of subsequent 2012 nonphysical barrier deterrence testing at the same location were not yet available for inclusion in this effects analysis.

An example of the postprocessing undertaken for the assessment of nonphysical barriers is provided here for fall-run Chinook salmon smolts under the ESO_ELT in 1984. In that year, the DPM estimated that 2.4% of smolts took the Yolo Bypass pathway and had survival 46.8%; 42.3% of smolts took the mainstem Sacramento River pathway and had survival of 20.4%; 27.9% of smolts took the Sutter-Steamboat pathway and had survival of 23.5%; and 27.3% of smolts took the interior Delta pathway and had survival of 10.1%. The overall survival for all pathways is therefore the average pathway-specific survival weighted by the percentage of fish taking each pathway, in this case 19.1% (calculated when using unrounded data). Under the assumption that 67% of smolts that would have otherwise entered Georgiana Slough were deterred from entering the interior Delta by a nonphysical barrier at the mouth of Georgiana Slough, only 9% of smolts would take the Interior Delta pathway (and have the same survival, 10.1%, as before) and 60.6% of smolts would therefore take the mainstem Sacramento River pathway (and also have the same survival as before, i.e., 20.4%); there would be no difference in the percentage of smolts taking the Yolo Bypass or Sutter-Steamboat pathways or their survival. The overall survival for all pathways in this case is 21.0%, which again is the average pathway-specific survival weighted by the percentage of smolts taking each pathway.

There are concerns that the construction of three 3,000-cfs water intakes in the north Delta under *CM1 Water Facilities and Operation* has the potential to increase predation on downstream migrating juvenile salmonids. Based primarily on the study of the Glenn-Colusa Irrigation District Vogel (2008, described more fully in Appendix 5.F, *Biological Stressors on Covered Fish*, Section 5F.3.2.2), the BDCP Biological Goals and Objectives (see Section 3.3 of Chapter 3, *Conservation Strategy*) include a target survival within the reach containing the north Delta intakes of no less than 0.95 of the baseline survival, with the baseline to be established through monitoring and focused studies during the near-term implementation period of the BDCP. The potential effect of lower survival in the reach containing the north Delta intakes was assessed by multiplying average

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[4] The primary salmonid smolt outmigration season includes the December-June period during which the Delta Cross Channel would be closed as part of *CM1 Water Facilities and Operation*. For runs with outmigration periods overlapping periods of DCC opening, e.g., late fall–run Chinook salmon, the multiplier of 0.33 for the Geo/DCC effectively means that nonphysical barriers would be applied to the divergence with the DCC as well as Georgiana Slough.

annual survival in reach Sac1 by 0.95 for the ESO scenarios and recomputing the overall through-Delta survival.

There are a number of other proposed BDCP conservation measures that may influence reach-specific survival of Chinook salmon smolts, e.g., *CM4 Tidal Natural Communities Restoratio*n, *CM5 Seasonally Inundated Floodplain Restoration*, and *CM6 Channel Margin Enhancement*, among others. It was felt, however, that there were not sufficient published data to inform potential modifying values for survival in specific reaches under these conservation measures. As more research into these types of actions and the effects they have on Chinook salmon smolts becomes available, there will be greater potential to attempt to quantify potential changes in survival that may occur under these actions and/or adjust the BDCP through adapative management to meet the biological goals and objectives.

5C.4.3.2.3 Juvenile Spring-Run and Fall-Run Chinook Salmon Smolt Through-Delta Survival (Newman 2003)

Introduction

The Delta Passage Model (DPM), described above, employs a detailed reach-specific examination of through-Delta survival. Agency comments on earlier drafts of the effects analysis have noted that further development of the DPM will occur as more data to inform the model become available. It has also been noted that various aspects of the DPM such as reach-specific smolt survival are based on acoustic-tag results on larger smolts (i.e., hatchery-reared late fall–run Chinook salmon) that occurred in a relatively small number of years. As a supplement to the through-Delta Chinook smolt survival analysis provided by the DPM, another examination of through-Delta smolt survival was conducted based on the work of Newman (2003).

Newman (2003) investigated through-Delta Chinook salmon survival of hatchery-origin coded-wire tagged fall-run Chinook salmon smolts released between 1979 and 1994 as a function of various biological and environmental variables using Bayesian hierarchical nonlinear modeling, as well as two additional model formulations. The coefficients of the Bayesian hierarchical modeling were used for the BDCP effects analysis because Newman (2003:176) noted that this approach yielded a similar predictive ability to a pseudo-likelihood approach but the “hierarchical model was considerably more stable, however, and the signs of the coefficients were more sensible given the nature of the physical and biological process involved in survival and capture.”

A through-Delta Chinook smolt survival model based on Newman (2003) was applied in this effects analysis to fall-run and spring-run Chinook salmon because the studies upon which the model is based were conducted during the spring migration period of these two runs and do not overlap the main migration periods of winter-run and late fall–run Chinook salmon.

Model Structure and Covariates

The basic model of through-Delta survival developed by Newman (2003) is the logit (probability) of survival in relation to a number of covariates:

$$Survival = \frac{e^{x'\beta}}{1 + e^{x'\beta}}$$

Where $x'\beta = \beta_0 + \beta_1$Sacramento + β_2Courtland + β_3Size + β_4Log Flow + β_5Salinity + β_6Release Temperature + β_7Hatchery Temperature + β_8Tide + β_9Exports + β_{10}Gate + β_{11}Turbidity

The definitions of these covariates, their coefficients, their ranges in the modeling conducted by Newman (2003) and their ranges in the current effects analysis, and other relevant details are summarized in Table 5C.4-15. Note that the analysis conducted for the current effects analysis was based on a deterministic implementation using the coefficients from Newman's (2003) Bayesian hierarchical modeling (Table 5C.4-15); standard errors are provided in Table 5C.4-15 to provide an indication of the likely statistical significance of each covariate (e.g., based on the ratio of the coefficient to its standard error being greater than about 2). Newman (2003) standardized continuous (nonindicator) covariates to zero mean and unit standard deviation in order to facilitate comparison between covariates in terms of the magnitudes of coefficients. This illustrates that log flow and release temperature had by far the greatest correlation with through-Delta survival, with lesser effects for turbidity, south Delta exports, salinity, and smolt size (Table 5C.4-15). Hatchery temperature and tide had little to no correlation with survival and were not included in the modeling for this effects analysis. The effect on estimated survival of varying each covariate over the range of data modeled by Newman (2003) while holding other standardized covariates constant emphasizes the relative difference in coefficients of each covariate (Figure 5C.4-13): for example, survival would be estimated to vary from 0.18 from the lowest flow to 0.93 at the highest flow (holding other covariates at mean values and assuming DCC is closed and fish were released from Sacramento), whereas across the range of released fish sizes survival would be estimated to vary from 0.41at the smallest size to 0.66 at the largest size. Of direct relevance to the BDCP effects analysis is the estimated survival effect of changes in Sacramento River flow and south Delta exports because of the implementation of dual conveyance with the construction of the proposed north Delta intakes. Application of Newman's (2003) coefficients while holding other covariates constant at mean values, assuming DCC is closed, and fish were released at Sacramento, then back-transforming the standardized flow and exports covariates to their original units of measurement gives the following rates of change in survival.

- For south Delta exports (modeled range = ~1,300–8,600 cfs), a change in through-Delta survival of 0.01 (i.e., 1% of the migrating juveniles) would occur per ~280-cfs change in south Delta exports.
- For Sacramento River flow of ~6,000–14,700 cfs, a change in through-Delta survival of 0.01 would occur per ~240-cfs change in river flow.
- For Sacramento River flow of ~14,700–28,000 cfs, a change in through-Delta survival of 0.01 would occur per ~520-cfs change in river flow.
- For Sacramento River flow of ~28,000–51,000 cfs, a change in through-Delta survival of 0.01 would occur per ~3,000-cfs change in river flow.

Chinook salmon smolt survival was calculated on a daily basis under the assumption that smolts were 80-mm fork length (i.e., close to the mean of the data used by Newman [2003]) and took 10 days to migrate through Delta (Brandes pers. comm.). Covariates used to estimate survival that required computations over the 10-day outmigration period (i.e., Log flow, salinity, exports, gate, and turbidity) were based on values for a given day and the following nine days. Daily survival was multiplied by the assumed proportion of the fall-run and spring-run Chinook salmon smolt populations entering the Delta on each day, which was the same distribution developed from Sacramento trawl data for the DPM (Figure 5C.4-15). For each Chinook salmon run, daily survival multiplied by the proportion of fish entering the Delta on that day was summed for each water year in order to facilitate comparisons between scenarios (EBC1, EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, and ESO_LLT) over the water years 1976–1991 DSM2 simulation period.

As noted in Table 5C.4-15, log flow covariate data were based on DSM2-HYDRO modeling for the Sacramento River above Sutter and Steamboat Sloughs (downstream of the north Delta intakes) in order to account for the potential effects of the ESO on flow-related survival because of the proposed north Delta diversions. Flow at this location is quite similar to flow at Freeport with no north Delta diversions (Figure 5C.4-16), suggesting that this is a reasonable proxy for Sacramento River flows at Freeport for EBC scenarios.

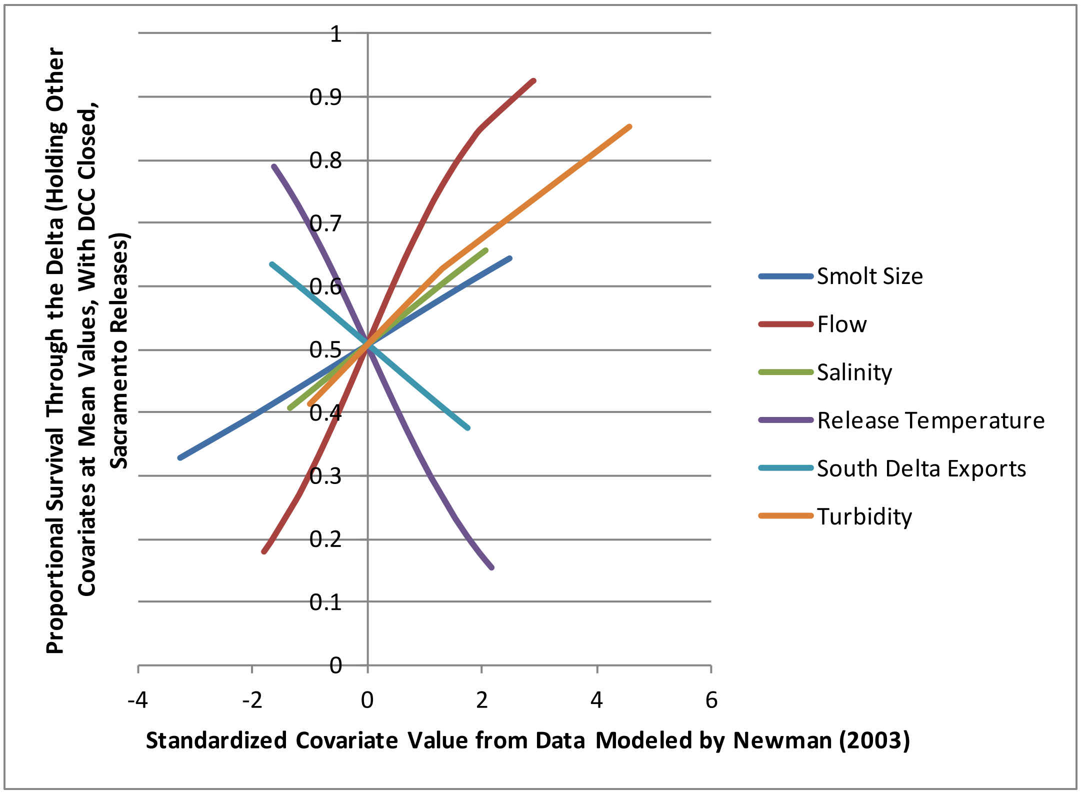
No turbidity modeling data were available for input into the through-Delta survival calculations. Turbidity covariate data were estimated from a regression of river flow—again, based on Sacramento River above Sutter and Steamboat Sloughs (downstream of the north Delta intakes)—against turbidity from Newman's (2003) original modeling data (Figure 5C.4-17) based on two alternative hypotheses. Firstly, it was hypothesized that turbidity would change in relation to precipitation events and therefore would not vary between EBC and ESO scenarios within the same time period (but may differ across time periods—near term, early long-term, late long-term—because of climate change assumptions). Accordingly, turbidity for each day of the year—which also included the subsequent nine days of the assumed outmigration period—was calculated based on river flows for EBC2 (applied to EBC1 and EBC2 scenarios), EBC2_ELT (applied to EBC2_ELT and ESO_ELT scenarios) and EBC2_LLT (applied to EBC2_LLT and ESO_LLT scenarios). It is acknowledged that the north Delta intakes may remove sediment (see Attachment 5C.D, *Water Clairty—Suspended Sediment Concentration and Turbidity*) but the first hypothesis essentially assumes that suspended sediment *concentration* is a function of upstream sediment inputs and therefore turbidity during the Chinook salmon smolt outmigration would not differ between EBC and ESO scenarios because the meteorological drivers of storm events would not differ between scenarios. A second hypothesis, which essentially functioned as a sensitivity analysis of the turbidity covariate, was that the north Delta intakes may affect suspended sediment concentration, for example by slowing river velocity and increasing sediment settlement. For this hypothesis, turbidity covariate data for the ESO_ELT and ESO_LLT scenarios were estimated separately from data for the EBC scenarios, again using flow data for Sacramento River above Sutter and Steamboat Sloughs (downstream of the north Delta intakes). The main through-Delta survival results for spring-run and fall-run Chinook salmon based on Newman's (2003) modeling focus on results using turbidity covariate values from the first hypothesis, with results from the second hypothesis compared to the results for the first hypothesis for the ESO scenarios.

Table 5C.4-15. Covariates and other Model Terms Used in Through Delta-Survival Modeling of Fall-Run and Spring-Run Chinook Salmon Smolts Based on Newman (2003)

				Summary of Covariate Data for BDCP Effects Analysis					
					Modeled Mean and Range; % of Days Within Original Modeled Range (EBC scenarios)		Modeled Mean and Range; % of Days Within Original Modeled Range (ESO scenarios)		
Covariate or Model Term	**Definition**	**Coefficient (Subscript = Standard Error)**	**Modeled Mean and Range (Newman 2003)**	**Source of Data (Details)**	**Spring-Run Chinook Salmon**	**Fall-Run Chinook Salmon**	**Spring-Run Chinook Salmon**	**Fall-Run Chinook Salmon**	**Comments**
Intercept	Intercept	β_0: $0.59_{0.10}$	–	–	–	–	–	–	
Sacramento	Indicator of release at Sacramento (Yes = 1, No = 0)	β_1: $-0.56_{0.16}$	–	–	–	–	–	–	All smolts assumed to be released at Sacramento
Courtland	Indicator of release at Courtland (Yes = 1, No = 0)	β_2: $-0.02_{0.17}$	–	–	–	–	–	–	No smolts assumed to be released at Courtland
Size	Average fork length (mm) of smolts release group	β_3: $0.23_{0.06}$	80.92 mm (61–96 mm)	Newman (2003) (Close to mean value)	–	–	–	–	All smolts assumed to be 80 mm
Log flow	Log-transformed median Freeport flow (cfs) during outmigration	β_4: $0.86_{0.12}$	9.53 (8.71–10.84); 15,379 cfs (6,085–50,800 cfs) when untransformed	DSM2-HYDRO (Sacramento River Upstream of Sutter and Steamboat Slough [downstream of North Delta Diversion], i.e., output location 418_mid)	9.77 (8.36–11.32); 17,435 cfs (4,289–82,317 cfs) when untransformed; 81%	9.60 (8.36–11.32); 14,734 cfs (4,289–82,317 cfs) when untransformed; 89%	9.59 (8.36–11.24); 14,647 cfs (4,286–75,783 cfs) when untransformed; 85%	9.43 (8.36–11.23); 12,449 cfs (4,286–75,206 cfs) when untransformed; 92%	Used data for Sacramento River below proposed north Delta intakes to assess ESO flow effect on survival

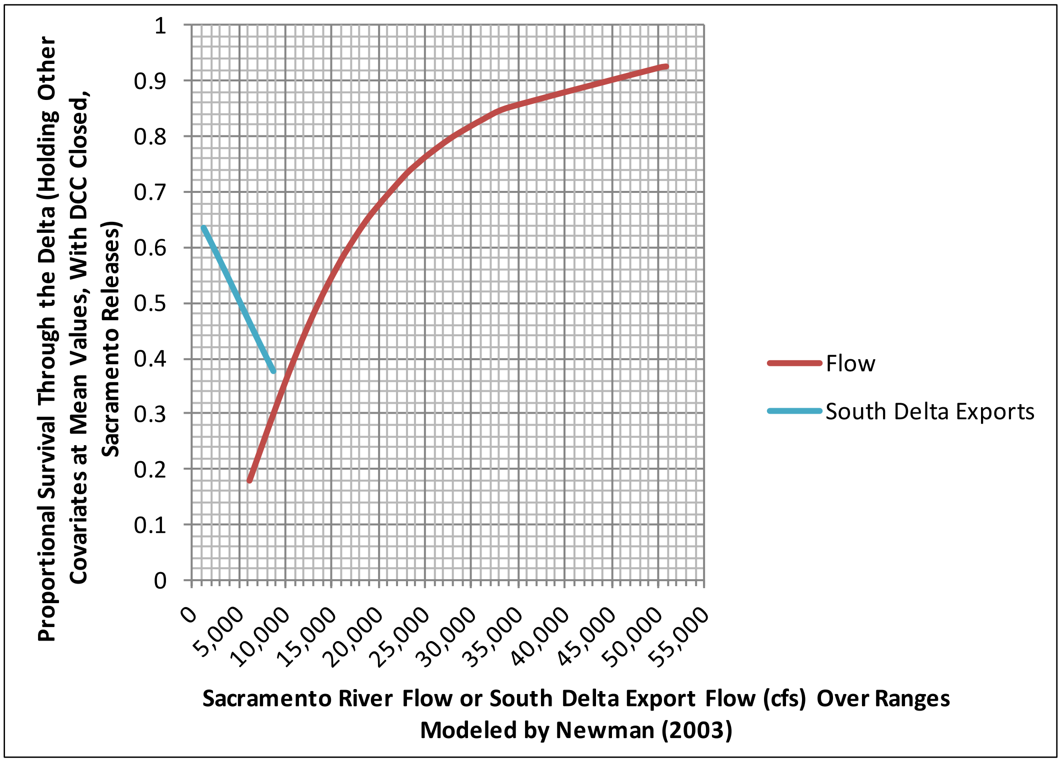
				Summary of Covariate Data for BDCP Effects Analysis					
					Modeled Mean and Range; % of Days Within Original Modeled Range (EBC scenarios)		Modeled Mean and Range; % of Days Within Original Modeled Range (ESO scenarios)		
Covariate or Model Term	**Definition**	**Coefficient (Subscript = Standard Error)**	**Modeled Mean and Range (Newman 2003)**	**Source of Data (Details)**	**Spring-Run Chinook Salmon**	**Fall-Run Chinook Salmon**	**Spring-Run Chinook Salmon**	**Fall-Run Chinook Salmon**	**Comments**
Salinity	Median conductivity (μ mho/cm) at Collinsville during outmigration	β_5: $0.30_{0.09}$	5,219.79 μ mho/cm (160-12,873 μ mho/cm)	DSM2-QUAL (Collinsville, RSAC081)	1,395.82 μmho/cm (179–9,659 μmho/cm); 100%	2,018.41 μmho/cm (179–9,659 μmho/cm); 100%	1,561.60 μmho/cm (178–10,322 μmho/cm); 100%	2,206.31 μmho/cm (178–10,324 μmho/cm); 100%	–
Release Temperature	River water temperature on day of release (°F)	β_6: $-0.80_{0.09}$	65.71°F (58–76°F)	DSM2-QUAL (Freeport, RSAC155)	58.44°F (42–78°F); 46%	62.22°F (49–78°F); 71%	59.11°F (43–78°F); 54%	62.97°F (49–79°F); 79%	–
Hatchery Temperature	Hatchery water temperature on day of release (°F)	β_7: $0.00_{0.09}$	54.55°F (49–60°F)	–	–	–	–	–	Not included in analysis because of little evidence of effect and lack of modeling data
Tide	Magnitude of change in low-low and high-low tides and whether Delta was filling/draining	β_8: $-0.04_{0.06}$	1.59 (0–2.7)	–	–	–	–	–	Not included in analysis because of little evidence of effect and lack of modeling data
Exports	Median rate of south Delta exports (cfs) during outmigration period	β_9: $-0.31_{0.10}$	4,888.23 cfs (1,289–8,621 cfs)	DSM2-HYDRO (Sum of Clifton Court and absolute value of Delta Mendota Canal flows)	3,890.36 cfs (800–13,218 cfs); 73%	3,772.34 cfs (20.7–12,118 cfs); 76%	1,936.82 cfs (0–6,397 cfs); 64%	2,022.55 cfs (0–14,364 cfs); 65%	–

				Summary of Covariate Data for BDCP Effects Analysis					
					Modeled Mean and Range; % of Days Within Original Modeled Range (EBC scenarios)		**Modeled Mean and Range; % of Days Within Original Modeled Range (ESO scenarios)**		
Covariate or Model Term	**Definition**	**Coefficient (Subscript = Standard Error)**	**Modeled Mean and Range (Newman 2003)**	**Source of Data (Details)**	**Spring-Run Chinook Salmon**	**Fall-Run Chinook Salmon**	**Spring-Run Chinook Salmon**	**Fall-Run Chinook Salmon**	**Comments**
Gate	Indicator of position of Delta Cross Channel during outmigration (Open = 1, Closed = 0)	β_{10}: $-0.78_{0.15}$	0.61 (0–1)	DSM2-HYDRO (Delta Cross Channel)	0.09 (0–1); 100%	0.32 (0–1); 100%	0.09 (0–1); 100%	0.32 (0–1); 100%	Assumed open at median Delta Cross Channel flow during outmigration >100 cfs
Turbidity	Median water turbidity near Courtland during outmigration (formazine turbidity units, FTU)	β_{11}: $0.38_{0.13}$	8.18 FTU (4.5–25.0 FTU)	Based on regression of flow at Freeport vs. turbidity at Courtland from raw data of Newman (2003)	9.93 FTU (4.2–27.6 FTU); 93%	8.41 FTU (4.2–27.6 FTU); 97%	As EBC scenarios for hypothesis 1; 8.76 FTU (4.1–25.7 FTU) for hypothesis 2 (see text); 97%	As EBC scenarios for hypothesis 1; 7.45 FTU (4.1–25.5 FTU) for hypothesis 2 (see text); 98%	Sensitivity analysis conducted based on two differing hypotheses to assess differences based on flows above/below proposed north Delta intakes



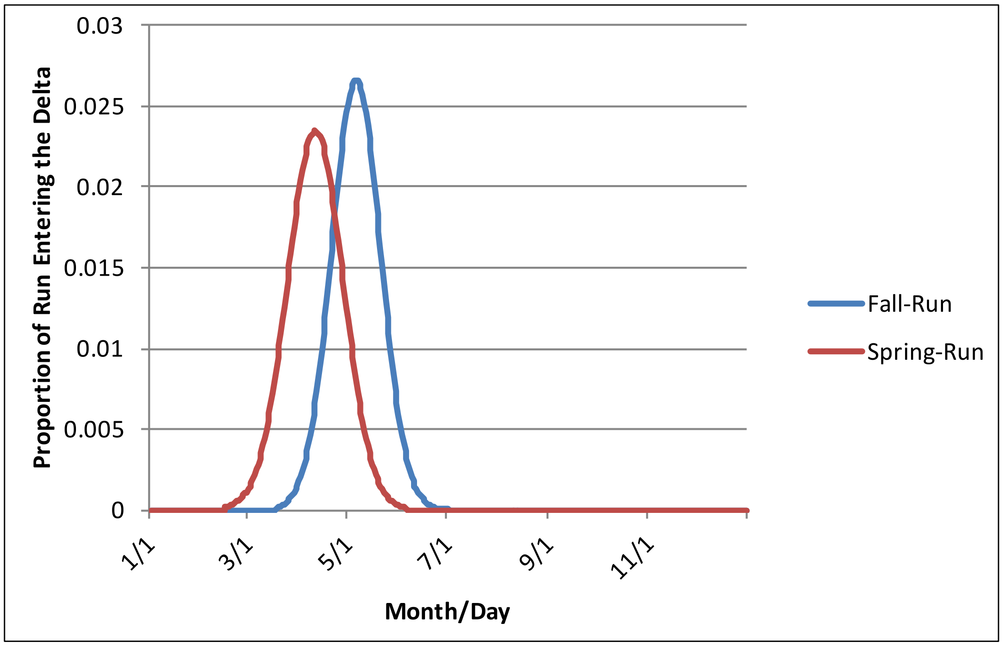
Standardized covariate values were plotted from range of values modeled by Newman 2003.

