# Appendix A

## Model Description for the Sacramento River Winter-run Chinook Salmon Life Cycle Model

# Model Description for the Sacramento River Winter-run Chinook Salmon Life Cycle Model

Noble Hendrix[1]
Ann-Marie K. Osterback[3,4]
Eva Jennings[2]
Eric Danner[3,4]
Vamsi Sridharan[3,4]
Correigh M. Greene[5]
Steven T. Lindley[3,4]

[1]QEDA Consulting, LLC
4007 Densmore Ave N
Seattle, WA 98103

[2]Cheva Consulting
4106 Aikins Ave SW
Seattle, WA 98116

[3]Institute of Marine Sciences
University of California, Santa Cruz
1156 High St
Santa Cruz, CA 95064

[4]National Marine Fisheries Service
Southwest Fisheries Science Center