Figure 5C.4-13. Effect of Varying Each Covariate Across the Range of Data Modeled by Newman (2003), Holding Other Covariates at Mean Values, Assuming Closed Delta Cross Channel Gates, and Fish Releases From Sacramento



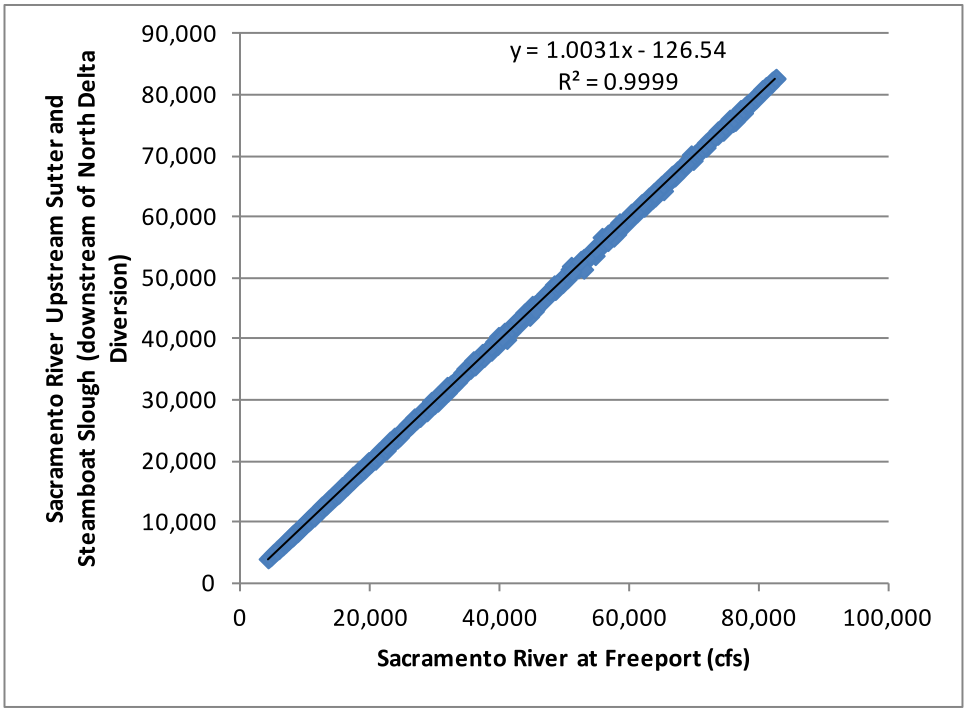
Values were plotted from range of values modeled by Newman (2003) and were back-transformed to original scale of measurement.

Figure 5C.4-14. Effect Varying Sacramento River Flow and South Delta Exports Across the Range of Data Modeled by Newman (2003), Holding Other Covariates at Mean Values, Assuming Closed Delta Cross Channel Gates, and Fish Releases From Sacramento



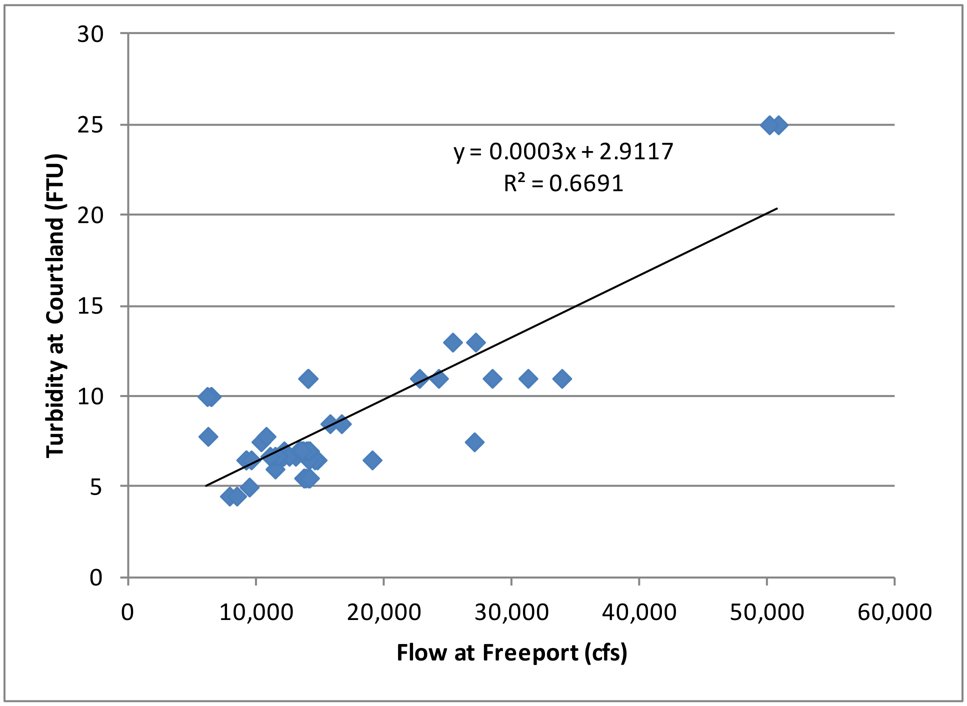
Based on Newman 2003.

Figure 5C.4-15. Assumed Proportional Distribution of Fall-Run and Spring-Run Chinook Salmon Smolts Entering the Delta For the Through-Delta Survival Analysis



Data Shown are for EBC2 Scenario

Figure 5C.4-16. Comparison of Sacramento River Flow at Freeport with Sacramento River Flow Upstream of Steamboat and Sutter Sloughs and Downstream of the North Delta Diversion



Using data from Newman 2003.

Figure 5C.4-17. Relationship between Sacramento River Flow at Freeport and Turbidity at Courtland

Model Assumptions and Limitations

As with the DPM, the through-Delta survival modeling based on Newman (2003) is a smolt-only analysis and does not provide information on pre-smolt migrants. As noted above, the model applies only to fall-run and spring-run Chinook salmon smolts. The model is based on survival of hatchery-origin fall-run Chinook salmon smolts, which may have differential survival than wild-origin smolts; however, it is assumed that the relative difference in survival between modeling scenarios provides a reasonable indication for Chinook salmon smolts of any origin. The model only considers the fate of fish migrating down the mainstem Sacramento River and does not account for fish entering the Yolo Bypass. As with many of the analysis techniques employed in the BDCP effects analysis, there is an assumption of stationarity, i.e., that the model coefficients based on historical data provide insight into future processes; this may not be the case. For example, there has been a long-term decrease in sediment supply to the Delta from upstream (Schoellhamer 2011), which is not accounted for in future scenarios because the future estimates are uncertain and would not differ between EBC and ESO scenarios within the same time period (ELT or LLT). It is assumed that the model coefficients serve to represent scenario covariate data beyond the range of the original data modeled by Newman (2003). Each covariate differed in the extent to which the scenario data were within the range originally modeled, from 100% of days for salinity to around 50% of days for spring-run Chinook salmon release temperature (Table 5C.4-12). In contrast to the DPM, the through-Delta survival modeling based on Newman (2003) generally cannot account for reach-specific differences between scenarios. For example, while there is a model term related to the position of the DCC (i.e., open or closed, with concomitant effects on through-Delta survival), the model cannot account for a change in the proportion of smolts entering the interior Delta (e.g., because of nonphysical barrier installation at the Sacramento River-Georgiana Slough divergence under *CM16 Nonphysical Fish Barriers*). The model thus provides an analysis of operations-related changes in survival that incorporate the main features of the existing configuration of the Delta; additional changes are discussed in light of the results.

HOS-LOS Scenarios

The above analyses were also undertaken for the high outflow scenario (HOS_ELT and HOS_LLT) and low outflow scenario (LOS_ELT and LOS_LLT). All data were specific to these scenarios, with the exception of release temperature, for which data were not available and for which ESO temperature data were assumed. Plan Area water temperatures would not differ greatly between scenarios within the same time period because climate is the main driver of temperature differences, as discussed in Attachment 5C.C, *Water Temperature*.

5C.4.3.2.4 North Delta Diversion Bypass Flow Effects on Chinook Salmon Smolt Survival

Background

In response to agency concern related to the effects of different levels of north Delta diversions, the present analysis assesses potential differences in Chinook salmon smolt survival based solely on flow changes between BDCP scenarios and existing biological conditions scenarios for different north Delta diversion bypass flow levels (pulse protection flows, level I post-pulse operations, level II post-pulse operations, and level III post-pulse operations). The flow criteria applied under the different bypass flow levels are described in Chapter 3.

The analysis focuses on survival of Chinook salmon smolts as estimated by the flow-survival relationships of Newman (2003) and Perry (2010), weighted by assumed species migration timing. The analysis consists of comparison of the modeled BDCP north Delta diversion flows to the corresponding 'No Action' scenario within the same time period (e.g., BDCP HOS_ELT scenario compared to EBC2_ELT scenario). This comparison represents the best estimate of effects of reduced Sacramento River bypass flows caused by the BDCP because it accounts for all the criteria affecting constraining Delta operations and their interaction with the north Delta diversion operations and the associated effects on migrating juvenile salmon. Not all of these Delta operational criteria are attributable to the BDCP. The BDCP is committed to operating in a way that ensures actual operations of the NDD as modeled.

In addition to species-specific weightings, a comparison using an equal weighting of fish presence (i.e., same daily potential for exposure) for each day between December 1 and June 30 was conducted to investigate effects of north Delta diversions over the main winter-spring period of relevance to migrating juvenile Chinook salmon. All of these analyses rely solely on the existing estimated values based on flow-survival relationships and do not account for other BDCP components including predation control, benefits of Yolo Bypass floodplain restoration, or changes to the actual relationships that may occur as a result of climate change or BDCP restoration effects.

Use of Hydrological Data

Modeled hydrological data were processed for the EBC2_ELT, EBC2_LLT, ESO_ELT, ESO_LLT, HOS_ELT, and HOS_LLT scenarios. Monthly modeled CALSIM data for water years 1922–2003 were downscaled to daily data based on historic hydrological patterns for several locations within the Plan Area, i.e., Sacramento River at Freeport, Sacramento River below the North Delta Diversions (i.e., the location at which bypass flows are determined), and the North Delta Diversions. In addition, the daily minimum bypass flow requirement for BDCP scenarios was computed based on the flow criteria described in Chapter 3. Each day was assigned a bypass flow level (pulse protection flows, level I post-pulse operations, level II post-pulse operations, or level III post-pulse operations). These data were used in flow-survival analyses (see below). Frequency (number of days) of different flow levels within each month of each water year. Statistical summaries (mean, median, percentiles) of modeled bypass flows, minimum required bypass flows, and flows without north Delta diversions.

Daily DSM2-HYDRO data exist for water years 1976–1991 and have been used extensively in the BDCP effects analysis (e.g., Delta Passage Model and analyses based on Newman [2003]). These data include, among many other locations, the Sacramento River below the north Delta diversions (upstream of Sutter/Steamboat Sloughs) as well as the Sacramento River below Georgiana Slough, which is of relevance to the flow-survival relationships of Perry (2010; see below). DSM2 attempts to divert the daily diversion estimated based on the monthly CALSIM results. The diversion in DSM2 is also subjected to 15-minute velocity criteria (i.e., no diversions occur when channel velocity downstream of the intakes falls below 0.4 feet per second), an adjustment that CALSIM does not incorporate. Therefore DSM2-HYDRO estimates of daily diversions may deviate slightly (some days higher, some days lower) from CALSIM downscaled daily estimates. However, the differences generally are not substantial and so the classification of each day's pumping to a particular north Delta diversion bypass level was made based on the classification of the daily downscaled CALSIM data (outlined above).

Methods for Evaluating Survival Based on Flow-Survival Relationships

Analysis Based on Perry (2010)

Perry (2010) used binomial generalized linear models to estimate survival of acoustically-tagged Chinook salmon smolts in relation to flow in the Sacramento River below Georgiana Slough. Survival was estimated from the Sacramento River at its junction with the Delta Cross Channel and Georgiana Slough to Chipps Island[5], and from the upstream entry points of Steamboat/Sutter Sloughs to Chipps Island (Perry 2010: 107–108). The resulting coefficients from this modeling are shown in Table 5C.4-16 (reproduced from Perry 2010: 127) and Table 5C.4-17 (reproduced from Perry 2010: 217) below; yellow highlights indicate the relevant coefficients for the present analysis. Only the Sacramento River relationship is used in the present analysis, as the survival curves are very similar (Figure 5C.4-18). Release- and route-specific coefficients were used to derive median intercepts for the present proposed analysis (Perry pers. comm.) (Table 5C.4-18). The resulting equations used to estimate survival are as follows (note that fork length is held constant at its mean value and therefore does not appear in the equations because its standardized value is zero).

$$\text{Survival (Sacramento route)} = \frac{e^{[0.075+0.52(standardized\ flow)]}}{1+ e^{[0.075+0.52(standardized\ flow)]}}$$

The flow term in these equations is the standardized three-day mean flow (cfs) in the Sacramento River below Georgiana Slough (termed Q_S by Perry [2010]). The mean and standard deviation of flow for the standardization are 5127.18 and 3821.8, respectively (Perry pers. comm.).

The resulting flow-survival relationships from Perry (2010) using median intercepts as outlined above are shown in Figure 5C.4-18. There is not a great difference between the Sacramento River and Steamboat/Sutter routes (also plotted for comparison), with survival ranging from between 0.4 and 0.5 at 2,500 cfs to around 0.9 at 20,000 cfs.

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[5] Perry (2010: 108) noted: “The upper reaches in the Sacramento River were excluded because telemetry stations were not implemented consistently in all years and survival in these reaches remained relatively high over all years of study.”

Table 5C.4-16. Parameter Estimates on the Logit Scale for Individual-Level Covariates Best Explaining Survival Probabilities of the CJS Model

Parameter Modeled	Variable	Group Decision	β (SE)	95% Confidence Interval (±1.96 SE)
S		Intercept (Sacramento River, Release group 5)	0.13 (0.50)	-0.84, 1.10
	Route	Sutter and Steamboat S	-0.01, (0.81)	-1.60, 1.58
		Interior Delta	-0.58, (0.91)	-2.36, 1.20
	Fork length		0.26, (0.09)	0.09, 0.43
	$(I_{Sac}+I_{SS})Q_S$		0.52, (0.18)	0.17, 0.87
p	Year	Intercept (2009)	1.59, (0.20)	1.20, 1.98
		2007	-0.80, (0.37)	-1.53, -0.06
		2008	0.02 (0.35)	-0.67, 0.70
λ	Year	Intercept (2009)	1.77, (0.21)	1.35, 2.18
		2007	-0.90 (0.39)	-1.66, -0.13
		2008	-0.83 (0.30)	-1.43, -0.24

Source: Reproduced from Perry 2010: 127, Table 5.11.

Highlighted coefficients were used in the analysis of North Delta Diversion Bypass Flows based on Perry (2010).

Parameter estimates for categorical variables (Route and Release Group) are estimates as differences from a reference category set as the intercept. Parameter estimates for Release Group and Route:Release Group interaction terms can be found in Table 5C.4-17 (Appendix Table 4.4 reproduced from Perry 2010).

Table 5C.4-17. Parameter Estimates on the Logit Scale for the Effect Release Group and Route:Release Group on Survival for the Best-Fit Individual Covariate Model

Coefficient	β (SE)	95% Confidence Interval (±1.96 SE)
Release 1	-1.24 (0.75)	-2.71, 0.23
Release 2, 3	0.15 (0.63)	-1.08, 1.39
Release 4	-0.71 (0.61)	-1.90, 0.49
Release 6	-0.84 (0.58)	-1.98, 030
Release 7	-0.76 (0.69)	-2.10, 0.58
Release 8	0.39 (0.59)	-0.76, 1.54
Release 9	0.15 (0.61)	-1.04, 1.34
Release 10	-0.11 (0.70)	-1.48, 1.26
Release 11	0.46 (0.58)	-0.68, 1.60
I_{SS}: Release 1	0.43 (1.14)	-1.81, 2.67
I_{SS}: Release 2, 3	-0.18 (0.98)	-2.11, 1.75
I_{SS}: Release 4	-0.96 (0.98)	-2.87, 0.96
I_{SS}: Release 6	-1.19 (1.07)	-3.28, 0.90
I_{SS}: Release 7	1.31 (1.40)	-1.44, 4.06
I_{SS}: Release 8	-0.27 (0.91)	-2.04, 1.51
I_{SS}: Release 9	0.39 (1.00)	-1.57, 2.34
I_{SS}: Release 10	0.24 (1.09)	-1.90, 2.37
I_{SS}: Release 11	-0.21 (0.92)	-2.01, 1.59

Coefficient	**β (SE)**	**95% Confidence Interval (±1.96 SE)**
I_{ID}: Release 1	1.27 (1.35)	-1.39, 3.92
I_{ID}: Release 4	-0.22 (1.04)	-2.26, 1.82
I_{ID}: Release 6	-0.31 (1.01)	-2.29, 1.67
I_{ID}: Release 7	0.63 (1.20)	-1.72, 2.98
I_{ID}: Release 8	0.19 (1.00)	-1.78, 2.15
I_{ID}: Release 9	0.33 (1.09)	-1.81, 2.47
I_{ID}: Release 10	2.35 (1.60)	-0.77, 5.48
I_{ID}: Release 11	-0.21 (0.99)	-2.16, 1.74

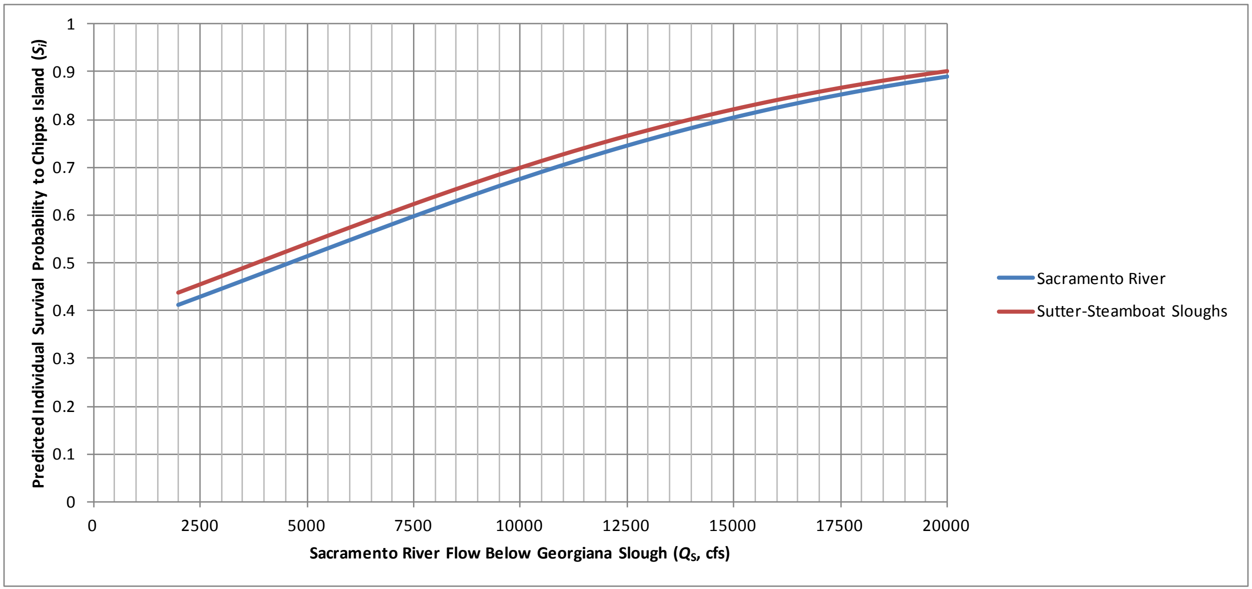
Source: Reproduced from Perry 2010: 217, Appendix Table 4.4.

Highlighted coefficients were used in the analysis of North Delta Diversion Bypass Flows based on Perry (2010).

Table 5C.4-18. Combination of Release and Route-Specific Coefficients to Calculate Median Intercept for Flow-Related Survival Analysis along the Sacramento River Route Based on Perry (2010)

Release	**Release Effect**	**Route Effect**	**Release*Route Interaction**	**Reference Intercept**	**Adjusted Intercept**
Release 5, Sac (reference)	0	0	0	0.13	0.13
Release 1	-1.24	0	0	0.13	-1.11
Release 2,3	0.15	0	0	0.13	0.28
Release 4	-0.71	0	0	0.13	-0.58
Release 6	-0.84	0	0	0.13	-0.71
Release 7	-0.76	0	0	0.13	-0.63
Release 8	0.39	0	0	0.13	0.52
Release 9	0.15	0	0	0.13	0.28
Release 10	-0.11	0	0	0.13	0.02
Release 11	0.46	0	0	0.13	0.59
				Median	0.075

Source: Perry pers. comm.



Based on Perry 2010.

Figure 5C.4-18. Predicted Individual Survival Probability to Chipps Island as a Function of Three-Day Mean Sacramento River Flow below Georgiana Slough, for Sacramento River and Sutter/Steamboat Slough Routes

The flow-survival relationship derived from the work of Perry (2010) was used to estimate survival from the downscaled daily CALSIM data. The flow-survival relationship requires estimates of Sacramento River below Georgiana Slough flows. These flows were estimated from the bypass flows using regressions derived for EBC2 and ESO scenarios from daily data outputs from DSM2-HYDRO (Figure 5C.4-19 and Figure 5C.4-20). The regressions were derived separately for periods when the Delta Cross Channel was closed (January–May) and open (July–September). Daily survival estimates were made using the regression above and by applying a run-specific weighting based on assumed Chinook salmon smolt migration periods, which were the same weightings as those used in the Delta Passage Model analyses and the analyses based on Newman (2003). Survival estimates for the BDCP scenarios (ESO_ELT, ESO_LLT, HOS_ELT, and HOS_LLT) under the different bypass flow levels were compared to survival estimates for the EBC scenarios (EBC2_ELT and EBC2_LLT) for each water year. This comparison was made by classifying dates for EBC scenarios based on the flow level for the same date under the BDCP scenarios. For example, if March 15, 1983 has a flow level of III under ESO_ELT, then the flow for March 15, 1983 under the EBC2_ELT scenario also would be classified as level III for comparison to ESO_ELT flows. In addition to the analyses using run-specific weightings, analyses were also undertaken using an equal weighting for each day between December 1 and June 30 (i.e., 1/213 days = weight of 0.00469 for each day).

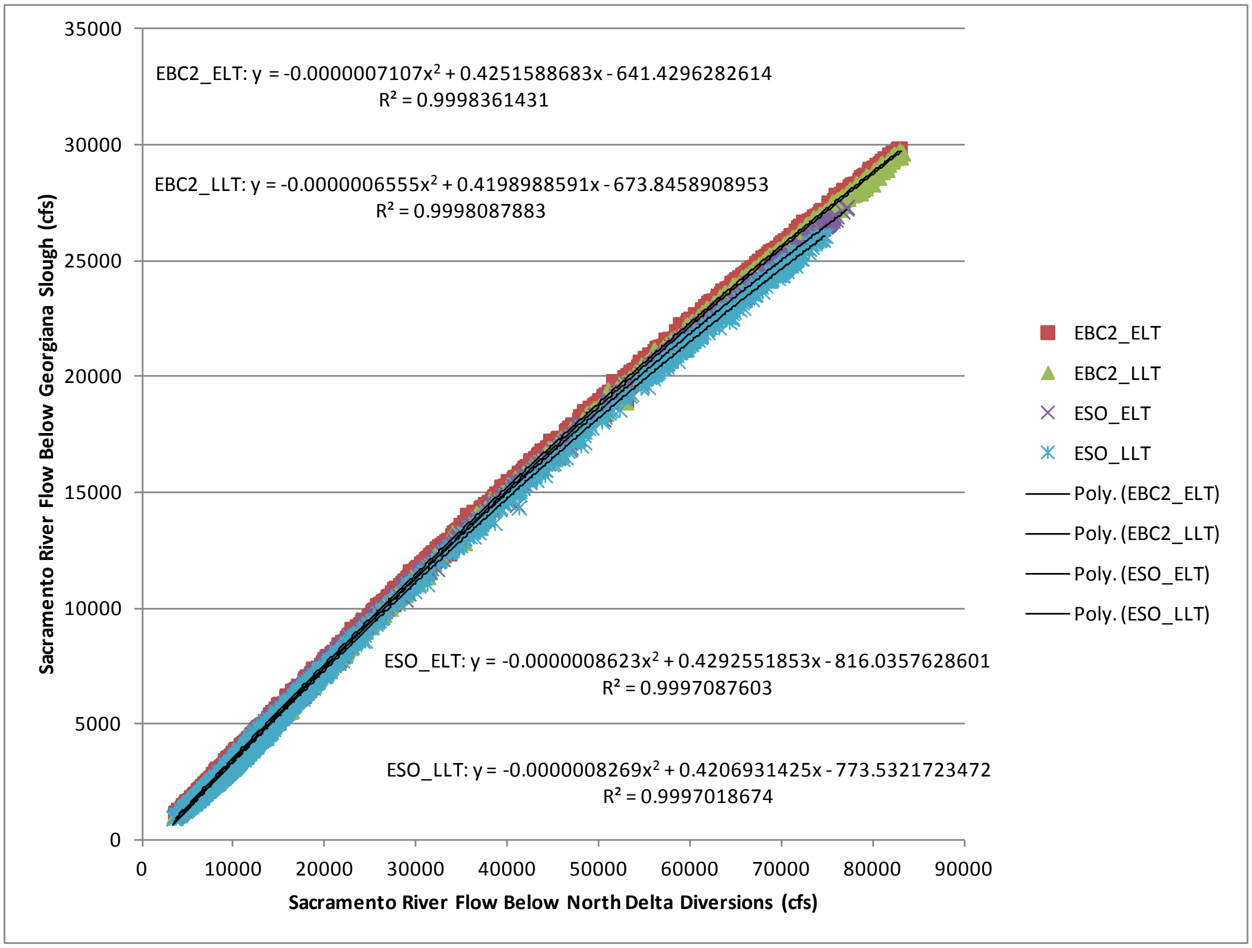
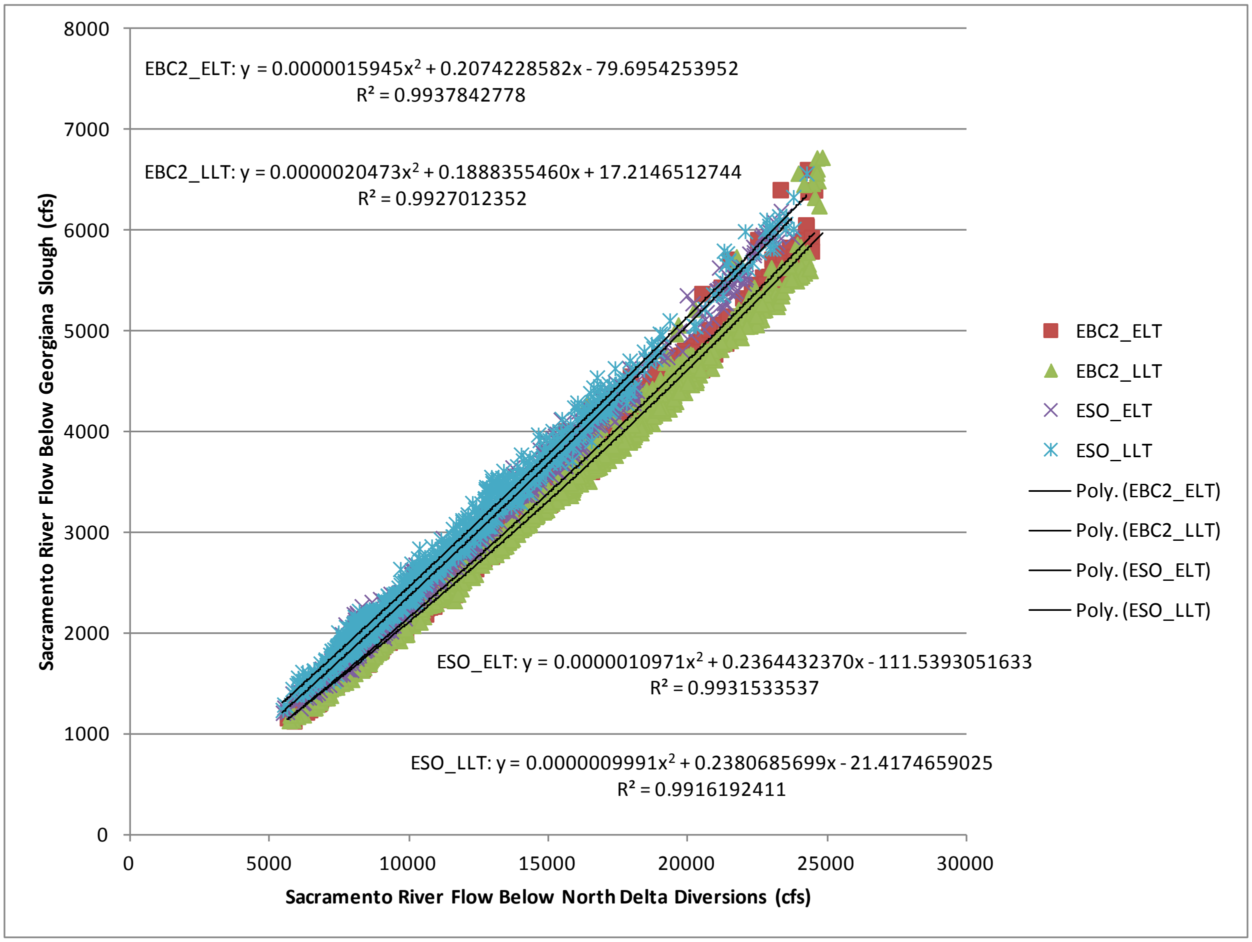


Figure 5C.4-19. Regressions Predicting Sacramento River Flow below Georgiana Slough from Sacramento River below North Delta Diversion Flows, from Daily CALSIM Modeling during January-May Days with the Delta Cross Channel Closed



Analysis Based on Newman 2003.

Figure 5C.4-20. Regressions Predicting Sacramento River Flow below Georgiana Slough from Sacramento River below North Delta Diversion Flows, from Daily CALSIM Modeling during July-September Days with the Delta Cross Channel Open

Analysis Based on Newman (2003)

Additional analysis of the effects of different bypass flow levels on Chinook salmon survival through the Delta was conducted by reprocessing the results from the analysis based on the Newman (2003) flow-survival relationship as described in Section 5C.4.3.2.3 above. The reprocessing of the original results involved generating summaries of survival by pumping level within each water year of the DSM2-HYDRO simulation (i.e., water years 1976–1991). As with the analysis based on Perry (2010), survival for the BDCP scenarios (ESO_ELT, ESO_LLT, HOS_ELT, and HOS_LLT) was compared to the EBC2_ELT and EBC2_LLT survivals from the corresponding dates. Note that this analysis was limited to the DSM2-HYDRO data period because data for other covariates required to use the downscaled CALSIM data (e.g., conductivity) were not available.

5C.4.3.2.5 Particle Tracking Modeling Nonlinear Regression Analyses (Chinook Salmon Fry/Parr)

Introduction

The DPM, described above, employs a detailed reach-specific examination of through-Delta survival but is limited only to Chinook salmon smolts. Ideally, similar models would be available for other covered fish species, including smaller life stages of Chinook salmon. Miller et al. (2010) showed that adult fall-run Chinook salmon collected in the Oregon troll fishery in 2006 had emigrated from Central Valley freshwater habitats—the downstream end of which is the Delta—in 2003 and 2004 not only as smolts (>75 mm FL), but also as fry (≤ 55-mm fork length, FL) and parr (56–75 mm FL). Around 20% of adults had emigrated as fry, 48% as parr, and 32% as smolts (Miller et al. 2010). Thus it is important to consider potential effects of the BDCP on through-Delta migration of smaller life stages of Chinook salmon than those represented by the DPM. Differences in average channel flows between EBC and ESO scenarios as modeled in CALSIM are provided elsewhere in this appendix; although the consideration of average monthly flow differences is informative, a framework that considers the time to pass through the Delta, accounting for differences in channel flows between scenarios is desirable. Particle tracking modeling (PTM) provides one such method and forms the basis for the Particle Tracking Modeling Nonlinear Regression Analyses described in this section. The method is based on assessing the proportion of simulated particles released at certain important Delta entry points (Sacramento River, Yolo Bypass, San Joaquin River, and Mokelumne River) that reach Chipps Island in 30 days, which can be regarded as a Chinook salmon fry/parr downstream migration index for the Delta portion of the Plan Area.

A concise rationale for using PTM as the basis for analysis of effects on salmonid through-Delta migration was provided by National Marine Fisheries Service (2009:366–367):

> NMFS uses the findings of the PTM simulations to look at the eventual fate of objects in the river over a defined period of time from a given point of origin in the system. While salmonids and green sturgeon are not “neutrally buoyant particles”, they can be represented to some degree by the PTM modeling results. The fish occupy a given body of water in the river and that body of water has eventual fates in the system, as represented by the dispersion of the injected particles. The salmonids have volitional movement within that body of water and react to environmental cues such as tides, water velocity vectors, and net water flow movement within the channel. The eventual fate of that body of water signifies the potential vulnerabilities of fish within that body of water to external physical factors such as export pumping or river inflows. For example, if exports increase, and the eventual fate of the water body indicates that it has a higher probability of entrainment compared to other conditions (i.e., lower export pumping), then NMFS believes that salmonids within that same body of water will also experience a higher probability of entrainment by the export pumping. Conversely, under conditions where the eventual fate of injected particles indicate a high probability of successfully exiting the Delta at Chipps Island, NMFS believes salmonids traveling in the same body of water will have a higher probability of exiting the Delta successfully. Furthermore, conditions which delay movement of particles out of the Delta yet don’t result in increased entrainment at the export facilities would indicate conditions that might delay migration through the Delta, which would increase vulnerabilities to predation or contaminant exposure. Finally, flow conditions at river channel splits indicate situations where migrating fish must make a “decision” as to which channel to follow. If water is flowing into a given channel, then fish closer to that channel bifurcation are more likely to be influenced by the flow conditions adjacent to the channel opening than fish located farther away from the channel mouth. Burau et al. (2007) describes the complexity of these temporal and spatial conditions and their potential influence on salmonid movement. PTM simulations currently do not give the necessary fine scale resolution both temporally (minutes to fractions of hours) and spatially (three dimensional on the scale of meters) to give clear results at these channel

> splits. Burau states that spatial distribution of fish across the river channel occurs upstream of the channel splits and is dependent "upon the interaction between local hydrodynamic processes (e.g., secondary currents) and subtle behaviors that play out in a Lagrangian reference frame. These spatial structures evolve over fractions of hours to hours. Junction interactions, on the other hand, happen very rapidly, typically within minutes. Thus, route selection may only minimally depend on behavioral responses that occur in the junction, depending to a greater degree on spatial distributions that are created by subtle behavioral responses/interactions to geometry-mediated current structures that occur up-current of a given junction." This description illustrates the complexity of route selection. Based on Burau's explanation, fish upstream of the split are dispersed by the environmental conditions present in the channel into discrete locations across the channel's cross section. The proximity of these locations to the channel mouth is predictive of the risk of diversion into the channel itself. PTM data can be useful to indicate the magnitude of the net movement of water through the channel after the junction split (and the route selected by the fish), and thus can be used to infer the probable fate of salmonids that are advected into these channels during their migrations.

In contrast to NMFS (2009), Baxter et al. (2012:9-11) urged caution regarding the use of PTM results in assessing salmonid survival:

> A long-held assumption in Delta studies is that "net" negative flows exert a strong influence on juvenile salmonid behavior and survival (Newman 2008; Newman and Brandes 2010; Dauble et al. 2010). This assumption is also implicit in the NMFS recent use of a Particle Tracking Model (PTM) to evaluate Delta hydrodynamic conditions experienced by juvenile salmonids (NMFS 2009). Kimmerer and Nobriga (2008) demonstrate that particle fate, both in terms of destination and arrival timing, was very sensitive to river inflows and, to a somewhat lesser extent, on exports. They observed that tides acted only to “spread out and delay the passage of particles” and that the fate of particles largely reflects “net”, non-tidal flow. Thus, particle fates reported by PTM are largely determined by “net” flows. However, acoustic telemetry studies (Perry et al. 2010; Holbrook et al. 2009; SJRGA 2011), like earlier coded-wire tag studies (Baker and Morhardt 2001), have shown salmon smolts are strong swimmers; moving through the Delta more quickly than tracer particles and not in correspondence with “net” flows (Baker and Morhardt 2001). In addition to rapid, directed swimming behavior, juvenile salmonids are known to successfully navigate through non-riverine environments with weak or no “net” flow (e.g., lakes and estuaries). This navigation appears to be guided by polarized light and the Earth's magnetic field (Quinn 1980; Quinn and Brannon 1982; Parkyn et al. 2003).
>
> Though “net” flows may be important to some species and ecological processes, our focus here is on juvenile salmon migratory behavior. A new analysis by Cavallo et al. (2012) describes sub-daily hydrodynamics in the main stem of the San Joaquin River and shows “net” flows are largely unrelated to sub-daily hydrodynamics. The authors’ description of sub-daily hydrodynamics in the Delta also appears relatively consistent with patterns of salmon movements observed in acoustic telemetry studies (e.g., Perry et al. 2010; Holbrook et al. 2009; SJRGA 2011). This new study also proposes a specific mechanism for how sub-daily flows may influence juvenile salmonid migration behavior.
>
> Thus, Delta juvenile salmon studies and management may have become overly reliant on an assumed major adverse effect of “net” negative flows on juvenile salmon behavior and movement. Though “net” flow (and “net” negative flows in particular) may prove a useful indicator of juvenile salmonid migratory behavior and success, a sufficiently detailed mechanistic hypothesis for how this relationship might function needs to be clearly articulated. Overall, these new studies suggest that sub-daily hydrodynamics, not just “net” negative flows, should be considered when evaluating water quality objectives intended to benefit juvenile salmonids.

There therefore is support and caution regarding the use of PTM as the basis for the Particle Tracking Modeling Nonlinear Regression Analysis for the BDCP effects analysis. It is felt that the use of PTM for salmonids is appropriate because (1) PTM is a well-established method that is familiar to stakeholders, and (2) PTM is employed here to provide a migration index for smaller outmigrating Chinook salmon than those that have been researched by acoustic-tagging or coded wire tagging.

Research and monitoring during the BDCP implementation period will further knowledge regarding the importance of factors such as sub-daily hydrodynamics and net negative (reverse) flows for smaller Chinook salmon migrants.

Computation of Nonlinear Regressions

The underlying equations forming the basis of the Particle Tracking Modeling Nonlinear Regression Analysis are derived from nonlinear regressions that estimate the proportion of simulated particles reaching Chipps Island over 30 days as a function of various Delta channel and water export flow terms. The form of the regressions is the same as those used by Kimmerer and Nobriga (2008) to describe the percentage of particles being entrained by the south Delta export facilities as a function of export flow/total Delta inflow.

The nonlinear regressions have the form:

$$\text{Proportion of particles reaching Chipps Island after 30 days} = \frac{1}{1+\ a * e^{b*flow}}$$

Where *a* and *b* are coefficients to be estimated and *flow* is a flow term that differs depending on particle release location.

The form of the nonlinear regressions results in predicted curves with a characteristic sigmoid (‘S’) shape, reflecting a rapidly increasing proportion of particles reaching Chipps Island as the flow term increases, followed by a subsequent leveling-off as the proportion of particles reaching Chipps Island approaches one.

The input data for the nonlinear regression calculations were the results of 31 PTM runs conducted for each of the six scenarios in the BDCP effects analysis. Table 5C.4-19 provides the total Delta inflow and combined north and south Delta exports for each of the runs, by scenario (note that other flow variables were also used, see below, but that the table illustrates only the Delta inflow and total exports variables). The runs chosen represented the months of December to June because this is the main migratory period of juvenile Chinook salmon and lessens unwanted variability in PTM outputs caused by factors such as agricultural diversions during the summer and fall. Four particle release locations were chosen to represent the main entry points for Chinook salmon fry/parr into the Delta.

- Sacramento River at (upstream of) Sutter Slough.
- Cache Slough at Liberty Island.
- San Joaquin River at Mossdale.
- Mokelumne River downstream of the Cosumnes River confluence.

The Sacramento River at Sutter Slough particle release location was chosen in order to avoid entrainment of particles at the north Delta intakes. As described in Appendix 5.B, *Entrainment*, the north Delta intakes would be expected to screen effectively nearly all sizes of juvenile salmonids passing through the Plan Area and so entrainment of particles at the north Delta intakes—as would be found if particle release sites upstream of the intakes were chosen—would be unrepresentative of their fate as fish. There is considerable uncertainty surrounding potential predation in the vicinity of the north Delta intakes (see Appendix 5.F, *Biological Stressors on Covered Fish*) that will require monitoring during the BDCP implementation period. Selection of the the Sacramento River at Sutter Slough particle release location reflects the desire to provide information on the effects of the lower channel flows under the ESO scenarios because of north Delta exports and it is acknowledged that this does not encompass the entire Sacramento River pathway through the Plan Area. The Cache Slough at Liberty Island particle release location was felt to be representative of fish that had migrated into the Plan Area through the Yolo Bypass subregion (i.e., over Fremont Weir). The San Joaquin River and Mokelumne River particle release locations represent the Delta entry points for fall-run Chinook salmon fry/parr from the various San Joaquin River tributaries and the Mokelumne River.

Nonlinear regression coefficients were calculated for each scenario (EBC1, EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, and ESO_LLT) at each particle release location using the NLIN procedure of the Statistical Analysis Software (SAS/STAT software Version 9.3 of the SAS System for Windows[6]). The Gauss-Newton iteration method was used for computing the nonlinear least squares. Preliminary analyses suggested that appropriate flow terms for each location were as follows.

- Sacramento River at (upstream of) Sutter Slough: Total Delta inflow (i.e., Sacramento River at Freeport + Yolo Bypass at Delta + San Joaquin River at Vernalis + Mokelumne River at Delta) – (north Delta exports + south Delta exports).
- Cache Slough at Liberty Island: Total Delta inflow - (north Delta exports + south Delta exports).
- San Joaquin River at Mossdale: San Joaquin River inflow (San Joaquin River at Vernalis) – south Delta exports.
- Mokelumne River downstream of the Cosumnes River confluence: Mokelumne River at Delta + Georgiana Slough + Delta Cross Channel + San Joaquin River inflow – south Delta exports.

For the ESO scenarios, it was found that the fit of the regressions was improved by multiplying the south Delta export flow term by the proportion of the month in the given PTM run that the proposed Head of Old River operable barrier was assumed to be open. In essence this captures the ‘shielding’ of San Joaquin River inflow from the Head of Old River channel split, which has important consequences for particle fate and therefore potentially also fry/parr migration. The proportion of time that the barrier was assumed to be open for modeling purposes is summarized generally in Table 5C.4-20. It was assumed that the barrier would be fully open for San Joaquin River at Vernalis flows of greater than 10,000 cfs. For EBC scenarios, it was assumed that a fall barrier is installed from September 16-November 30 when San Joaquin River flows at Vernalis are less than 5,000 cfs—in practice, this is not consequential to the PTM nonlinear regression analysis because assumed fall-run Chinook salmon fry/parr timing generally does not overlap this time period (see below) and the PTM nonlinear regression analysis is not applied in these months.

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[6] Copyright 2002-2010, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

Table 5C.4-19. Summary of Total Delta Inflow (Sacramento River at Freeport + Yolo Bypass at Delta + San Joaquin River at Vernalis + Mokelumne River at Delta) and Combined North and South Delta Exports for the 31 Particle Tracking Modeling Periods Used to Develop Nonlinear Regressions Between Proportion of Particles Reaching Chipps Island and Flows. Data are Sorted by Increasing EBC2 Flow

	Total Delta Inflow (cfs)						Total North + South Delta Exports (cfs)					
Period	**EBC1**	**EBC2**	**EBC2_ELT**	**EBC2_LLT**	**ESO_ELT**	**ESO_LLT**	**EBC1**	**EBC2**	**EBC2_ELT**	**EBC2_LLT**	**ESO_ELT**	**ESO_LLT**
Dec1923	14,270	11,637	10,942	10,313	11,484	10,775	8,281	6,224	5,527	4,303	5,917	5,248
Apr1929	12,323	12,231	11,527	11,449	11,618	11,849	2,602	2,586	2,206	1,761	2,147	2,161
Jun1934	12,854	12,536	12,264	12,751	12,555	12,302	1,606	1,277	1,005	1,498	1,254	1,011
Feb1948	12,899	12,903	12,990	13,086	13,474	13,291	1,100	1,167	1,357	1,349	1,751	1,393
May1966	14,131	14,209	15,497	15,767	19,738	16,515	1,500	1,500	1,647	1,941	4,520	2,282
Jan1929	14,805	14,768	14,572	14,690	14,849	18,407	6,571	6,573	6,569	6,425	5,199	2,317
Jun1940	16,540	16,573	16,933	22,510	19,976	24,667	5,263	5,268	5,216	5,217	8,083	10,760
Apr1970	17,116	16,671	16,671	16,623	17,340	16,123	1,500	1,500	1,500	1,500	2,379	1,991
Dec1933	16,064	16,718	16,736	16,921	17,543	17,593	10,296	9,969	6,845	5,356	10,101	9,764
Mar1961	20,445	20,454	20,468	17,352	20,451	19,882	6,289	6,273	4,665	4,626	7,463	5,706
Dec1931	23,584	24,029	23,387	23,197	24,649	23,586	11,385	11,770	11,770	11,769	9,046	8,830
May1935	24,756	24,607	23,813	24,868	24,057	32,769	1,500	1,500	1,500	1,660	4,826	8,875
Jun1978	26,445	25,237	19,656	21,076	20,106	25,131	8,454	8,068	6,809	6,082	4,516	9,440
May1937	25,364	25,782	24,145	23,981	24,145	23,480	2,400	2,565	2,393	2,572	2,515	2,147
Jan1979	27,044	27,328	27,191	28,074	27,156	27,891	7,753	7,803	7,760	8,062	6,248	6,384
Mar2001	28,494	28,211	27,601	27,993	27,590	28,065	5,568	5,411	5,274	5,274	8,592	8,647
Feb2003	27,520	28,770	29,527	28,751	32,440	29,126	6,549	6,751	6,751	6,506	13,291	8,895
Apr1986	31,626	31,633	31,990	31,156	31,989	31,155	3,064	3,055	3,269	3,365	6,451	5,998
Jan1966	33,595	31,728	31,757	30,965	35,831	30,934	7,732	7,760	7,841	7,295	5,379	3,330
Mar1942	33,102	33,230	35,293	34,933	35,248	34,907	9,202	9,153	9,396	9,200	9,367	9,206
May1963	33,791	33,434	32,299	28,886	32,288	31,154	1,500	1,500	1,500	1,570	9,871	9,575
Jun1993	33,161	33,506	27,538	20,777	27,468	28,462	6,776	6,921	6,864	5,850	7,803	8,789
Dec2002	42,036	41,553	47,494	44,467	44,196	43,366	7,662	7,659	7,486	7,659	8,891	8,867
Mar1993	42,745	41,687	51,731	58,341	50,298	59,169	7,365	7,382	7,648	7,530	10,533	10,568
Apr1996	48,838	49,018	47,729	47,454	47,719	47,574	1,836	1,832	1,844	2,130	10,700	10,728
Jun1952	52,189	51,828	45,264	33,169	45,258	36,799	10,467	10,508	9,198	7,030	11,684	10,661

Period	Total Delta Inflow (cfs)						Total North + South Delta Exports (cfs)					
	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
May1941	52,259	52,047	50,168	41,509	50,163	41,503	2,562	2,549	3,162	3,105	10,311	10,554
Jan1971	53,353	54,067	57,699	61,845	57,752	61,526	6,424	6,583	6,784	6,812	10,522	10,566
Apr1927	54,810	55,130	52,464	52,801	52,439	52,733	1,500	1,500	1,500	1,770	9,936	9,932
Feb1945	60,198	60,018	62,079	60,194	61,874	59,967	8,480	8,371	7,748	6,907	12,058	11,576
Feb1940	65,908	66,190	72,392	72,124	75,584	75,695	6,597	6,565	7,032	7,649	14,527	14,532

Table 5C.4-20. Assumptions Regarding Proportion of Each Month that Head of Old River Operable Barrier Would be Open under Evaluated Starting Operations Scenarios

Month	Proportion Open[a]
Jan	0.5
Feb	0.5
Mar	0.5
Apr	0.5
May	0.5
Jun	0.75[b]
Jul	1
Aug	1
Sep	1
Oct	0.5
Nov	1
Dec	1

[a] Values are for modeling purposes only; actual operations would differ.

[b] Reflects 0.5 for June 1–15 and 1.0 for June 16–30.

The resulting regression curves and their coefficients are shown in Figure 5C.4-21, Figure 5C.4-22, Figure 5C.4-23, Figure 5C.4-24, and Table 5C.4-21, Table 5C.4-22, Table 5C.4-23, Table 5C.4-24. Several features are apparent. The fits for the EBC scenarios were good, with pseudo-R^2 of 0.86–0.90, whereas fits for the ESO scenarios were not as good (pseudo-R^2 of 0.76–0.83) (Table 5C.4-21, Table 5C.4-22, Table 5C.4-23, Table 5C.4-24). The less good fits for ESO scenarios may reflect the influence of tidal habitat restoration causing particles to spread out and take varying migration pathways. Second, there were subtle differences in the shapes of the regression curves between scenarios for a given location, with the exception of the Mokelumne River location, for which ESO and EBC scenarios were quite different (Figure 5C.4-24). The Mokelumne River results reflect the assumption of tidal habitat restoration near to the particle release location, which results in an appreciably lower proportion of particles reaching Chipps Island for a given flow, e.g., at flow of 10,000 cfs, over 0.6 of particles reached Chipps Island under EBC scenarios, compared to 0.3–0.4 under ESO scenarios. This is a reflection of the increased tidal energy affecting particles in the ESO scenarios because of habitat restoration, causing particles to spread out more (Kimmerer and Nobriga 2008) which results in fewer particles reaching Chipps Island after 30 days. The difference between ESO_ELT and ESO_LLT scenarios for the Mokelumne River reflects greater tidal energy in the LLT because of additional tidal habitat restoration compared to the ELT. There also was some subtle separation between EBC1/EBC2 and ESO_ELT/ESO_LLT curves at the Mokelumne River and San Joaquin River locations, reflecting the increasing tidal energy that was modeled to occur with assumed sea level rise into the future, again causing a slightly lower propotion of particles to reach Chipps Island for a given level of flow.

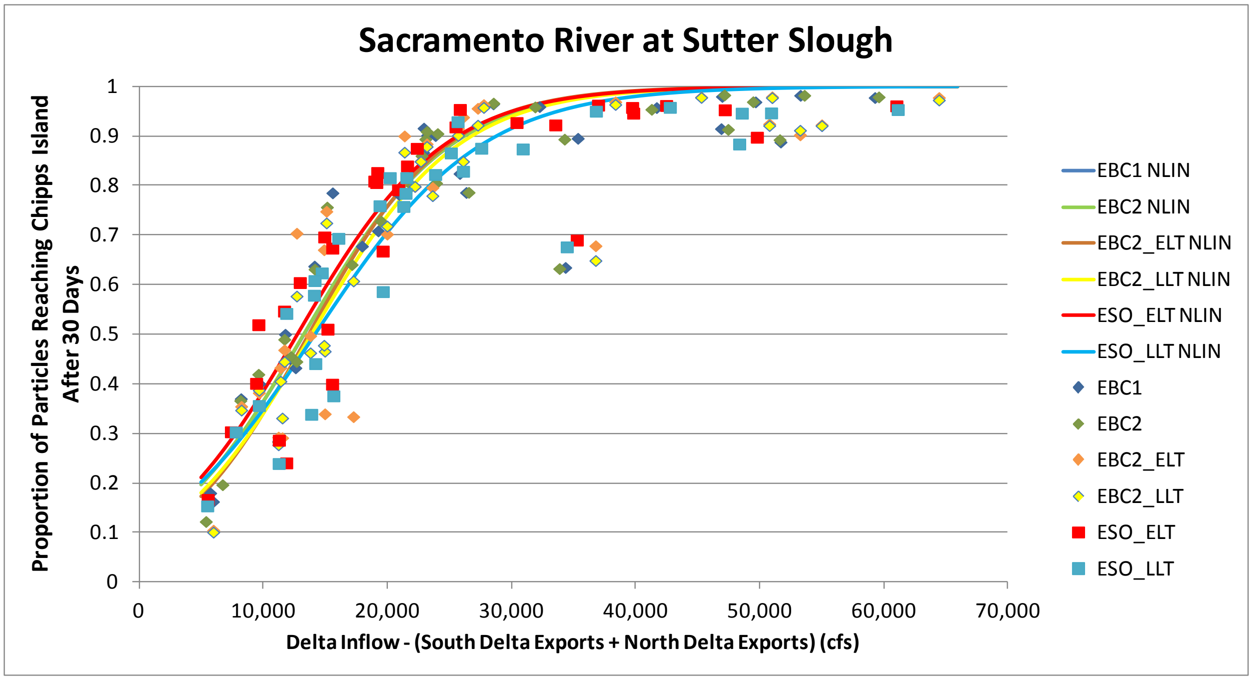


Figure 5C.4-21. Data (Points) and Nonlinear Regression Fits (Lines, NLIN in Legend) for the Proportion of Particles Reaching Chipps Island after 30 Days from Sacramento River at Sutter Slough as a Function of Total Delta Inflow and Combined North/South Delta Exports

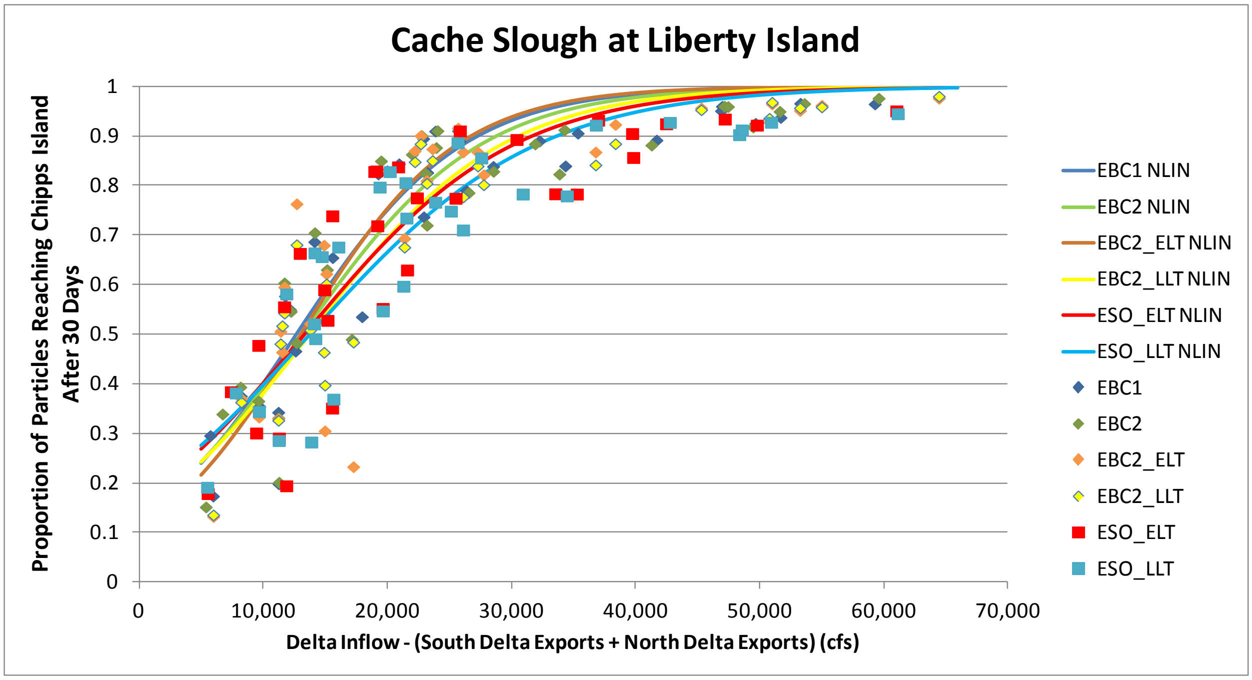


Figure 5C.4-22. Data (Points) and Nonlinear Regression Fits (Lines, NLIN in Legend) for the Proportion of Particles Reaching Chipps Island after 30 Days from Cache Slough at Liberty Island as a Function of Total Delta Inflow and Combined North/South Delta Exports

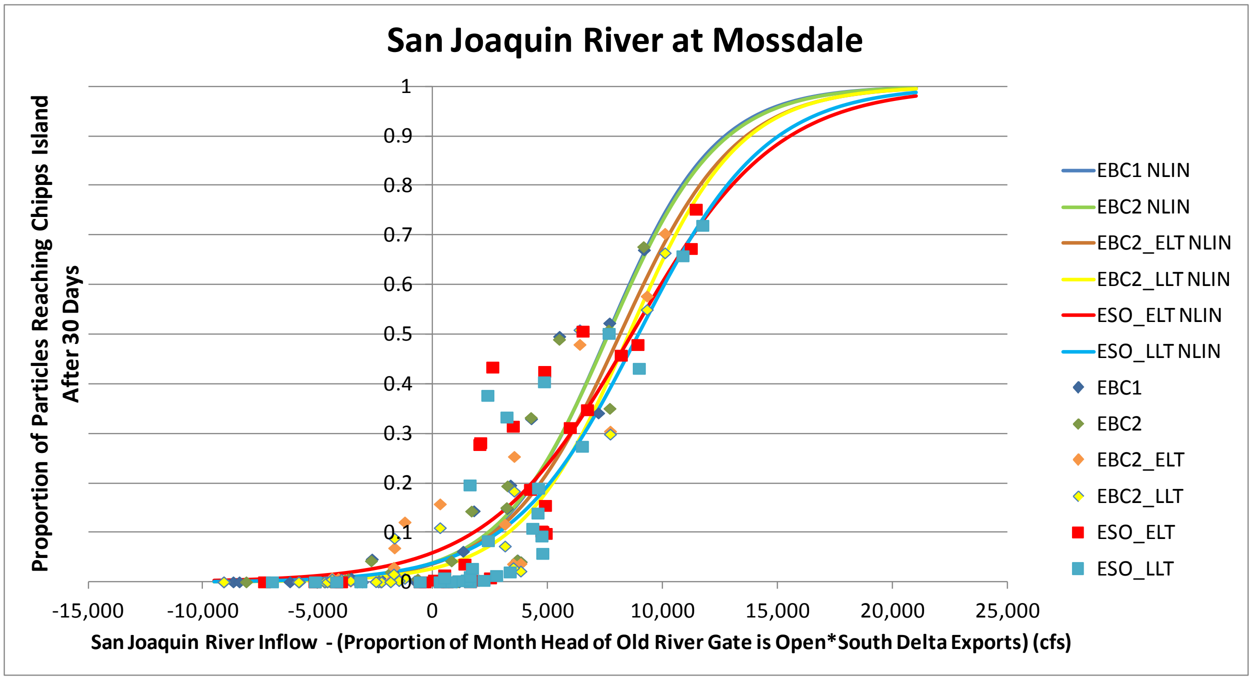


Figure 5C.4-23. Data (Points) and Nonlinear Regression Fits (Lines, NLIN in Legend) for the Proportion of Particles Reaching Chipps Island after 30 Days from San Joaquin River at Mossdale as a Function of San Joaquin River Inflow and South Delta Exports

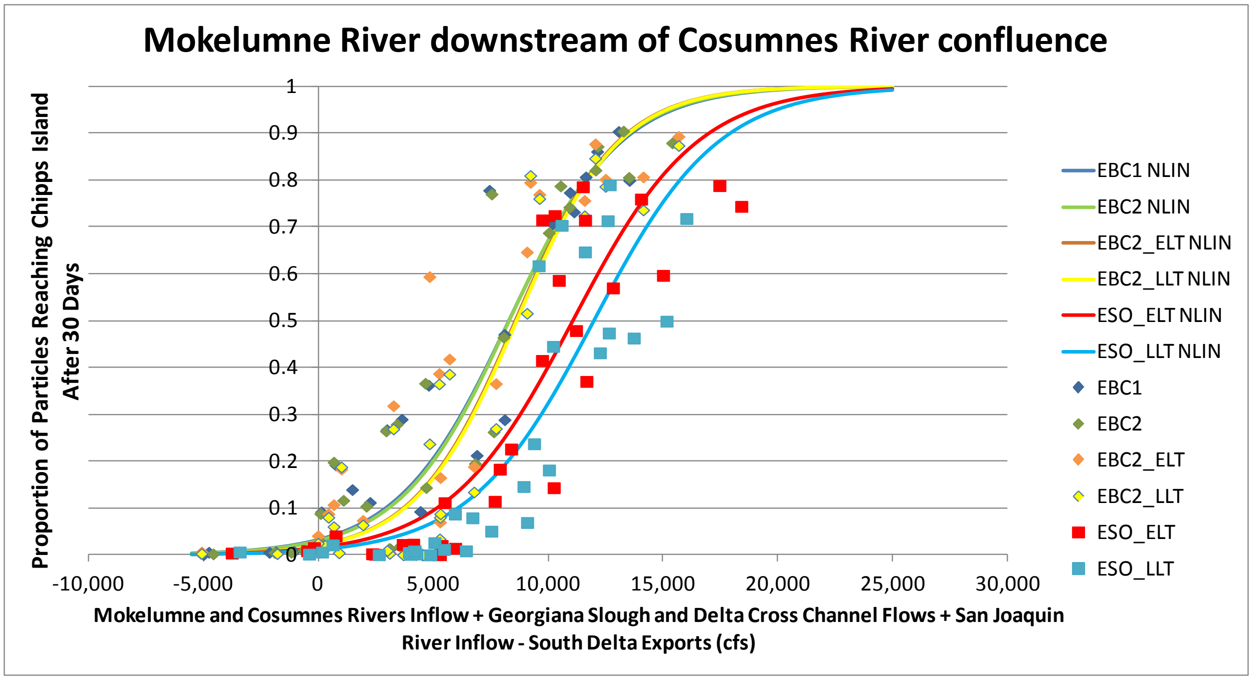


Figure 5C.4-24. Data (Points) and Nonlinear Regression Fits (Lines, NLIN in Legend) for the Proportion of Particles Reaching Chipps Island after 30 Days from Mokelumne River Downstream of the Cosumnes River Confluence as a Function of Mokelumne River Inflow, San Joaquin River Inflow, Georgiana Slough and Delta Cross Channel Flow, and South Delta Exports

Table 5C.4-21. Regression Coefficients, Sums of Squares, and Pseudo-R^2 for the Nonlinear Regression of the Proportion of Particles Reaching Chipps Island after 30 Days from Sacramento River at Sutter Slough as a Function of Total Delta Inflow and Combined North/South Delta Exports

	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
a	9.6238	9.5722	11.7248	10.6079	8.7795	8.4087
b	-0.00017	-0.00017	-0.00018	-0.00017	-0.00017	-0.00015
Residual Sum of Squares	0.2742	0.2715	0.2564	0.2486	0.3197	0.2889
Total Corrected Sum of Squares	2.1073	2.1221	2.1399	1.9502	1.8492	1.7127
Pseudo-R^2	0.87	0.87	0.88	0.87	0.83	0.83

Note: Pseudo-R^2 is calculated as 1-(Residual Sum of Squares – Total Corrected Sum of Squares).
Source: UCLA Statistical Consulting Group 2012.

Table 5C.4-22. Regression Coefficients, Sums of Squares, and Pseudo-R^2 for the Nonlinear Regression of the Proportion of Particles Reaching Chipps Island after 30 Days from Cache Slough at Liberty Island as a Function of Total Delta Inflow and Combined North/South Delta Exports

	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
a	6.6949	6.3168	8.0476	5.9893	4.9474	4.5572
b	-0.00015	-0.00014	-0.00016	-0.00013	-0.00012	-0.00011
Residual Sum of Squares	0.2362	0.273	0.2623	0.2301	0.4139	0.3287
Total Corrected Sum of Squares	1.8749	1.87	1.9426	1.688	1.6979	1.4603
Pseudo-R^2	0.87	0.85	0.86	0.86	0.76	0.77

Note: Pseudo-R^2 is calculated as 1-(Residual Sum of Squares – Total Corrected Sum of Squares).
Source: UCLA Statistical Consulting Group 2012.

Table 5C.4-23. Regression Coefficients, Sums of Squares, and Pseudo-R^2 for the Nonlinear Regression of the Proportion of Particles Reaching Chipps Island after 30 Days from San Joaquin River at Mossdale as a Function of San Joaquin River Inflow and South Delta Exports

	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
a	26.2879	24.7512	25.9794	35.9185	15.8924	24.9523
b	-0.00043	-0.00042	-0.0004	-0.00042	-0.00032	-0.00036
Residual Sum of Squares	0.125	0.1361	0.125	0.1021	0.3562	0.2885
Total Corrected Sum of Squares	1.2815	0.9744	1.0007	0.938	1.4951	1.305
Pseudo-R^2	0.90	0.86	0.88	0.89	0.76	0.78

Note: Pseudo-R^2 is calculated as 1-(Residual Sum of Squares – Total Corrected Sum of Squares).
Source: UCLA Statistical Consulting Group 2012.

Table 5C.4-24. Regression Coefficients, Sums of Squares, and Pseudo-R^2 for the Nonlinear Regression of the Proportion of Particles Reaching Chipps Island after 30 Days from Mokelumne River Downstream of the Cosumnes River Confluence as a Function of Mokelumne River Inflow, San Joaquin River Inflow, Georgiana Slough and Delta Cross Channel Flow, and South Delta Exports

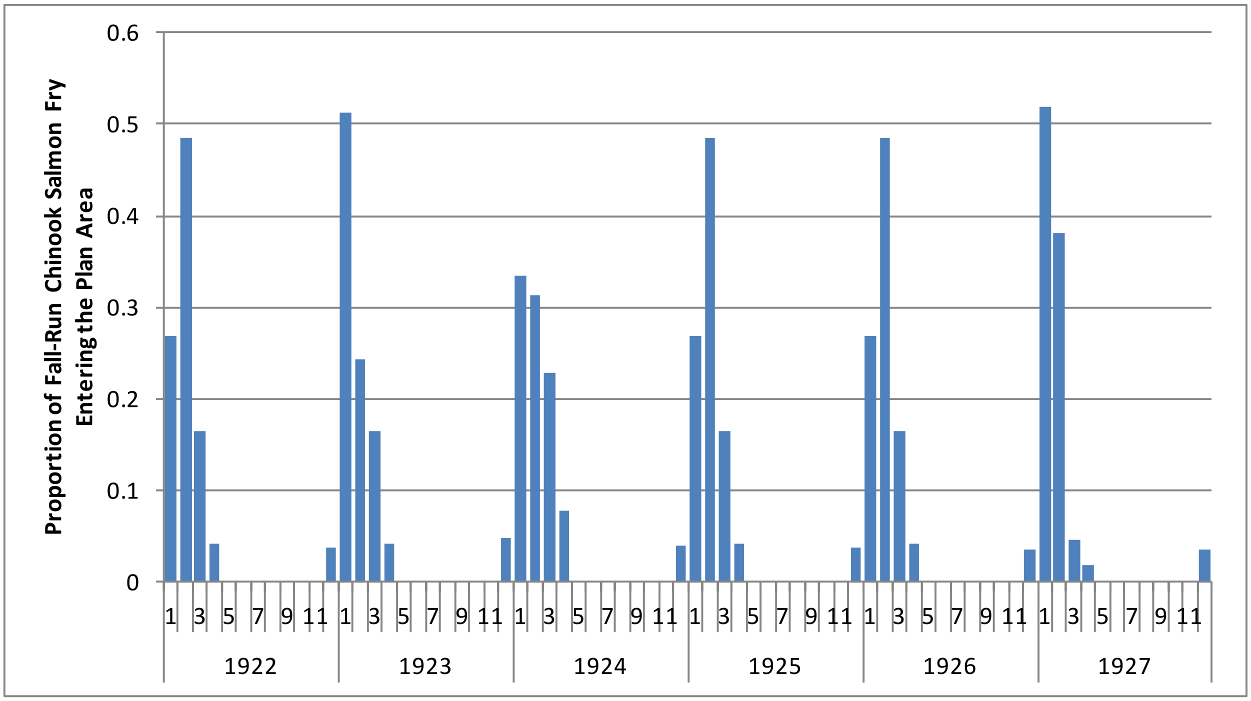
	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
a	30.2475	33.0439	47.7776	48.9827	60.5532	85.0839
b	-0.00041	-0.00042	-0.00045	-0.00045	-0.00037	-0.00037
Residual Sum of Squares	0.4217	0.4097	0.4471	0.3951	0.593	0.5812
Total Corrected Sum of Squares	3.4464	3.4721	3.2575	2.9631	2.8837	2.3545
Pseudo-R^2	0.88	0.88	0.86	0.87	0.79	0.75

Note: Pseudo-R^2 is calculated as 1-(Residual Sum of Squares – Total Corrected Sum of Squares).
Source: UCLA Statistical Consulting Group 2012.

Application to CALSIM Data

The nonlinear regression equations for each scenario at each particle release location were then applied to monthly flow and export data from the CALSIM modeling of 1922–2003 water years in order to compute monthly proportions of particles reaching Chipps Island after 30 days from each location. The average annual proportion of particles reaching Chipps Island was calculated, weighted by the monthly proportion of Chinook salmon fry/parr entering the Plan Area. The weighting factors were derived from the daily proportions of fry/parr approaching Fremont Weir that were calculated in the Yolo Bypass Fry Rearing Model, which are a function of upstream flows at Wilkins Slough (see description in *Methods* Section 5C.4.4.2.3). The main distribution is assumed to represent fall-run Chinook salmon fry, although there may be representation of spring-run Chinook salmon fry that have an overlapping downstream migration period and are of small size (Williams 2006). It was assumed that the timing of Chinook salmon fry/parr at Fremont Weir would be representative of the through-Delta migration timing at all four particle release locations at the monthly scale used in the analysis, which appears reasonable given the monthly timings for smaller fish from other systems such as the Mokelumne and San Joaquin that were summarized by Williams (2006: 83–96).

Daily proportions of fry were summed to give monthly proportions, which were then standardized to make the sum of monthly proportions for each water year equal 1 (Figure 5C.4-25). These monthly proportions were the weighting factors that were used to calculate the weighted average annual proportion of particles reaching Chipps Island after 30 days. Note that water year types were not weighted differentially, although downstream migration of Chinook salmon fry/parr as opposed to smolts is more pronounced in wetter years (Williams 2006). In addition to being applied to CALSIM data for the EBC1, EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, and ESO_LLT scenarios, the PTM nonlinear regression method was applied to the HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT scenarios.



(1 = January, 3 = March, etc.)

Figure 5C.4-25. Example of Monthly Proportions of Fall-Run Chinook Salmon Fry/Parr Assumed to be Entering the Plan Area for the Particle Tracking Modeling Nonlinear Regression Analyses. Data are for ESO_ELT Scenario over Calendar Years 1922–1927, With Individual Months Noted as Digits

March–May Differences

In addition to the analysis described above, which focused on a primarily winter migration period representative of fall-run Chinook salmon fry, further analysis was undertaken to illustrate differences between scenarios for migration during March–May. A hypothetical Plan Area entry spread evenly across these three months was represented by applying a weighting of 0.33 to each of the months; all other months received a weighting of zero.

5C.4.3.2.6 Sacramento River Reverse Flows Entering Georgiana Slough

Introduction

Background

Construction and operation of the proposed north Delta intakes as part of *CM1 Water Facilities and Operation* combined with diversion of more water into the Yolo Bypass as part of *CM2 Yolo Bypass Fisheries Enhancement* inevitably would result in less Sacramento River flow below the intakes than would otherwise occur for a given upstream river flow passing Freeport. Much attention has been paid to developing bypass flow criteria—i.e., the required river flow immediately below the intakes—that would limit the potential for greater incidences of Sacramento River flow reversals in the vicinity of Georgiana Slough and the DCC. Depending on the timing and magnitude, flow reversals could affect migrating covered fish species and may increase the likelihood of entry into the interior Delta (i.e., the East Delta subregion in this case), where through-Delta survival probability is considerably lower than that of fish that remain in the mainstem Sacramento River (Perry et al. 2010). The analysis described below assessed the incidence of reverse flows below the

Sacramento River's junction with Georgiana Slough for the EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, ESO_LLT, HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT scenarios using 15-minute outputs from DSM2-HYDRO modeling. The analysis also considered the percentage of total Sacramento River flows approaching the Sacramento River-Georgiana Slough junction that entered Georgiana Slough, as well as the percentage contribution of Sacramento River reverse flows to the Georgiana Slough flow. Finally, the analysis used the results of the DPM (described in detail above) in order to assess the percentage of Chinook salmon smolts migrating down the Sacramento River that entered the interior Delta through Georgiana Slough/DCC.

Summary of Bypass Flow Assumptions

Given the importance of bypass flows, it is useful to review the main elements of the bypass flows that were assumed for modeling purposes, as well as the assumed north Delta intakes pumping regime. Bypass flows were formulated in order to limit upstream tidal transport in the Sacramento River upstream of Sutter Slough and in the Sacramento River downstream of Georgiana Slough. The latter of these is the focus of some of the analyses presented below. The bypass flows are intended to be triggered by pulses of flow that are indicative of major pulses of downstream juvenile fish migration, particularly juvenile Chinook salmon. The main elements of the north Delta diversion bypass flows assumed in the modeling[7] are as follows, with more detailed provided in Chapter 3, *Conservation Strategy*.

Initial pulses of flow (and fish) are indicated by Sacramento River at Wilkins Slough flow (1) changing by more than 45% over a 5-day period and (2) being greater than 12,000 cfs. During the initial pulse period, north Delta intake diversions may be up to 6% of total Sacramento River flow such that bypass flow never falls below 5,000 cfs, with no more than 300 cfs at any one intake; this is referred to as low-level pumping. Low-level pumping triggered by the initial pulse continues until one of the following occurs: Wilkins Slough flow decreases to flow on first day of the 45% increase; flows decrease for 5 consecutive days; or Sacramento River flows at Wilkins Slough are greater than 20,000 cfs for 10 consecutive days.

Post-pulse operations have three levels. Level I post-pulse operations begin following the initial pulse and last until there have been 15 days of post-pulse bypass flows above 20,000 cfs. In December-April, a sliding scale of bypass flow requirements operates, ranging from requiring 100% of Sacramento River flow to bypass the intakes for river flows of 0–5,000 cfs, up to a bypass flow of 18,400 cfs plus 30% of the amount over 20,000 cfs for river flows over 20,000 cfs. Level II post-pulse operations begin after 15 total days of Level I operations achieving bypass flows above 20,000 cfs. Level II post-pulse operations follow Level I, and also have a sliding scale, ranging from requiring 100% of Sacramento River flow to bypass the intakes for river flows of 0–5,000 cfs, up to 15,900 cfs plus 20% of the amount over 20,000 cfs for river flows over 20,000 cfs. Level III post-pulse operations begin after 30 total days of Level 1 and Level II operations achieving bypass flows above 20,000 cfs. The sliding scale for Level III operations ranges from requiring 100% of Sacramento River flow to bypass the intakes for river flows of 0–5,000 cfs, up to 13,000 cfs for river flows greater than 20,000 cfs. Criteria for May and June differ from these criteria. More detail is provided in Chapter 3.

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[7] Modeling assumptions may differ from actual operations because of real-time monitoring of fish entry into the Plan Area and other variables.

DSM2 Assumptions for North Delta Intakes Operation

The bypass rules summarized above were simulated in CALSIM using daily Sacramento River flow, which provided the maximum potential diversion that can occur at the north Delta intakes for each day. CALSIM uses the monthly average of this daily potential diversion as one of the constraints in determining the final monthly north Delta diversion. Other goals and constraints may result in CALSIM's monthly diversion amount being substantially less than the potential diversion that CALSIM's daily logic identified. For use in DSM2, the monthly diversion amount was distributed onto the daily pattern of the potential diversion estimated in CALSIM.

Diversion at each intake was subjected to surrogate sweeping velocity criteria for fish protection at intakes. Since DSM2 is a one dimensional model, an average cross-sectional velocity criterion of 0.4 feet/second was used to determine whether or not water could be diverted at an intake. This criterion was based on having a sweeping velocity at least twice that of the approach velocity, the latter having been limited to 0.2 feet/second or less to meet criteria for delta smelt. The sweeping velocity criterion calculated 1,000 feet downstream from each diversion node in DSM2 to represent the minimum sweeping velocity (at downstream end of screen).

The intake operations were also subjected to ramping rates that were required to shut off or start the pumps. The current design allowed ramping up or down the pumps between 0 and 3,000 cfs in less than an hour. These criteria cannot be simulated in CALSIM. They were dynamically simulated using the operating rules feature in DSM2. The north Delta diversion operating rule in DSM2 allows diversion up to the amount specified by CALSIM each day while subjecting each intake to the surrogate sweeping velocity and ramping criteria. The intakes were operated as long as the daily diversion volume specified by CALSIM was not met. Once the specified volume was diverted for the day, the pumps were shut off until the next day.

The volume corresponding to the first 900 cfs of the daily north Delta diversion specified by CALSIM was diverted equally at all three intakes (low level pumping of 300 cfs at each intake). The remaining volume for the day was diverted such that operation of the upstream intakes was prioritized over the downstream intakes. Intake diversions were ramped over an hour to allow smooth transitions and minimize model instabilities when they were turned on and off. The diversion flow at an intake for each time step was estimated assuming that the remaining diversion volume in a day would have to be diverted in one time step at the upstream-most intake first, followed by the next downstream intake, and finally the most downstream intake until the daily specified total was diverted. This basic scheme was adjusted by the surrogate sweeping velocity criteria noted above.

The salient point from these detailed modeling assumptions is that the north Delta intake operations largely were governed by cross-section-averaged sweeping velocity (unadjusted for the velocity at the screen face) downstream of each intake, as opposed to further downstream. There was no explicit consideration of tidal state (e.g., "do not pump during flood tides"), although tidal state would influence the criteria expressed in the modeling assumptions. Multi-dimensional modeling will be necessary to refine estimates of potential diversions.

Analyses of Sacramento River Reverse Flows and Sacramento River Flow Entering Georgiana Slough

The analyses of reverse flows and flow entry into Georgiana Slough were based on 15-minute outputs from the DSM2-HYDRO simulations for each scenario. The results were computed for

16 years, starting from water year 1976 to water year 1991. Flow outputs for Sacramento River downstream of Georgiana Slough (Channel 423 at 1,000 feet or SAC_37), Sacramento River upstream of Georgiana Slough (Channel 422 at 1320 feet or SAC_36), Georgiana Slough (Channel 366 at 0 feet or GEORG_SL), and the net DICU (Delta Island Consumptive Use) flow at node 343 were used.

Monthly Percentage of Sacramento River Reverse Flows Downstream of Georgiana Slough

The frequency of flow reversals in the Sacramento River downstream of Georgiana Slough (SAC_37) was computed by determining the percentage of all the 15-minute flow outputs in each month that had reverse flows, i.e., reverse flows towards the Sacramento River-Georgiana Slough junction. This analysis was conducted for all months and all scenarios.

Percentage of Total Sacramento River Flow Entering Georgiana Slough and Percentage of Reverse Flows

The percentage of Sacramento River flow that approached the Sacramento River-Georgiana Slough junction and entered Georgiana Slough was calculated for each 15-minute output period from DSM2-HYDRO. Three main conditions could occur during each 15-minute time step.

- **Condition 1:** Negative (reversed) Sacramento River flow downstream of Georgiana Slough (SAC_37), i.e., the direction of flow was upstream towards the junction, coupled with positive Sacramento River flow upstream of Georgiana Slough (SAC_36), i.e., the direction of flow was downstream towards the junction. During condition 1, the flow in Georgiana Slough is assumed to be contributed by Sacramento River flows, originating from both upstream and downstream of the junction, as the ratio of the upstream and downstream flow magnitudes, e.g., a reverse Sacramento River flow of 1,000 cfs and a downstream Sacramento River flow of 3,000 cfs would mean that 25% of the water in Georgiana Slough would be from Sacramento River reverse flows and 75% of the water would be from positive Sacramento River flows flowing in a downstream direction.
- **Condition 2:** Negative Sacramento River flow downstream of Georgiana Slough (SAC_37), i.e., the direction of flow was upstream towards the junction, coupled with negative Sacramento River flow upstream of Georgiana Slough (SAC_36), i.e., the direction of flow was upstream away from the junction. During condition 2, the flow entering Georgiana Slough is assumed to be entirely from the reversed Sacramento River flows from downstream of the junction.
- **Condition 3:** Positive flow upstream and downstream of Georgiana Slough. For this condition, only Sacramento River upstream of Georgiana Slough (SAC_36) contributes to Georgiana Slough flow.

For each 15-minute time step, the percentage contribution of upstream and downstream (reverse flows) to Georgiana Slough flows was calculated. The rare occasions in which Georgiana Slough flow was reversing and for which no Sacramento River flow entered Georgiana Slough were excluded from the calculations. The results for all 15-minute time steps were averaged by month. Results are reported below for the monthly average percentage of total Sacramento River flow approaching the Sacramento River-Georgiana Slough junction that entered Georgiana Slough. Also presented in the results is the percentage of reverse flows that entered Georgiana Slough, as this provides an indicator of the risk of advection back upstream into Georgiana Slough for fish that have passed the Sacramento River-Georgiana Slough junction.

The DSM2 simulation period is limited to 16 water years (1976–1991), with a different percentage of water-year types compared to the 82-year CALSIM period (Table 5C.4-25). To assess possible differences in the results based on the percentage of different water-year types, the average percentage of total Sacramento River flow entering Georgiana Slough was calculated for each month in each water-year type for each scenario from the results based on the DSM2 modeling. The monthly averages for each water-year type were then weighted by the percentage of that water year type that is present in the 82-year CALSIM simulation period. This recalculated 82-year grand average for each month was then compared to the grand average from the original DSM2 simulation period.

Table 5C.4-25. Comparison of Number and Percentage of Different Water Year Types from DSM2 and CALSIM Simulation Periods

Water-Year Type	Number of Years		Percentage of Years	
	DSM2	CALSIM	DSM2	CALSIM
Wet	4	26	25%	32%
Above Normal	2	12	13%	15%
Below Normal	1	14	6%	17%
Dry	4	18	25%	22%
Critical	5	12	31%	15%

Assumptions

The main assumptions for the two analyses described above were as follows.

- The 15-minute time step flow data at Sacramento River downstream of Georgiana Slough (SAC_37) is the closest to the junction available from DSM2-HYDRO outputs and represents the flow downstream of the Georgiana Slough junction.
- The 15-minute time step flow data at Sacramento River upstream of Georgiana Slough (SAC_36) is the closest to the junction available from DSM2-HYDRO outputs and represents the flow upstream of the Georgiana Slough junction.
- 15-minute time step flow data at Georgiana Slough (GEORG_SL) is the closest to the junction available from DSM2-HYDRO and represents the flow in Georgiana Slough.
- Flow directions were determined based on the magnitude of the 15-minute instantaneous flow data, where positive flow was assumed to be greater than or equal to 1.0 cfs and negative (reverse) flow was assumed to be less than or equal to -1.0 cfs.
- When upstream and downstream flows are towards the junction (i.e., Condition 1 above), Georgiana Slough flow is assumed to be contributed by both upstream and downstream flows in the ratio of their relative magnitudes. Similarly, DICU is assumed to be contributed by upstream and downstream flows in the same ratio.
- During conditions when flows downstream of the junction are reversing and this is the only flow towards the junction (i.e., Condition 2 above), Georgiana Slough flow is assumed to be contributed entirely by the reversed flow. Similarly DICU is assumed to be contributed entirely by the reversed flow.

- During conditions when flows upstream and downstream of the junction are positive (i.e., Condition 3 above), Georgiana Slough flow is assumed to be contributed entirely by the Sacramento River flow from upstream. Similarly DICU is assumed to be contributed entirely by the Sacramento River flow from upstream.

Percentage of Chinook Salmon Smolts Entering Georgiana Slough/Delta Cross Channel and Steamboat/Sutter Sloughs (Delta Passage Model)

The methods of analysis for reverse flows in the Sacramento River described above provide important context for understanding potential differences in river hydrodynamics between existing biological conditions and BDCP scenarios. A more direct biological linkage is provided by considering the percentage of Chinook salmon smolts from the Sacramento River watershed entering Georgiana Slough and the Delta Cross Channel, using available outputs of the DPM for winter-run, spring-run, fall-run, and late fall–run Chinook salmon. Detailed methods for the DPM are provided in Section 5C.4.3.2.2, *Juvenile Chinook Salmon Smolt through-Delta Survival (Delta Passage Model)*. As discussed therein, Perry (2010) found a linear, nonproportional relationship between flow and smolt entry in Georgiana Slough/Delta Cross Channel. His relationship was applied in the DPM to assess the percentage of downstream-migrating Chinook salmon smolts entering Georgiana Slough/Delta Cross Channel:

$y = 0.22 + 0.47x$;

where y is the proportion of fish diverted into Georgiana Slough/Delta Cross Channel and x is the proportion of Sacramento River flow diverted into Geo/DCC (using DSM2-HYDRO flow data for rsac128 and dcc+georg_sl). The proportion was converted to a percentage.

Note that this analysis does not deal directly with potential advection back upstream of Chinook salmon smolts that have passed the Georgiana Slough junction because the DPM does not allow for movement back upstream. Rather, the analysis accounts for the greater percentage of Chinook salmon smolts that would enter Georgiana Slough should reverse flows occur and contribute to greater Georgiana Slough flow relative to Sacramento River flow. The calculations are made on a daily basis and are summed to give the annual percentage of Chinook salmon smolts from each run that entered the interior Delta through Georgiana Slough or the Delta Cross Channel. Note that this is not the same as considering the percentage of smolts from each run that took the interior Delta pathway (as presented in the main DPM results), because the present analysis considers only those approaching the Georgiana Slough/Delta Cross Channel junctions and not the percentage of the total smolts assumed to be entering the Plan Area above Fremont Weir.

In addition to consideration of the percentage of smolts entering the interior Delta through Georgiana Slough/Delta Cross Channel, it is important to consider the percentage of smolts entering Steamboat/Sutter Sloughs, which are important divergences off the mainstem Sacramento River that are downstream of the north Delta intakes and upstream of Georgiana Slough and the Delta Cross Channel. Results from the DPM were used to estimate the percentage of fish entering Steamboat/Sutter Sloughs for each scenario. As described in the DPM methods, the entry of smolts into Steamboat/Sutter Sloughs is assumed to be the same as the flow split, which is derived from DSM2 modeling outputs. An adjusted estimate of the percentage of smolts approaching Steamboat/Sutter Sloughs that would enter Georgiana Slough/Delta Cross Channel, accounting for smolts that would have entered Steamboat/Sutter Sloughs, was made using the formula:

> Percentage of fish approaching Sutter/Steamboat Sloughs that enter Georgiana Slough or Delta Cross Channel = ([1 – proportion entering Steamboat or Sutter Sloughs] × [Proportion entering Georgiana Slough orDelta Cross Channel]) × 100.

Note that this formula does not aim to account for any mortality of fish; it simply considers whether any between-scenario differences in the percentage of smolts entering Steamboat/Sutter Sloughs has an effect on the percentage of fish that could enter Georgiana Slough/Delta Cross Channel.

The daily proportion of smolts entering the Plan Area differs for each run of Chinook salmon from the Sacramento River and therefore provides information about potential entry into the interior Delta through Georgiana Slough/Delta Cross Channel over different seasons (Figure 5C.4-26). Winter-run Chinook salmon mostly overlaps winter (December–February) and early spring (March/early April). Spring-run Chinook salmon primarily overlaps spring (March–May). Fall-run Chinook salmon peaks in late spring (early May) and overlaps April–June. Late fall–run Chinook salmon has the broadest entry distribution (summer–winter), with the greatest entry assumed to be in fall (Figure 5C.4-26). Data sources for the derivation of these entry distributions is provided in the DPM methods section.

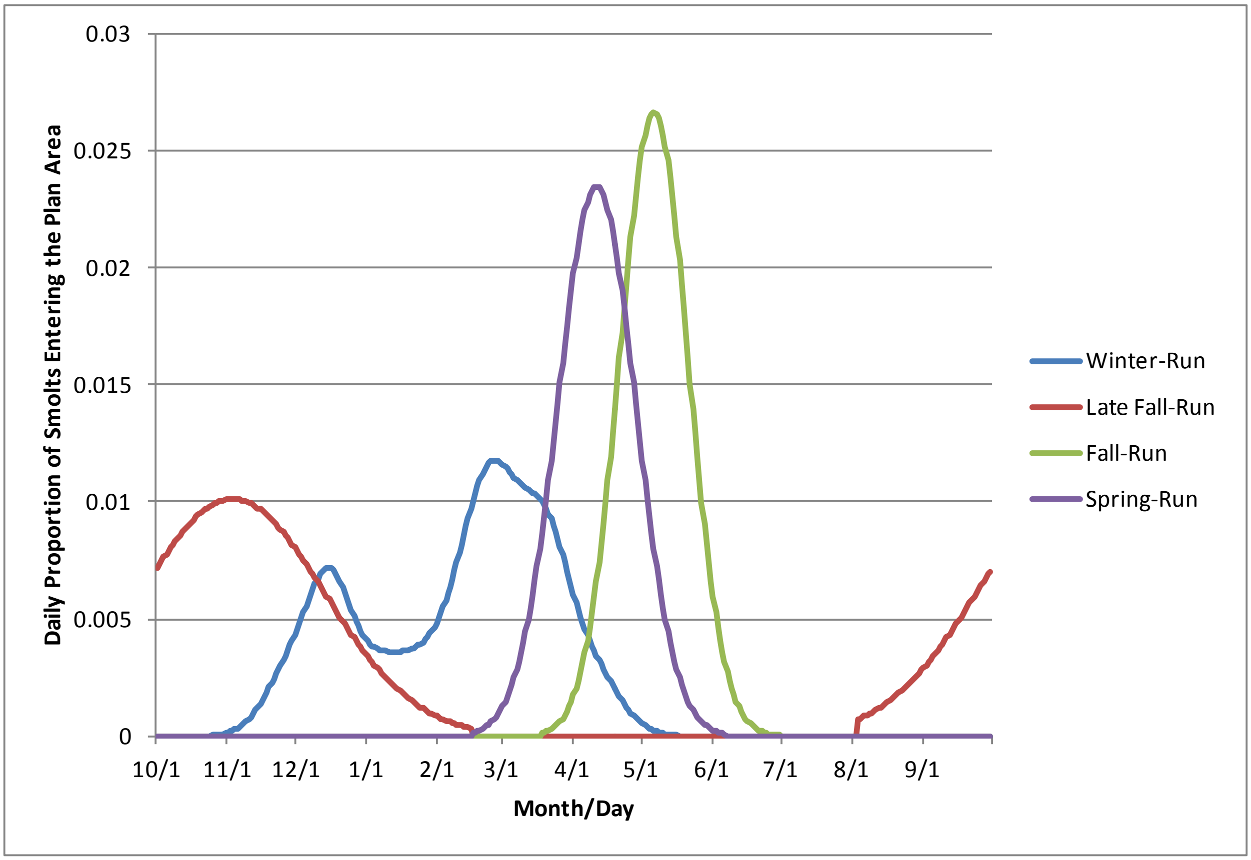

Figure 5C.4-26. Assumed Entry Distribution of Chinook Salmon Smolts from the Sacramento River Watershed into the Plan Area

5C.4.4 Delta Habitat (Plan Area) Methods

5C.4.4.1 General Flow Changes in the Plan Area

Flows in the Plan Area were based on a compilation of information from the hydrologic modeling of changes in seasonal flows in the lower Sacramento River (Rio Vista model node), reverse flows in OMR, and lower Sacramento River stage each month over the 82-year hydrologic period, as well as data summarized by month and water-year type using frequency of exceedance plots. A summary of changes in Delta outflow also was used as an indicator of habitat conditions in the Delta. Comparisons were made using monthly flow estimates for Sutter and Steamboat sloughs as well as Geo/DCC flows. Changes in flows and flow patterns in these areas were used as comparative indices of changes in Delta habitat conditions. Results of frequency of exceedance analyses were used to assess changes in flows over a range of hydrologic conditions.

5C.4.4.2 Yolo Bypass Floodplain Habitat (*CM2 Yolo Bypass Fisheries Enhancement*)

5C.4.4.2.1 Sacramento Splittail Habitat Area

Sacramento splittail typically spawn in inundated floodplains and channel margins of the Sacramento, San Joaquin, and Cosumnes Rivers during late winter and spring (Moyle et al. 2004; Feyrer et al. 2005; Sommer et al. 2007). The most important spawning habitat occurs in the inundated floodplains of the Sutter and Yolo Bypasses of the Sacramento River. The BDCP proposes in *CM2 Yolo Bypass Fisheries Enhancement* to increase the frequency and duration of Yolo Bypass inundation by lowering the height of a section of the Fremont Weir and replacing it with an operable gate.

This analysis of floodplain habitat availability addresses habitat availability for all floodplain-dependent life stages because the value of the habitat for the egg/embryo life stage is affected by the behavior (spawning adults) and survival (larvae and juveniles) of the other life stages that use that habitat. Thus, for example, floodplain habitat with suitable conditions for survival of the egg/embryo stage has no habitat value unless it remains inundated long enough for later floodplain-dependent life stages to complete their development.

The hydrologic results of CM2 were assessed using daily CALSIM II output of the Sacramento River spills at the Fremont Weir and concurrent flows for the major west-side bypass tributaries. Predicted spill timing and volume over the weir were used to determine the timing, frequency, and duration of inundation events. The combined volume of flow from Fremont Weir spills and the west-side tributaries was used with MIKE 21 to estimate the areal extent of inundation with depths and water velocities in the bypass. Results of the 2-D modeling were used to estimate habitat availability for splittail with and without implementation of CM2. Inundated floodplain parameters were used to assess benefits to splittail reproduction.

The MIKE 21 flexible mesh model (Attachment 5C.E, *BDCP Effects Analysis: 2D Hydrodynamic Modeling of the Fremont Weir Diversion Structure*) is modeling software used to develop a two-dimensional hydrodynamic model of the Yolo Bypass that predicts water surface elevation, flow, and average velocity at each computational grid cell. The model incorporates existing LiDAR and Toe Drain/Tule Canal bathymetry as well as estimated west-side tributary flows. Outputs of the model were used to predict the potential benefits to species that use the Yolo Bypass as habitat when inundated (e.g., splittail, Chinook salmon, etc.) and to food production.

There were 15 2-D scenarios run with the MIKE 21 model (Table 5C.4-26).

Table 5C.4-26. Description of Model Runs using MIKE 21 Yolo Bypass Model

Sacramento River Flow at Verona Sampling Range (cfs)		Restricted Notch Flow (cfs)	Knights Landing Ridge Cut (cfs)	Cache Creek (cfs)	Willow Slough (cfs)	Putah Creek (cfs)	West Side Tributaries Only[a]		West Side Tributaries Plus Notch Flow[b]	
							Run ID	Flow (cfs)	Run ID	Flow (cfs)
23,100	28,600	0	364	473	134	154	10A	1,125	10B	1,125
28,600	32,550	1,000	735	965	179	291	11A	2,170	11B	3,170
32,550	35,300	2,000	971	1,079	213	383	12A	2,647	12B	4,647
35,300	37,500	3,000	1047	1,344	243	439	13A	3,073	13B	6,073
37,500	39,200	4,000	998	1,235	329	415	14A	2,976	14B	6,976
39,200	40,750	5,000	1,359	2,227	353	403	15A	4,343	15B	9,343
40,750	42,150	6,000	1,654	1,891	218	273	16A	4,037	16B	10,037
54,000	56,000	6,000	1,911	3,190	428	760	17A	6,289	17B	12,289

[a] Without CM2.
[b] With CM2.

Post-processing analysis of the modeling results included the following assumptions regarding splittail habitat.

- Depth is the most important quantifiable habitat attribute for splittail on the floodplain. Flow velocity is also quantifiable, but model runs indicated that it is consistently low over much of the bypass at all flow rates, which makes it suitable for early stages of splittail.
- Shallow water habitat (less than 2 meters depth) must be inundated continuously for longer than 30 days to provide reproductive benefits for splittail. Thirty days is the estimated minimum time required for development from splittail eggs to emigrating juveniles, based on estimated values reported in the literature (e.g., Feyrer et al. 2004, 2006; Moyle et al. 2004; Sommer et al. 2007). The threshold for depth, 2 meters, is based on results from Sommer et al. (2004, 2008) and Feyrer et al. (2006).
- Only floodplain inundation between February 1 and June 30 benefits splittail. This period was used because year-class abundance of splittail is determined primarily by floodplain spawning and rearing habitat conditions during these months (Sommer pers. comm.).
- HSI values for depth ranges for young splittail were estimated from results in Sommer et al. (2008) and discussions with Dr. Sommer as follows: 0 to 1.5 feet = 1.0, deeper than 1.5 to 4.5 feet = 0.5, deeper than 4.5 to 6.5 feet = 0.16, and deeper than 6.5 feet = 0.

An index of Yolo Bypass splittail habitat was computed as the surface area of habitat of the depth ranges listed in the assumptions above weighted by their HSI values and summed over days from February 1 to June 30, but only following 30 days of continuous bypass inundation. It should be noted that MIKE 21 cannot simulate inundated surface areas greater than about 25,000 acres in the bypass because it is designed to model flows only up to those expected in the bypass when the Fremont Weir, with the proposed notch, has just begun to spill. Higher inundated surface areas are expected to be similar among the different scenarios. In addition, surface areas were not estimated for bypass flows (weir plus west-side tributaries) less than 1,125 cfs because this is the lowest flow included in the model simulations.

5C.4.4.2.2 Stranding (Steelhead, Chinook Salmon, Sacramento Splittail, White Sturgeon, and Green Sturgeon)

Increased Yolo Bypass floodplain inundation that would occur under the BDCP increases the risk of stranding of covered fish species that may occupy the bypass during their lives, in particular salmonids, Sacramento splittail, and sturgeons. An assessment of this potential negative effect was conducted using best professional judgment and the 2009 DRERIP evaluation of Fremont Weir and Yolo Bypass Inundation (previously referred to as Water Operations Conservation Measure 2), Outcome N3 (Increased stranding of covered species). As with all DRERIP evaluations, the outcomes were rated on a scale of 1–4 for magnitude of the effect on the population and certainty of the outcome (4 being the greatest effect on the population or highest certainty).

5C.4.4.2.3 Proportion of Chinook Salmon That Could Benefit from *CM2 Yolo Bypass Fisheries Enhancement*

CM2 Yolo Bypass Fisheries Enhancement proposes a number of modifications to the Yolo Bypass and its associated infrastructure (see Chapter 3, *Conservation Strategy*, for more details). Paramount among these modifications is the notching of Fremont Weir that would allow more upstream flow to enter the Yolo Bypass. It is important to place into context the proportion of each Chinook salmon ESU that could potentially benefit from greater access to Yolo Bypass under this action, based on the relative abundance of the constituent populations from different tributaries within each ESU and their geographic position in relation to Fremont Weir. This analysis was undertaken by collating Chinook salmon ESU adult run sizes over the last decade (2002–2011) by tributary and examining the relative proportion of the each ESU occurring above and below Fremont Weir in order to infer potential enhanced use of Yolo Bypass attributable to Fremont Weir notching.

5C.4.4.2.4 Chinook Salmon Fry Yolo Bypass Growth Analysis (Fall-Run and Winter-Run Chinook Salmon)

Yolo Bypass Fry Rearing Model Methods

[*Note to Reader: Below ICF presents the results of the Yolo Bypass Fry Rearing Model. While the model has been developed and revised based on informal review by agency personnel, it is anticipated that further revision will be undertaken in response to formal comments received from this documented version of the model and additional meetings with agency personnel. In particular, ICF anticipates conducting analyses for several runs of Chinook salmon fry.*]

To inform the evaluation of *CM2 Yolo Bypass Fisheries Enhancement* in relation to potential Chinook salmon growth and survival benefits associated with proposed Fremont Weir modifications and increased floodplain rearing opportunities in the Yolo Bypass, a spreadsheet model, the Yolo Bypass Fry Rearing (YBFR) model, was developed. The YBFR model was designed to evaluate potential benefits by simulating variation in the daily percentages of Chinook salmon fry entering the Yolo Bypass and tracking their relative growth and survival to the estuary and ocean fishery.

The following text describes the model development, data sources, functional components, and results of the initial application of the model to the BDCP scenarios and Fremont Weir modifications.

The results of the model are provisional as the functional components and assumptions may be revised pending review and completion of other supporting analyses.

The YBFR model was applied to the evaluated starting operations scenarios (ESO_ELT and ESO_LLT) and the benefits were evaluated by comparing the results with those of the EBC scenarios (EBC1, EBC2, EBC2_ELT, and EBC2_LLT). The model was also applied to the high outflow scenario (HOS_ELT and HOS_LLT) to evaluate how the benefits might change relative to the ESO scenarios. The low outflow scenarios were assumed to the same as the ESO scenarios because they have the same winter-spring operations.

Model Development and Overview

The model was formulated as an Excel spreadsheet that can be readily modified to evaluate and compare the effects of alternative hydrologic and Fremont Weir structural and operational conditions. The initial model was formulated to address fall-run Chinook salmon but the model was subsequently adapted for winter-run Chinook salmon as well. Development of the initial model is described below along with modifications that were made to address winter-run. The YBFR model uses a daily timestep to track the daily percentages and growth of Chinook salmon fry that enter the Yolo Bypass or remain in the Sacramento River downstream of the Fremont Weir. The percentages of fry entering the Yolo Bypass are simulated as a function of upstream flows and the frequency and duration of Fremont Weir spills under existing and proposed structural and operational scenarios. Differential growth and survival rates are applied depending on the migration route and availability of floodplain habitat. The size of fish entering the estuary is determined based on residence time, availability of floodplain habitat, and the duration of floodplain inundation. The relative benefits of each of the scenarios are evaluated in terms of the annual percentages of fry entering the Yolo Bypass and their relative contributions to the ocean fishery. For fall-run, the results are limited to juveniles that enter the lower Sacramento River (i.e., migrate past the Fremont Weir or enter the Yolo Bypass) at a mean size of 70 mm or less. This size range was selected because juveniles within this size range appear to be most sensitive to the effects of flow on downstream movements. In addition, juveniles in this size range are most likely to benefit from floodplain rearing because of their emigration timing relative to the timing of peak spills (January through March) and their small size and capacity for additional freshwater growth before entering the estuary. For winter-run, the results reflect the full range of sizes that occur at the Fremont Weir because of their earlier emigration timing and dominance of >70-mm juveniles during peak spill periods.

This analysis is based on simulated hydrology (CALSIM II results) and synthesized daily flows in the Sacramento River at Wilkins Slough, Sacramento River at Verona, and at the Fremont Weir (daily spills) for the period 1921–2003 for the EBC and ESO scenarios.[8] For the EBC scenarios, the daily proportion of Sacramento River flow entering the Yolo Bypass is calculated using the following equation:

$$P_{YB} = S_{FW}/(S_{FW} + F_V)$$

P_{YB} = proportion of Sacramento River flow entering Yolo Bypass

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[8] CALSIM II is a monthly timestep model. All the decisions in the CALSIM II model occur on a monthly timestep. Daily flow patterns used in the YBFR model are provided only to improve the estimates of flows such as the weir spills. CALSIM II does not necessarily comply with regulatory constraints and operational requirements on a daily timestep. This analysis does not imply that all the flow requirements are complied with on a daily timestep, but daily data are used to provide an indication of sub-monthly trends.

S_{FW} = spill at Fremont Weir (cfs)

F_V = Sacramento River flow at Verona (cfs)

For the ESO scenarios and associated Fremont Weir modifications, the daily proportion of Sacramento River flow entering the Yolo Bypass is calculated using one of the following equations depending on the magnitude of Fremont Weir spills:

1) Fremont Weir spills ≤6,000 cfs:

   $P_{YB} = S_{FW}/F_{WS}$

   F_{WS}= Sacramento River flow at Wilkins Slough (cfs)

2) Fremont Weir spills >6,000 cfs:

   $P_{YB} = S_{FW}/(S_{FW} + F_V)$

Under the first condition, it is assumed that spills would be conveyed into the Yolo Bypass through the proposed notch in the Fremont Weir, and that the Sacramento River flow at Wilkins Slough approximates the total flow passing the weir (excludes Feather River and Sutter Bypass inflows until spills exceed 6,000 cfs). Under the second condition, it is assumed that spills into the Yolo Bypass would exceed the capacity of the proposed notch (i.e., the proposed notch would not be operated) and that the Sacramento River flow at Verona is most representative of the total flow subject to spill at the Fremont Weir (includes Sutter Bypass and Feather River flows minus Fremont Weir spill). This is an oversimplification of the complex hydrology that occurs in this portion of the Sacramento River system. The timing and magnitude of flows from various sources and the degree to which each source contributes to spill at the Fremont Weir is incompletely understood at this time.

Functional Components of Model

Temporal Distribution of Juveniles at Fremont Weir

Chinook salmon juveniles are tracked as daily cohorts passing Fremont Weir or entering the Yolo Bypass during the primary emigration periods. These periods are week 50 through week 15 (approximately December 10 through April 12) for fall-run fry and week 40 through week 16 (approximately October 1 through April 18) for winter-run juveniles. For fall-run, Week 15 corresponds to the time when the mean size of fry approaching the Fremont Weir reaches 70 mm based on the sizes of fall-run juveniles (identified using size-at-date criteria) captured in rotary screw traps at Knights Landing in 1996–1999 and 2002 (Snider and Titus 1998, 2000a, 2000b, 2000c) (Figure 5C.4-27). The migration patterns of Chinook salmon fry in the Sacramento River are tied to flow, with peak fry movements generally corresponding to the first major flow peaks during the fry rearing and emigration season. A preliminary analysis of this relationship for winter-run Chinook salmon indicates that peak fry movements past Knights Landing typically are triggered by flows of 400 m^3/sec (approximately 14,000 cfs) measured at Wilkins Slough (Redler pers. comm.). This threshold response is also evident for fall-run Chinook salmon juveniles trapped at Knights Landing in 1996–1999 and 2002 (Snider and Titus 1998, 2000a, 2000b, 2000c).

Based on examination of fall- and winter-run migration patterns at Knights Landing (weekly catches standardized by sampling effort), the following rules were developed to simulate weekly changes in the relative abundance of juveniles in the Sacramento River at the Fremont Weir.

- Fall-Run Chinook Salmon
  - Peak movements of fall-run fry are characterized by one or more pulses of fry that are triggered by pulse flow events in which 7-day mean daily flows exceed 14,000 cfs at Wilkins Slough between week 1 and week 10 (approximately January 1 and March 10).
  - 30% of the total numbers of juveniles that arrive at the Fremont Weir during the emigration period occur during the first two weeks following the flow trigger (15% in the first week and 15% in the second week).
  - Multiple fry pulses can occur if flow drops below and then increases above 14,000 cfs more than once during the January 1–March 15 window.
  - Assumes the following default distribution if flow trigger does not occur:
    - Week 50–53 (December 10–December 31): 1% per week.
    - Week 1–10 (January 1–March 10): 5% per week.
    - Week 11–26 (March 11–June 30): 0–2% per week depending on percentage passing earlier in season.
- Winter-Run Chinook Salmon
  - Peak movements of winter-run juveniles are characterized by a single pulse of juveniles that is triggered by the first pulse flow event in which daily flows exceed 14,000 cfs at Wilkins Slough between week 40 and week 10 (October 1 and March 10).
  - 60% of the total numbers of juveniles that arrive at the Fremont Weir during the emigration period occur during the first two weeks following the flow trigger (40% in the first week and 20% in the second week).
  - Assumes the following default distribution if flow trigger does not occur:
    - Week 40–46 (October 1–November 18): 1.5% per week
    - Week 47–10 (November 19–March 10): 5% per week
    - Week 11–17 (March 11–April 30): 0–1.5% per week depending on percentage passing earlier in season.

Currently, the spreadsheet partitions the weekly percentages of fish into equal daily percentages over each 7-day period to accommodate a daily timestep.

A multiplier has been built into the spreadsheet to convert daily percentages of fry to numerical abundance. This multiplier is the total number of juveniles (in millions) approaching the Fremont Weir over the entire emigration season, and can be fixed or allowed to vary to reflect annual variation in upstream fry production. The initial model runs have assumed a fixed total of 30 million fall-run fry and 2 million winter-run juveniles approaching Fremont Weir per year, i.e., survival from upstream spawning areas to Fremont Weir is assumed to be the same in each year.

Sizeof Juveniles at the Fremont Weir

The size of fall-run fry in each daily cohort passing the Fremont Weir was based on the mean fork lengths of fall-run (identified using length-at-date criteria) captured in rotary screw traps at Knights Landing in 1996–1999 and 2002 (Snider and Titus 1998, 2000a, 2000b, 2000c) (Figure 5C.4-27).

The size of winter-run juveniles in each daily cohort passing the Fremont Weir was based on mean monthly fork lengths of winter-run (identified using length-at-date criteria) captured in rotary screw traps at Knights Landing from 1998–2007 (National Marine Fisheries Service unpublished data). Daily length at date was derived from the relationship between mean monthly length and date, assuming that the mean monthly length was representative of the mean daily length on the 15th of each month (Figure 5C.4-28).

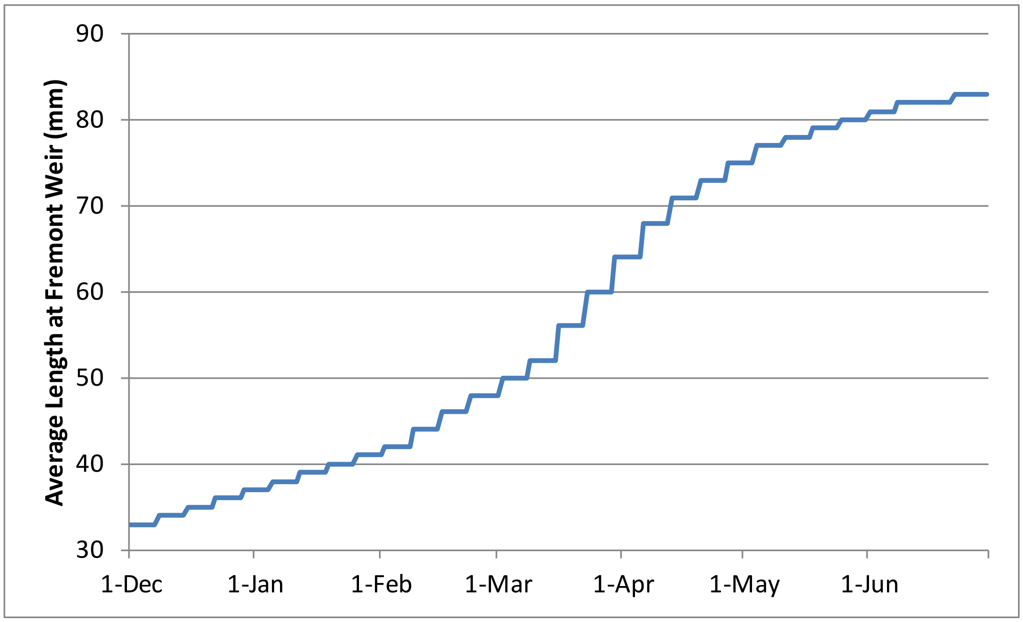


Figure 5C.4-27. Weekly Average Lengths of Fall-Run Chinook Salmon Captured by Rotary Screw Trap at Knights Landing in 1996–1999 and 2002

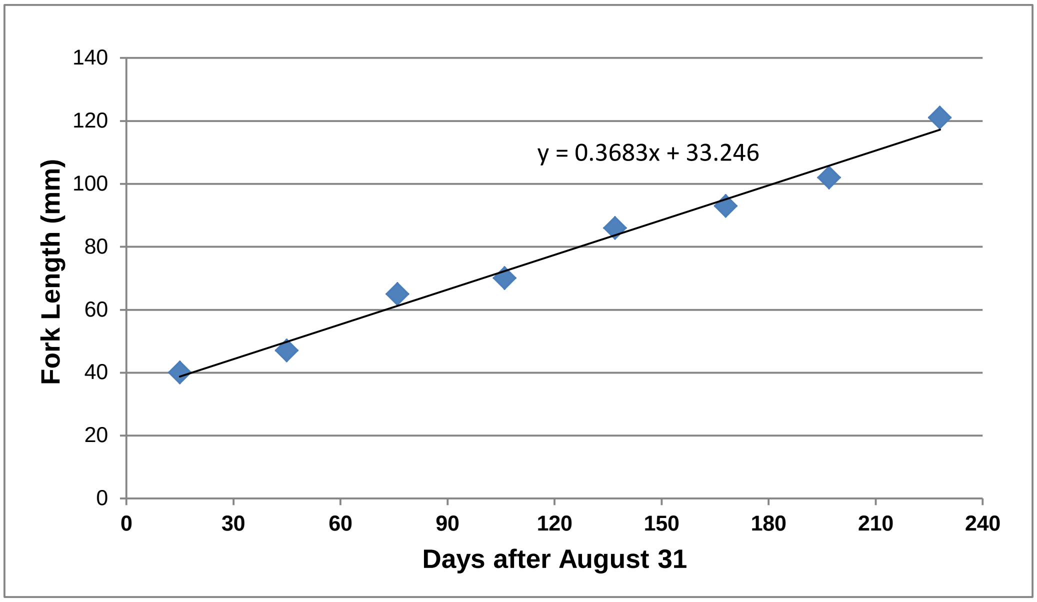


Figure 5C.4-28. Relationship Used to Derive Daily Lengths at Date for Winter-Run Chinook Salmon Based on Mean Monthly Illustrate the Fork Lengths of Winter-Run Captured by Rotary Screw Trap at Knights Landing in 1998–2007

Percentages of Juveniles Entering Yolo Bypass

The percentage of juveniles entering the Yolo Bypass during a given timestep is assumed to be the percentage of the population emigrating past the Fremont Weir multiplied by the percentage of the Sacramento River flow spilling over the Fremont Weir into the Yolo Bypass. This percentage can be adjusted to reflect a higher or lower probability of fish entering the bypass depending on their susceptibility to encountering the weir. For example, somewhat higher percentages of fry may enter the bypass than would be suggested by the percentage of flow alone because of the tendency of fry to occur along the margins of large rivers.

Currently, it is assumed that the Knights Landing catch data provide a reasonable approximation of migration timing and relative abundance of juveniles approaching the Fremont Weir. This assumption is likely to be most accurate for winter-run because all naturally produced juveniles originate in the upper Sacramento River upstream of Knights Landing (although a portion may enter the Sutter Bypass upstream of Knights Landing during flood flows and re-enter the Sacramento River downstream of Knights Landing in the vicinity of the Fremont Weir). This assumption is least accurate for fall-run because it does not account for the contributions of fall-run juveniles from other sources, including the Sutter Bypass, Butte Creek, and Feather River.

Growth Rate

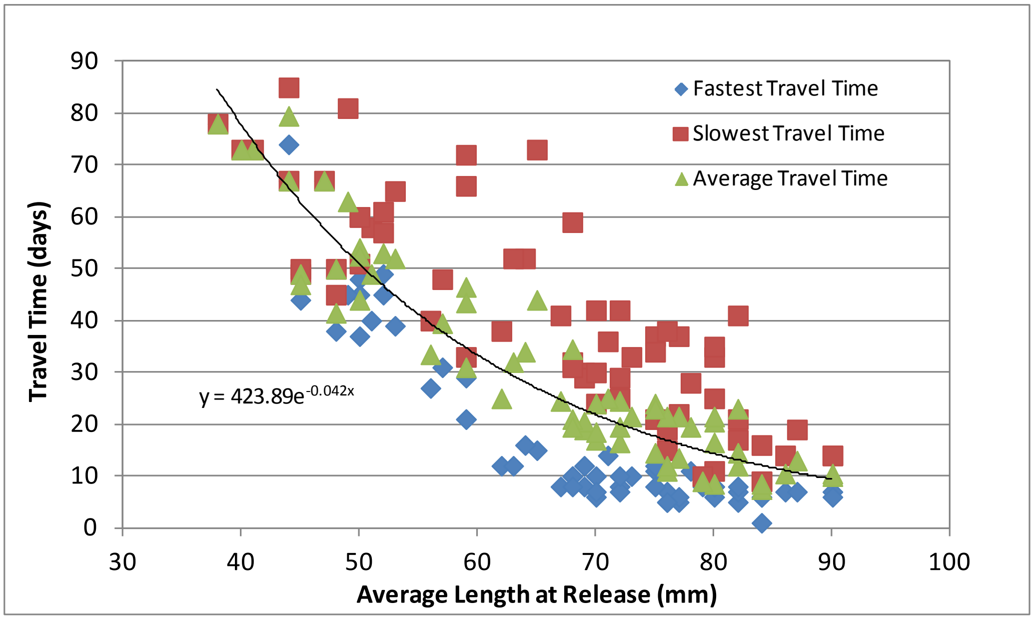
The growth rate of juvenile salmon following their arrival at the Fremont Weir depends on their migration route (Sacramento River or Yolo Bypass) and the availability and duration of floodplain habitat in the Yolo Bypass. Apparent growth rates of tagged fall-run fry released in the Yolo Bypass below the Fremont Weir and recovered at Chipps Island were higher than those of fry released in the adjacent reach of the Sacramento River in 1998 and 1999 (Sommer et al. 2001). Based on the release size of fish in this study, the apparent growth rates of these release groups were 0.8–1.1% (percent change in length per day) for fish in the Yolo Bypass and 0.6–0.7% for fish in the Sacramento River.

The following assumptions were applied to characterize growth of juvenile fall-run and winter-run in the Yolo Bypass and Sacramento River.

- The growth rates of juveniles in the Yolo Bypass and Sacramento River were set at 1.0% and 0.7%, respectively (change in body length per day). These are the average apparent growth rates of fry released in the Yolo Bypass and Sacramento River and recovered at Chipps Island in 1998 and 1999 (Sommer et al. 2001).
- Juveniles experience faster growth in the Yolo Bypass only when Fremont Weir spills are ≥3,000 cfs (corresponds to overbank flows in Toe Drain and initial floodplain inundation of Yolo Bypass). Otherwise, growth rates are equal to those of fish in the Sacramento River.
- The growth rate of fish in the Yolo Bypass shift to that of fish in the Sacramento River when fish leave the Yolo Bypass (see residence time assumptions below).

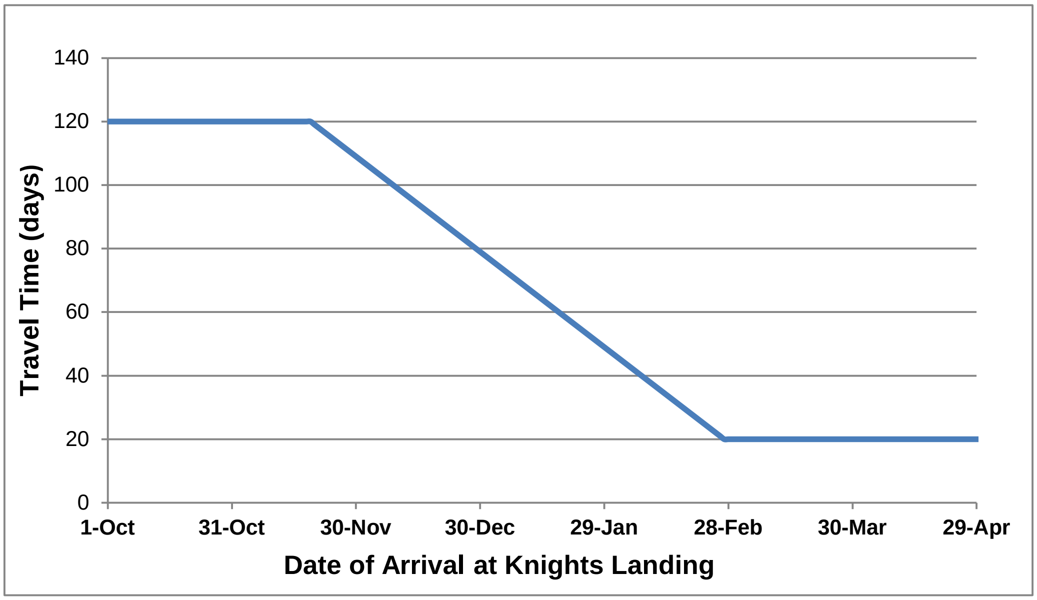
Residence Time

The migration rate or residence time of daily cohorts of fry in the lower Sacramento River or Yolo Bypass is determined by the mean size or time of arrival of fish at the Fremont Weir. For fall-run Chinook salmon, this relationship is based on average travel time (average number of days after release) of tagged hatchery fall-run juveniles released in the Sacramento River upstream of the Fremont Weir and recaptured at Chipps Island between 1980 and 2001 (Figure 5C.4-29). Similarly, the travel time or residence time of winter-run juveniles between Knights Landing and Chipps Island varies inversely with date of arrival at Knights Landing (Figure 5C.4-30). For the purposes of this analysis, this relationship was extended to April 30 and travel time was assumed to be 20 days for fish arriving at Knights Landing after February 28.



Source: U.S. Fish and Wildlife Service unpublished data.

Figure 5C.4-29. Travel Time (Average Number of Days Since Release) of Tagged Hatchery Fall-Run Chinook Salmon Juveniles Released in the Sacramento River Upstream of the Fremont Weir and Recaptured at Chipps Island between 1980 and 2001



Source: Adapted from National Marine Fisheries Service unpublished data.

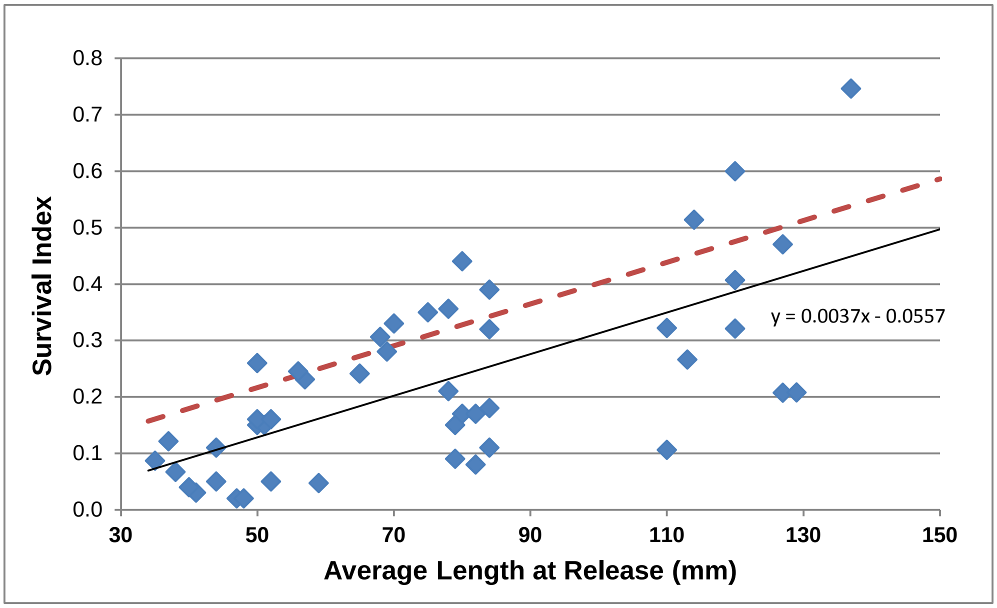
Figure 5C.4-30. Travel Time of Winter-Run Chinook Salmon Juveniles Between Knights Landing and Chipps Island

It is assumed that travel time in the lower Sacramento River or Yolo Bypass between the Fremont Weir and Chipps Island varies according to these relationships unless modified by floodplain habitat availability. Specifically, all fish that enter the Yolo Bypass when Fremont Weir spills are ≥3,000 cfs remain in the Yolo Bypass for the duration of the flood event (exiting the bypass 7 days after spills cease to account for floodplain drainage) regardless of residence time. However, if these drainage events occur before the end of the residence period, the fish are assumed to spend the remainder of this period in the Delta before entering the estuary. This simplification is intended to capture the maximum growth opportunity associated with floodplain rearing. Although residence time of juveniles in the Yolo Bypass is variable, the extended period of floodplain rearing is supported by the relatively slow migration rate, substantial growth, and relatively high concentration of juveniles moving off the floodplain during drainage events (Sommer et al. 2005).

Survival to Estuary

Differences in the relative survival and ocean recovery rates of fry released in the Yolo Bypass and Sacramento River in 1998, 1999, and 2000 suggest that survival may, at least in some years, be substantially higher for salmon that migrate through the Yolo Bypass floodplain (Sommer et al. 2001, 2005). Fry released into the Yolo Bypass in 1998, a year of extensive floodplain inundation, had the highest estuarine and ocean recovery rates as well as the highest apparent growth rates observed during the study. Although the mechanisms are not well defined for most populations, higher growth rates and/or larger size of juvenile Chinook salmon during rearing and outmigration periods have been shown to correlate with higher survival of juveniles to the smolt and adult life stages (Zabel and Achord 2004; Beckman et al. 1999). For the purposes of this assessment, the survival rates of fall-run fry (30–70 mm) migrating to the estuary via the Yolo Bypass and lower Sacramento River routes were set at 12.5% and 8.0%, respectively, based on the average survival indices for fry released in the Yolo Bypass and Sacramento River and recovered at Chipps Island in 1998 and 1999.

Because of the larger range of sizes of winter-run juveniles addressed by the model (30–150 mm), survival to the estuary (i.e., Chipps Island) was assumed to increase with size based on coded-wire-tagged (CWT) recoveries of hatchery juveniles released in the Sacramento River upstream of the Fremont Weir and recaptured at Chipps Island (Figure 5C.4-31). The Chipps Island survival indices are the observed recovery rate (number of fish recovered divided by number released) scaled by a measure of gear efficiency. Most of the release groups were fall- and late fall–run hatchery juveniles released in the Sacramento River at Red Bluff Diversion Dam and in Battle Creek at Coleman National Fish Hatchery. The resulting regression equation was applied to winter-run juveniles remaining in the Sacramento River based on their mean size at the Fremont Weir (Figure 5C.4-31). In the absence of data on the relative survival of juveniles migrating to the estuary via the Yolo Bypass and lower Sacramento River, the regression intercept was shifted upward based on the percent difference in survival of fry released in the Yolo Bypass and Sacramento River in 1998 and 1999 (56% higher on average for fry released in the Yolo Bypass at a mean size of 57 mm) and the resulting regression equation was applied to winter-run juveniles entering the Yolo Bypass during periods of floodplain inundation (Figure 5C.4-31).



Source: U.S. Fish and Wildlife Service unpublished data. Note: Regression lines represent relationships applied to winter-run juveniles in the lower Sacramento River [solid line) and Yolo Bypass (dashed line).

Figure 5C.4-31. Chinook Salmon Survival Indices Based on Recoveries of Tagged Hatchery Juveniles Released in the Sacramento River Upstream of the Fremont Weir and Recaptured at Chipps Island, 1980–2001

Ocean Survival Index

Relative survival of juveniles from the estuary (Chipps Island) to the ocean fishery was computed using a regression equation between ocean recovery rate and fish size developed from the data presented in Sholes and Hallock (1979) (Figure 5C.4-32). Ocean recovery rates are the estimated recovery rate (number of fish recovered in the ocean commercial and sport fisheries divided by number released) expanded for sampling effort. The regression is supported by the general trend in ocean recovery rates reported for tagged hatchery fall-run juveniles released in the estuary between 1993 and 2006 (U.S. Fish and Wildlife Service unpublished data). Most of these releases were made in the Sacramento River at Red Bluff Diversion Dam and in Battle Creek at Coleman National Fish Hatchery. The data reported by Reisenbichler (1981) also support this general relationship. Although highly variable (due in part to annual variation in fishing effort), the data indicate a general positive relationship between body size and subsequent fishery returns.

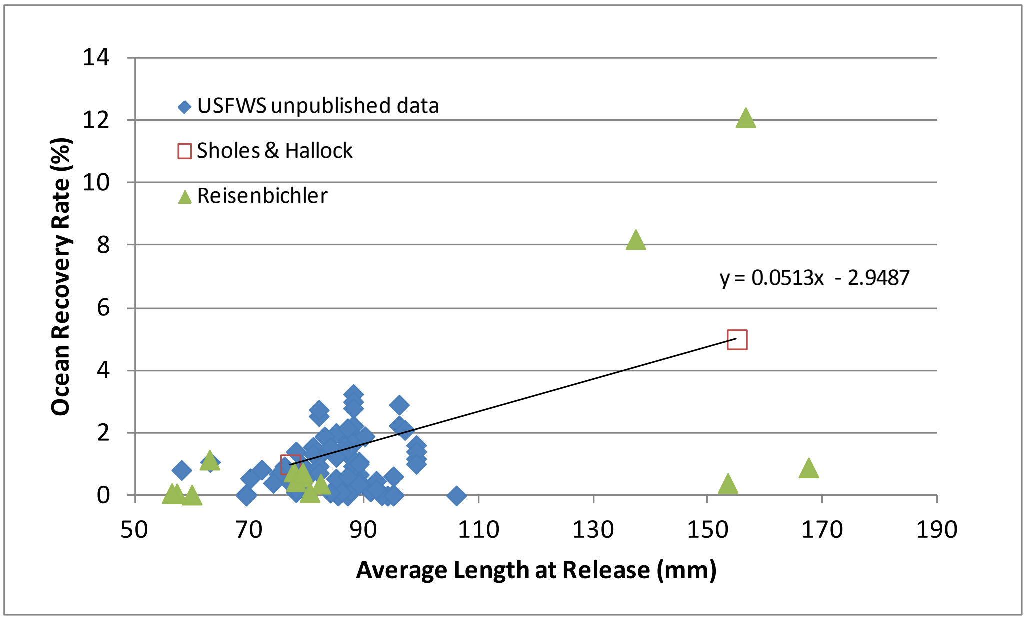


Figure 5C.4-32. Estimated Ocean Recovery Rates for Tagged Hatchery Fall-Run Chinook Salmon Juveniles Released in the Estuary between 1993 and 2006

Model Sensitivity to Changes in Fry Survival in Sacramento River

A sensitivity analysis was performed to evaluate the potential effects of changes in fry survival in the lower Sacramento River on overall benefits associated with implementation of proposed Fremont Weir modifications under *CM2 Yolo Bypass Fisheries Enhancement*. In the main analyses, a fixed survival rate of 8.0% was applied under both the EBC and ESO scenarios to characterize fry survival in the the Sacramento River between the Fremont Weir and Chipps Island. However, the BDCP has the potential to negatively affect fry survival in the Sacramento River from baseline levels because of factors such as less river flow (caused by greater spill into the Yolo Bypass and the use of the north Delta intakes) and impingement or predation at the north Delta intakes, both as a result of *CM1 Water Facilities and Operation*. Changes in survival could also occur because of positive aspects of the BDCP such as *CM6 Channel Margin Enhancement*, and *CM16 Nonphysical Fish Barriers*. The YBFR model was used to examine the effects of lower survival in the Sacramento River on overall returns to the ocean fishery, and determine the extent to which survival would need to be reduced to offset the benefits associated with implementation of proposed Fremont Weir modifications under CM2. Note that this analysis focuses only on the aspects included in the YBFR model.

The sensitivity analysis was applied to fall-run and performed for the ESO_LLT scenario. For the ESO_LLT, fry survival in the Sacramento River between the Fremont Weir and Chipps Island was reduced in 1% increments from 8.0% to 5.0% (while holding fry survival in the Yolo Bypass constant at 12.5%) and the results were presented in terms of changes in ocean fishery returns relative to total fishery returns under EBC2_LLT.

5C.4.4.2.5 Lower Sutter Bypass Inundation

The Sutter Bypass is the second largest floodplain system of the Sacramento River, after the Yolo Bypass. It provides important spawning and rearing habitat for Sacramento splittail and is a major rearing habitat area for salmonids and other native fish species (Feyrer et al. 2006b). Source water for the Sutter Bypass includes the Butte Creek–Butte Slough system; overtopping by the Sacramento River of the Tisdale Weir, Moulton Weir, and Colusa Weir at high river flows; and inundation of the lower Sutter Bypass when elevated Sacramento River flow backs up into the bypass at its confluence with the river. The lower Sutter Bypass is defined as the portion of the Sutter Bypass that extends from Willow Slough to the Sacramento River.

The lower Sutter Bypass enters the Sacramento River about two kilometers downstream of the Fremont Weir at the head of the Yolo Bypass. *CM2 Yolo Bypass Fisheries Enhancement* includes installation of a notch in the Fremont Weir to allow diversion Sacramento River flow into the Yolo Bypass at lower river stages than currently required. The notch, as currently planned, would have a capacity of 6,000 cfs. Assuming no offsetting changes in operations, the diversion of this flow would reduce the flow in the river at its confluence with the Sutter Bypass, which has the potential to reduce the frequency and extent of inundation of the lower Sutter Bypass. Reducing inundation of the lower Sutter Bypass has the potential to reduce the availability of habitat for splittail and juvenile salmonids in this portion of the bypass.

The potential effect of the ESO on inundation of the lower Sutter Bypass was evaluated by assessing the effect of the ESO on the stage of the Sacramento River at Verona, which is located at the confluence of the bypass and the river, and estimating how changes in the stage would affect the surface area of bypass inundation. CALSIM II simulations of daily flow of the Sacramento River at Verona for 10/1/1922–9/30/2003 under the EBC1, EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT and ESO_LLT scenarios were converted to estimates of river stage using the stage–discharge relationship for the USGS gage at Verona. The stage data were converted to NAVD88 to match the elevation data obtained for the bypass. The surface area of the bypass inundated at different rivers stages was estimated from DWR's LiDAR data of the lower Sutter Bypass, which provide ground elevation estimates for a large number of locations within the lower bypass. The elevation and location data were converted to lower bypass surface areas for a range of elevations using GIS (Table 5C.4-27). The daily estimates of Sacramento River stage, converted to NAVD88 elevations, were used with DWR's LiDAR data to obtain daily estimates of the surface area inundated in the lower Sutter Bypass (Table 5C.4-27). The analysis was seasonally restricted to the wet season (December–June), when most inundation of the lower Sutter Bypass occurs.

Table 5C.4-27. Cumulative Surface Area at Different Elevations in the Lower Sutter Bypass Area

Elevation (NAVD88) (feet)	Surface Area (acres)
19.5	91
20.5	348
21.5	720
22.5	1,217
23.5	1,735
24.5	2,273
25.5	2,979
26.5	3,659
27.5	4,188
28.5	4,540
29.5	4,872
30.5	5,116
31.5	5,290
32.5	5,486
33.5	5,663
34.5	5,933
35.5	6,186
36.5	6,714

5C.4.4.3 Wetland Bench Inundation (Juvenile Salmonids)

A number of Delta levees maintained by USACE and DWR incorporate habitat benches (also referred to as *relic benches*). These are shallow areas along the channel margins that have shallower slopes (e.g., 1:10 instead of the customary 1:3) and are designed to be wetted or flooded during certain parts of the year to provide habitat for covered fish and other species. Generally, there are two types of habitat benches: wetland benches and riparian benches. Wetland benches are at lower elevations where more frequent wetting and inundation may be expected, and riparian benches occupy higher portions of the slope where inundation is restricted to high-flow events. Benches were planted and often secured with riprap or other materials.

Covered activities that would result in changes in river stage, and inundation frequency and duration of wetland benches, include water operations (reductions in flow below the north Delta diversions; increased flow down the Yolo Bypass into the Cache Slough subregion) and habitat restoration (tidal muting in areas upstream of Restoration Opportunity Areas [ROAs]). A comparison of bench elevation data with modeled river stage was conducted at each of 11 wetland benches for which elevation data were available (Figure 5C.4-33).

Daily river stage outputs from DSM2-HYDRO at the node nearest to each habitat bench were paired with each particular bench. Sites that included several habitat benches with identical elevations close to the same DSM2-HYDRO node were combined for the analysis (i.e., sites 3, 4, and 5; sites 6 and 7) (Figure 5C.4-33). Because actual elevations of habitat benches varied among sites, inundation frequencies were derived for four different elevations (0, 2, 4, and 6 feet [North American Vertical Datum of 1988 (NAVD 88)]) representing hypothetical bench habitats occurring at these elevations.

This facilitated a systematic cross-comparison among sites, without the confounding effect of varying elevations of actual habitat benches. By comparing inundation frequencies across different scenarios and time horizons, we were able to address potential effects of BDCP on the frequency of bench inundation and hence the functionality of habitat benches under difference scenarios. The lower elevations were assumed to represent the intertidal portion of habitat benches, whereas the higher elevations were assumed to represent the riparian portion of habitat benches.

If the minimum daily stage at the respective site exceeded the elevation of the site, the site was deemed to be completely inundated for a full 24-hour period. The frequency of inundation was calculated as the number of days during which river stage exceeded the minimum elevation of the habitat bench for all model scenarios at each site.

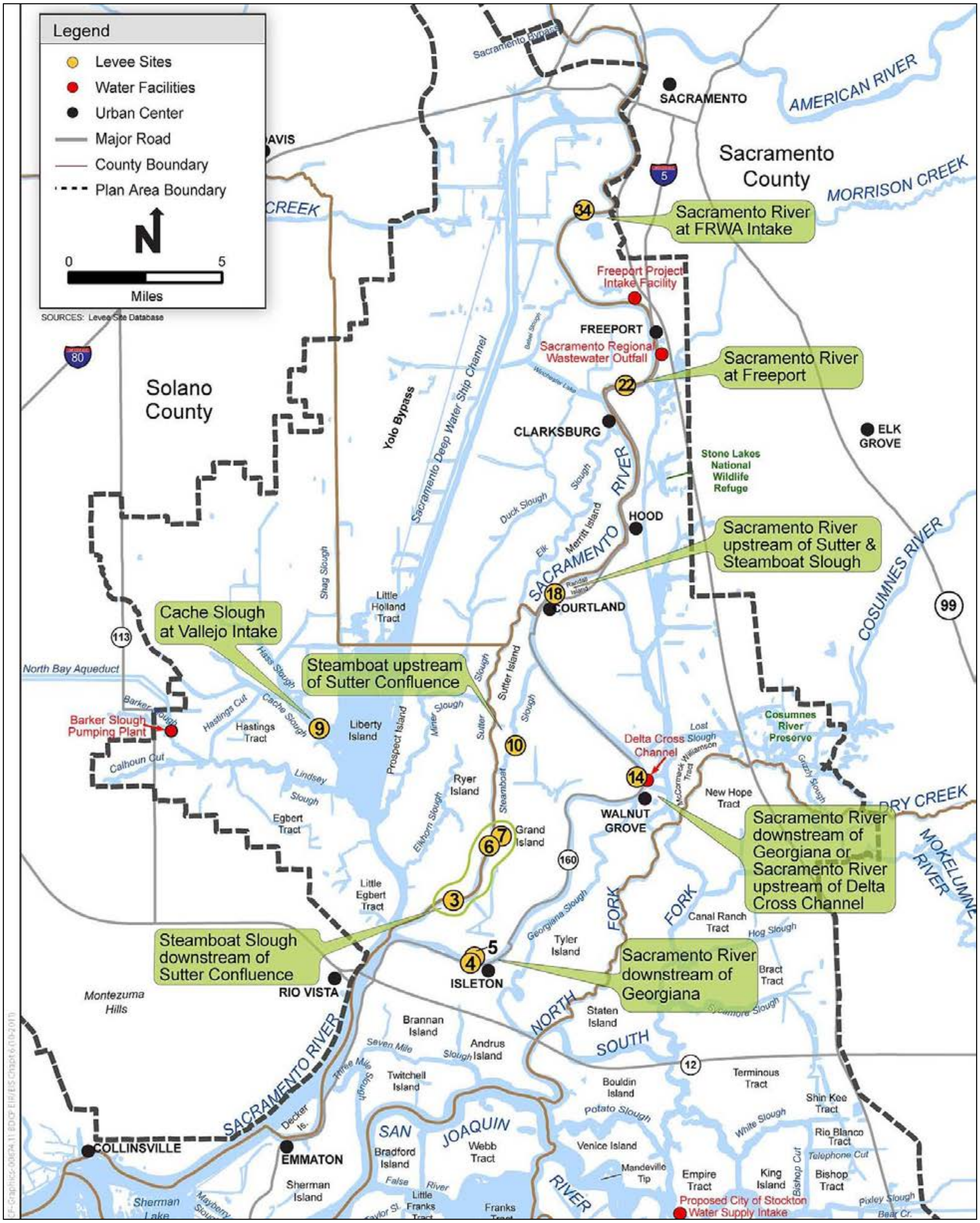


Figure 5C.4-33. Bench Habitat Analysis Sites

5C.4.4.4 Water Temperature

Comparisons of water temperature differences between existing biological conditions and evaluated starting operations scenarios were not conducted for the Plan Area. The reasoning behind this is provided in the USFWS (2008:194) OCAP BiOp:

> The [state and federal] water projects have little if any ability to affect water temperatures in the Estuary (Kimmerer 2004). Estuarine and Delta water temperatures are driven by air temperature. Water temperatures at Freeport can be cooled up to about 3°C by high Sacramento River flows, but only by very high river flows that cannot be sustained by the projects. Note also that the cooling effect of the Sacramento River is not visible in data from the west Delta at Antioch (Kimmerer 2004) so the area of influence is limited.

Attachment 5C.C, *Water Temperature*, provides the DSM2-QUAL comparison of water temperatures under existing biological conditions with BDCP's preliminary proposal. Although the preliminary proposal has been superceded by the evaluated starting operations (one potential outcome of the decision tree process, as encompassed by Alternative 4 of the BDCP EIR/EIS), the comparison between EBC scenarios and Alternative 1A scenarios is provided to illustrate that there is very little difference in Plan Area water temperatures between these scenarios. Water temperature differences between scenarios are attributable to climate change, as discussed in Appendix 2.C, *Climate Change Implications and Assumptions*.

5C.4.4.5 Dissolved Oxygen

Changes to the foodweb as a result of the BDCP may alter the amount of biochemical oxygen demand, which, when combined with changes to residence time and water temperatures as a result of the BDCP, can alter the concentration of DO in Delta channels. Two sets of analyses were conducted to assess potential changes in DO. At the broad scale, spatial and seasonal patterns of DO concentrations in the Delta for the six scenarios were analyzed using DSM2-QUAL estimates for the stations in the subregions shown in Table 5C.C-2 (in Attachment 5C.C, *Water Temperature*). The DSM2-QUAL nutrient model (Attachment 5C.F, *Numerical Modeling in Support of Bay Delta Conservation Plan: DSM2/QUAL Nutrient Model, Modeling Nutrients and Temperature*) was used for each model scenario to estimate DO concentrations because of the combined changes in hydrology, phytoplankton production, residence time, and water temperature. The *Water Quality Control Plan for the Sacramento River and San Joaquin River Basins* (Central Valley Regional Water Quality Control Board 2009) sets DO objectives for the Delta. The objectives are 7.0 mg/L for the Sacramento River (below the I Street Bridge) and all Delta waters west of the Antioch Bridge, 6.0 mg/L for the San Joaquin River (between Turner Cut and Stockton from September 1 through November 30), and 5.0 mg/L for all other Delta waters. Analyses were conducted in relation to these general criteria because few species-specific criteria are given for covered species in the DRERIP conceptual models. An exception is white sturgeon, for which Israel et al. (2009) suggested increased levels of stress occur when DO levels are less than 56% of saturation. A rough estimate of the equivalent of 56% saturation in milligrams per liter was obtained through back calculation to predict oxygen solubility in water under a temperature of 68°F (20°C), which equals 4.85 mg/L using a pressure of 720 torr. DO estimates were examined in relation to this criterion for both white and green sturgeon.

The effects analysis of *CM14 Stockton Deep Water Ship Channel Dissolved Oxygen Levels* on DO is described under Section 5C.4.3, *Passage, Movement, and Migration Methods*.

5C.4.4.6 Turbidity (Water Clarity)

Water clarity is an important flow-related habitat feature that correlates with the presence of covered species such as delta smelt. No turbidity (water clarity) model exists that is suitable for full integration with other effects analysis tools such as CALSIM. Instead, potential changes in water clarity between the BDCP and existing biological conditions scenarios were assessed for each Plan Area subregion using best professional judgment based on existing published and unpublished literature, particularly the DRERIP conceptual model for sediment (Schoellhamer et al. 2007), and consideration of changes in biological components of turbidity and the likelihood of each subregion becoming erosional/depositional or experiencing changes in wind-driven resuspension of sediment given the anticipated extent of restoration in each ROA. This detailed assessment is provided in Attachment 5C.D, *Water Clarity—Suspended Sediment Concentration and Turbidity*.

5C.4.4.7 Residence Time

Water residence time is an important physical property of the Plan Area because it can influence biological factors such as the ability of phytoplankton biomass to build up over time (e.g., Cloern and Jassby 2012), with implications for higher trophic level consumers such as the covered fish species. Residence time in the different subregions of the Plan Area under the EBC and ESO scenarios was assessed using the results of DSM2 PTM for 38 particle release locations (Table 5C.4-28). Residence time was defined as the time (days) at which 50% of particles from a given release location exited the Plan Area (either by movement downstream past Martinez or else through entrainment at the south Delta export facilities, north Delta diversions, North Bay Aqueduct, or agricultural diversions in the Delta). Estimates were available for 24 month/year combinations representing a variety of hydrological conditions in winter (December–February, n = 6), spring (March–May, n = 8), summer (June–August, n = 6), and fall (September–November, n = 4) (Table 5C.4-29). The data were reduced into mean residence time by subregion and season and compared between EBC and ESO scenarios. The fate of the particles contributing to residence time estimates is also of interest, and so the percentage of particles entrained after 30 and 60 days by the diversions listed above was summarized for each season in each subregion. The analysis of residence time differences was also conducted for HOS and LOS scenarios in comparison to EBC scenarios.

Table 5C.4-28. Particle Tracking Modeling (PTM) Release Locations Used for Analysis of Residence Time

Subregion	Particle Release Location
Cache Slough	Cache Slough at Liberty Island
Cache Slough	Cache Slough at Shag Slough
Cache Slough	Lindsey slough at Barker Slough
East Delta	Georgiana Slough
East Delta	Little Potato Slough
East Delta	Mokelumne River d/s of Cosumnes confluence
East Delta	Mokelumne River d/s of Georgiana confluence
East Delta	North Fork Mokelumne
East Delta	South Fork Mokelumne
North Delta	Miner Slough
North Delta	Sacramento Deep Water Ship Channel
North Delta	Sacramento River at Ryde
North Delta	Sacramento River at Sacramento
North Delta	Sacramento River at Sutter Slough
North Delta	Sacramento River near Cache Slough confluence
South Delta	Grant Line Canal
South Delta	Middle River at Victoria Canal
South Delta	Middle River u/s of Mildred Island
South Delta	Old River at Railroad Cut
South Delta	Old River near Quimby Island
South Delta	Old River near Victoria Canal
South Delta	San Joaquin River at Buckley Cove
South Delta	San Joaquin River at Mossdale
South Delta	San Joaquin River D/S of Rough and Ready Island
South Delta	San Joaquin River near Medford Island
Suisun Marsh	Montezuma Slough at Suisun Slough
Suisun Marsh	Montezuma Slough near National Steel
West Delta	Frank's Tract East
West Delta	Sacramento River at Pittsburg
West Delta	Sacramento River at Port Chicago
West Delta	Sacramento River at Rio Vista
West Delta	Sacramento River at Sherman Lake
West Delta	Sacramento River d/s of Decker Island
West Delta	San Joaquin River at Potato Slough
West Delta	San Joaquin River at Twitchell Island
West Delta	San Joaquin River d/s of Dutch Slough
West Delta	San Joaquin River near Jersey Point
West Delta	Threemile Slough

Table 5C.4-29. Seasonal Month/Year Combinations Used for Analysis of Residence Time

Season	Month/Year
Winter	January 1929
Winter	December 1931
Winter	December 1933
Winter	February 1940
Winter	February 1948
Winter	January 1979
Spring	April 1929
Spring	May 1935
Spring	May 1937
Spring	March 1961
Spring	May 1966
Spring	April 1970
Spring	April 1986
Spring	March 2001
Summer	June 1934
Summer	June 1940
Summer	July 1948
Summer	July 1957
Summer	August 1987
Summer	June 1993
Fall	September 1939
Fall	November 1941
Fall	October 1953
Fall	November 1967

5C.4.5 Analyses Related to Decision Tree Outcomes

The following methods (longfin smelt X2-relative abundance regressions and the delta smelt fall abiotic habitat index) are distinctly related to the decision tree. As described in Chapter 3, *CM1 Water Facilities and Operation* includes alternative outcomes related to spring and fall outflow operations. These are driven by the decision tree process, in which scientific investigation will lead to reduced uncertainty about the importance of outflow for longfin smelt in the spring and delta smelt in the fall, and the operations will be implemented accordingly. There are two potential outcomes for spring outflow and two potential outcomes for fall outflow. Consequently, there are four potential CM1 operations. In addition to the ESO, which represents high fall outflow coupled with low spring outflow, this effects analysis includes analysis of the high outflow and low outflow scenarios in the early and late long-term (HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT scenarios). The high outflow scenario includes high fall and spring outflow and the low outflow scenario includes low fall and spring outflow. The following methods all assume that the main driver of abundance or habitat extent is outflow.

5C.4.5.1 X2 Relative-Abundance Regressions (Longfin Smelt)

The abundance of longfin smelt in the Fall Midwater Trawl (FMWT) has been correlated to the location of X2 in the preceding winter and spring months (January–June) (Kimmerer 2002; Kimmerer et al. 2009). While the mechanism behind this relationship is not well understood, one hypothesis is related to the transport of larval longfin smelt out of the Delta to rearing habitats downstream in the Suisun Bay subregion and beyond (Moyle 2002). At the same time, however, while there is a correlation between X2 and longfin smelt abundance, longfin smelt abundance also is significantly correlated with factors such as food abundance (discussed further in Chapter 5, *Effects Analysis*). Therefore, there is uncertainty that this evaluation correctly characterizes the mechanism behind the correlation. The X2–longfin smelt abundance relationship was used to evaluate the effects of the BDCP on longfin smelt, under the assumption that lower X2 (farther downstream) would correspond to higher transport flows, which in turn would transport longfin smelt downstream more effectively and contribute to increased survival. Relationships between December and May X2 position and log longfin smelt abundance developed by Kimmerer et al. (2009) were used to determine how the changes in winter-spring X2 position described above might influence longfin smelt abundance the following fall. These relationships were developed using abundance data from the FMWT, Bay Midwater Trawl, and Bay Otter Trawl (Table 5C.4-30). The log abundance values were interpreted as a relative survival index for each of these relationships, and were reverse log-transformed to determine how the BDCP might influence actual numbers of longfin smelt surviving until the following fall.

Table 5C.4-30. Relationships between X2 and Longfin Smelt Abundance Indices (Log-Transformed) from Fall Midwater Trawls, Bay Midwater Trawl, and Bay Otter Trawl That Were Used to Estimate BDCP Effects

Data Source	Number of Observations (Years)	Statistical Significance (*P* Value)	Intercept	Slope (± 95% Confidence Limits)	1987–1988 Step Change[a] (± 95% Confidence Limits)
Fall Midwater Trawl	38	< 0.0001	7.0	-0.05 ± 0.01	-0.81 ± 0.28
Bay Midwater Trawl	26	0.0001	8.0	-0.06 ± 0.03	-0.75 ± 0.60
Bay Otter Trawl	27	< 0.0001	8.1	-0.06 ± 0.02	-0.46 ± 0.36

[a] The 1987–1988 step change was included to account for possible reduced zooplankton prey abundance following the invasion of *Potamocorbula amurensis*. It was not included in the BDCP effects analysis because the relative difference between scenarios is only dependent on the regression slope and not the step change.

Source: Kimmerer et al. 2009.

5C.4.5.2 Delta Smelt Fall Abiotic Habitat Index

Potential differences between the BDCP and existing biological conditions in the extent of abiotic habitat for delta smelt in the fall (September–December, the older juvenile rearing and maturation period) as a function of changes in flows were assessed using a technique based on the method of Feyrer and coauthors (2011). (Appendix 5.E, *Habitat Restoration* includes additional analyses of effects on delta smelt related to habitat. The results of this method will be interpreted with consideration of those additional analyses in determining the population-level effect on delta smelt. Chapter 5, *Effects Analysis*, considers all of these potential effects on delta smelt to make a final determination on the effects on abundance.) In this section, only the results of the application of the Feyrer and coauthors (2011) method are presented.

Feyrer and coauthors (2011) demonstrated that X2 in the fall correlates nonlinearly with an index of delta smelt abiotic habitat in the West Delta, Suisun Bay, and Suisun Marsh subregions, as well as smaller portions of the Cache Slough, South Delta, and North Delta subregions (see Figure 3 of Feyrer et al. 2011). Investigations in recent years have suggested that delta smelt occur year-round in the Cache Slough subregion, including Cache Slough, Liberty Island, and the Sacramento Deep Water Ship Channel (Baxter et al. 2010; Sommer et al. 2011). Whether the same individuals are residing in these areas for their full life cycles or different individuals are moving between upstream and downstream habitats is not known (Sommer et al. 2011). The delta smelt fall abiotic habitat index is the surface area of water in the west Delta, Suisun Bay, and Suisun Marsh (as well as smaller portions of the Cache Slough, South Delta, and North Delta subregions) weighted by the probability of presence of delta smelt based on water clarity (Secchi depth) and salinity (specific conductance) in the water. Feyrer and coauthors' method found these two variables to be significant predictors of delta smelt presence in the fall and also concluded that water temperature was not a predictor of delta smelt presence in the fall, although it has been shown to be important during summer months (Nobriga et al. 2008).

The extent of the low salinity zone, which is determined by the location of the X2 isohaline, largely overlaps with the distribution of other essential physical resources and key biotic resources that are necessary to support delta smelt, but is not the only factor that defines the extent of habitat for delta smelt. The delta smelt fall abiotic habitat index developed by Feyrer et al. (2011) is based on the probability of presence of delta smelt given certain water clarity and salinity and does not account for other abiotic (e.g., water velocity, depth) and biotic (e.g., food density) factors that may interact with water clarity and salinity to influence the probability of occurrence. The three physical variables (temperature, salinity, and turbidity) combined could explain just a quarter of the variance in patterns of delta smelt presence and absence in the estuary. It is unclear what portion of that fractional explained variance is actually due to turbidity, rather than salinity. (Temperature was not found to be important in the fall.)

The Feyrer 2011 method is based on only 75 of 100 FMWT survey stations in the Delta, which are already disproportionally located in areas that typically experience a circumscribed range of low salinity conditions. The index reflects the probability of occurrence of delta smelt primarily in the West Delta, Suisun Bay, and Suisun Marsh subregions, and does not provide full coverage of other areas (particularly the Cache Slough subregion) where appreciable portions of the population may exist in the fall. Additionally, the overall relationship between X2 and the delta smelt fall abiotic habitat index is the result of two linked statistical analyses, each of which has uncertainty that is compounded when the analyses are combined. The National Research Council (2010) has expressed concern about the effects of compounding uncertainty in linked statistical analyses such as Feyrer et al.'s (2011) analysis and its implication for quantitative conclusions. Additionally, they noted that the "weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action [the prescribed locations for X2 in the Delta in wet and above-normal years] difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes (Feyrer et al. 2007), the relationship of that distribution and smelt abundance indices is unclear" (National Research Council 2010). Nevertheless, this method has been previously applied to analyses for delta smelt habitat and therefore also is included in this effects analysis.

The following sections provide a brief overview of the Feyrer et al. (2011) method followed by details on how the method was adapted for use in the effects analysis.

5C.4.5.2.1 Development of the Original X2–Fall Abiotic Habitat Index

The methods for developing the abiotic habitat index and its relationship to X2 are described in more detail by Feyrer et al. (2011). The description below is adapted from their account.

FMWT survey data were used to develop the index. The FMWT samples approximately 100 stations across the estuary each month from September to December (Stevens and Miller 1983). A subset of 73 of the 100 stations was used for analyses to avoid including stations where sampling had not occurred consistently or where delta smelt were rare. Each station was sampled once per month, each of the four months, from 1967 to 2008 with a single 10-minute tow. The only exceptions were that sampling was not conducted in 1974 and 1979, and in 1976 was conducted only in October and November. Measurements of the water quality variables normally are taken coincident with each sample. In total, there were nearly 14,000 individual samples with complete data for analysis spanning 42 years.

Generalized additive modeling (GAM) was used to estimate the probability of occurrence of delta smelt at a trawl station in a given month and year based on water temperature (°C), water clarity (Secchi depth, meters), and salinity (specific conductance, microSiemens per centimeter [µs/cm]). The probability of occurrence (i.e., presence-absence data) was used as the dependent variable rather than a measure of abundance (e.g., catch per trawl) to minimize the possible influence of outliers and bias associated with long-term abundance declines. This approach is supported by recent simulations, based on assumed underlying statistical distributions of fish catch, that suggest habitat curves based on presence-absence are conservative relative to catch per trawl because high frequencies of occurrence could be associated with both high and moderate catch per trawl (Kimmerer et al. 2009).

Model fits were evaluated in terms of the reduction in deviance (a measure of the explanatory power of the model, similar to variance in other modeling techniques such as analysis of variance) attributable to each of the abiotic factors, relative to the null model. The final model included Secchi depth and specific conductance but did not include water temperature, as it did not give an appreciable reduction in deviance. The final model accounted for 26% of the deviance, although it is not possible to determine what proportion of the deviance is independently attributable to Secchi depth and specific conductance when both are combined. (When individually included in the model, Feyrer and coauthors [2011] noted that specific conductance reduced deviance by 18% and Secchi depth reduced deviance by 14%.)

The delta smelt fall abiotic habitat index was calculated as follows:

$$H_y = \sum_{S=1}^{73} \left[A_S \frac{1}{4} \sum_{m=Sep}^{Dec} \hat{\pi}_{y,m,s} \right] \qquad \text{(Equation 1)}$$

Where H_y is the fall abiotic habitat index, A_s is the surface area of station s and $\hat{\pi}_{y,m,s}$ is the GAM estimate of the probability of occurrence.

Station surface areas of each station were obtained from CDFW and originally were reported by Feyrer and coauthors (2007). Surface areas were generated by GIS and ranged from 90 to 1,251 hectares for the 73 stations. Summation of the probability of occurrence–weighted surface areas provided an index that accounts for both the quantity and value (in terms of probability of occurrence) of abiotic habitat for delta smelt.

Locally weighted regression–scatterplot smoothing (LOWESS regression) was used to develop a data-driven relationship between the habitat index and estuarine outflow (expressed as X2). Consistent with the habitat index described above, the average September through December X2 was used. The data were averaged over the 4-month fall period to minimize the influence of sampling error that could occur if the data were summarized over shorter temporal scales. For instance, shorter averaging periods might be less reliable because samples are taken irrespective of tidal conditions across a geographic region with large tidal excursions, and because abundance estimates, and by extension distribution, can be highly variable among months (Newman 2008). The delta smelt fall abiotic habitat index and its relationship to X2 are represented by the blue diamonds in Figure 5C.4-34, with the LOWESS smoothed fit depicted as the red squares. The LOWESS smoothed fit explained 85% of the variation in the estimates of abiotic habitat (i.e., $r^2 = 0.85$).

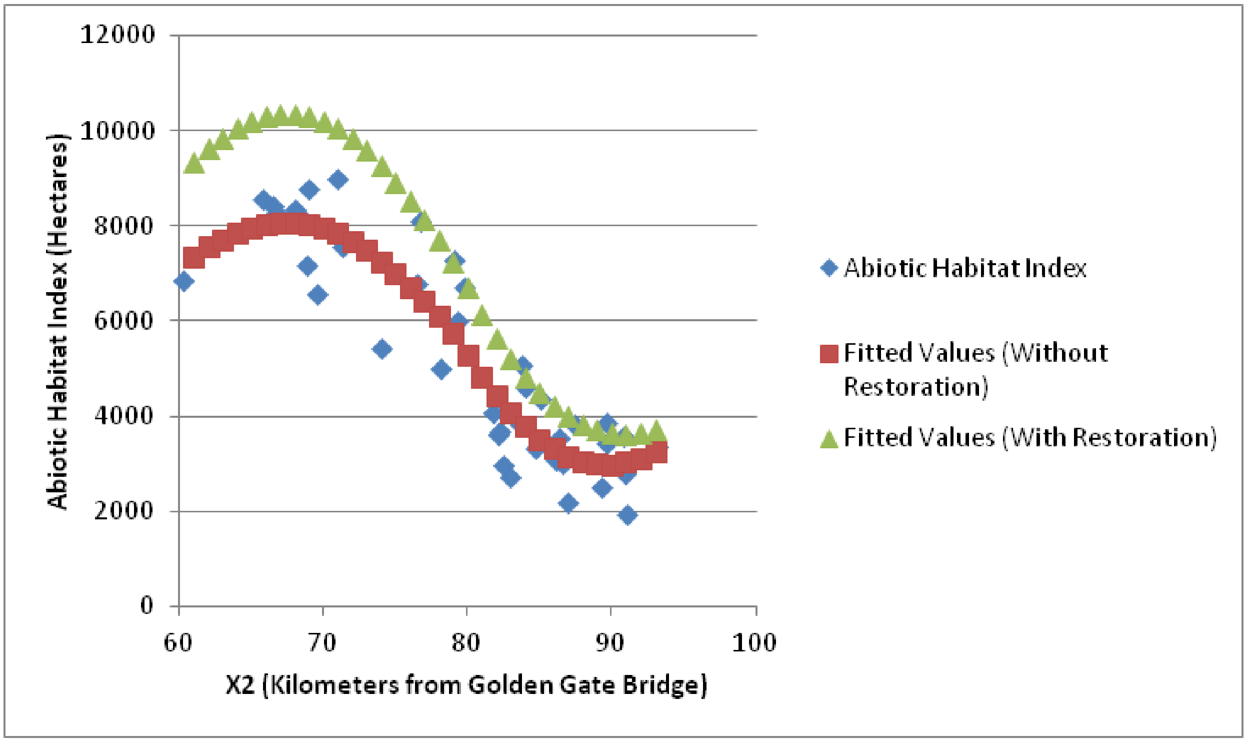


Figure 5C.4-34. Abiotic Habitat Index of Delta Smelt in Relation to X2

Blue diamonds represent values estimated by Feyrer and coauthors (2011), with red squares indicating the best-fit, locally weighted regression with the estimates (without habitat restoration, i.e., current Delta configuration). Green diamonds represent the fitted values based on the assumption that restored habitat in the Suisun Marsh and West Delta ROAs has a probability of delta smelt presence similar to adjacent areas. This is discussed in the next section.

5C.4.5.2.2 Adjustment of the Original Delta Smelt Fall Abiotic Habitat Index to Incorporate BDCP Restoration Areas

The original delta smelt fall abiotic habitat index was adjusted to incorporate hypothetical restoration areas in the West Delta and Suisun Marsh ROAs. The subtidal portions of the hypothetical restoration sites were assumed to have the same probability of occurrence of delta smelt as the existing estuary sites (stations) to which they were directly connected. The probability of occurrence was calculated for each station and associated restoration site in each month of the 42-year time series. The probability of occurrence and habitat area augmented by restoration were incorporated into Equation 1 to give an adjusted estimate of the delta smelt fall abiotic habitat index. These estimates were again related to average September through December X2 using a LOWESS regression ($r^2 = 0.87$), as illustrated by the green triangles in Figure 5C.4-34.

5C.4.5.2.3 Use of the Delta Smelt Fall Abiotic Habitat Index in the Effects Analysis

The two equations estimating delta smelt fall abiotic habitat index from X2 were used to generate a lookup table of X2 versus abiotic habitat index (Table 5C.4-31). The X2-abiotic habitat index equations estimate the habitat index to decrease with X2 downstream of 67 km and to increase with X2 upstream of 90 km (Figure 5C.4-34). It was assumed that there would be little change in habitat index with X2 position lower than 67 km and greater than 90 km. Therefore, X2 less than 67 km was given an index of 8,069 hectares without restoration and 10,341 hectares with restoration, whereas X2 greater than 90 km was given an index of 2,987 hectares without restoration and 3,642 hectares with restoration. For each year of the CALSIM period (1923[9]–2003), the average X2 was calculated for September through December and the abiotic habitat index for each of the six model scenarios was estimated by linear interpolation of the values shown in Table 5C.4-31. Two sets of analyses were conducted. The first analysis included all six scenarios and considered only the effects of the BDCP on the existing configuration of the Delta without accounting for habitat restoration. The second analysis examined differences in abiotic habitat index between the BDCP in the late long-term (ESO_LLT, assuming full restoration in the Suisun Marsh and West Delta ROAs) and EBC1, EBC2, and EBC2_LLT. In the second set of analyses, the abiotic habitat index was calculated using the assumption that 25%, 50%, 75%, and 100% of the restored habitat would be used by delta smelt. This analysis is limited to tidal restoration in the low salinity zone and doesn’t necessarily account for delta smelt use of inshore areas or areas outside the low salinity zone, such as Cache Slough.

Table 5C.4-31. Fitted Values for Delta Smelt Abiotic Habitat Index, without and with BDCP Late Long-Term Restoration Extent Included

X2 (kilometers)	Abiotic Habitat Index (Hectares)	
	Without Restoration	With Restoration
67	8,069	10,341
68	8,067	10,344
69	8,027	10,296
70	7,950	10,198
71	7,837	10,053
72	7,685	9,852
73	7,491	9,587
74	7,261	9,270
75	7,000	8,912
76	6,716	8,525
77	6,414	8,121
78	6,099	7,710
79	5,735	7,253

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[9] Water Year 1922 was omitted because water year classification for prior year was not available.

X2 (kilometers)	Abiotic Habitat Index (Hectares)	
	Without Restoration	**With Restoration**
80	5,292	6,712
81	4,835	6,158
82	4,430	5,659
83	4,081	5,225
84	3,777	4,840
85	3,523	4,511
86	3,314	4,231
87	3,160	4,007
88	3,054	3,834
89	2,996	3,712
90	2,987	3,642

5C.4.5.2.4 Major Assumptions

Two major assumptions are associated with the use of the delta smelt fall abiotic index for the BDCP effects analysis.

The relationship between X2 and the delta smelt fall abiotic habitat index that was developed under existing conditions remains the same under future configurations of the Plan Area incorporating restoration.

This assumption is unlikely to be valid because implementation of habitat restoration probably will change the relationship between X2 and the delta smelt fall abiotic habitat index because of changes in salinity and water clarity distributions in relation to X2. Changes in other abiotic (e.g., water temperature) and biotic factors (e.g., food density) also may influence the nature of the relationship. CALSIM and DSM2 modeling used for the effects analysis incorporate changes in channel geometry for a hypothetical habitat restoration program but cannot be used to adjust the fundamental X2–abiotic habitat index relationship. It is also unlikely that the actual location and extent of habitat restoration areas will be exactly the same as those used in the hypothetical case, which would affect the flow–X2 relationship, and by extension, the appropriateness of the X2–abiotic habitat relationship.

Subtidal restoration areas have the same probability of occurrence of delta smelt as adjacent open estuary sites.

This assumption may be only partially valid because the subtidal restoration sites may differ from adjacent open estuary sites in terms of important abiotic characteristics (e.g., water depth) that could alter the probability of delta smelt occurrence. However, delta smelt have been found across a wide range of habitats, including open-water areas (e.g., Moyle 2002), as well as small intertidal marsh channels (Gewant and Bollens 2011). It is likely that habitat characteristics within tidal habitat (e.g., tidal excursion, velocity, temperature, turbidity) influence their use by delta smelt and that channel width itself is not a constraint (Sommer and Mejia 2011). The width of levee breaches into the restoration areas also may influence the probability of occurrence of delta smelt.

5C.5 Results

5C.5.1 CALSIM and DSM2 Results

These results are presented in Attachment 5C.A, *CALSIM and DSM2 Modeling Results for the Evaluated Starting Operations Scenarios*.

5C.5.2 Upstream Habitat Results

[This section is a separate file.]

5C.5.3 Passage, Movement, and Migration Results

[This section is a separate file.]

5C.5.4 Delta Habitat (Plan Area) Results

[This section is a separate file.]

5C.6 References Cited

5C.6.1 Literature Cited

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5C.6.2 Personal Communications

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DeGeorge, John, Ph.D., P.E., Resource Management Associates, Inc., Fairfield, CA. June 7, 2013—email to Marin Greenwood, Fisheries Biologist,ICF International, Sacramento, CA. Containing instructions for downloading presentation on the effect of tidal habitat and restoration on hydrodynamics entitled *Recent Projects Modeling Local and Regional Impacts of Tidal Marsh Restoration*.

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Kirkland, M. Senior Engineer. California Department of Water Resources Division of Environmental Services. September 15, 2011—email response to Sophia Unger regarding potential effects of diverting Sacramento River flow at the Fremont Weir on Sutter Bypass inundation.

Kurth, Ryon. Staff Environmental Scientist. California Department of Water Resources. July 6, 2010—email to Rick Wilder about spawning location of Pacific and river lamprey in the Feather River.

Miller, B. J. Consulting Engineer. October 5, 2011—emails to Marianne Guerin, Associate, Research Management Associates, with Excel data analysis estimating entrainment.

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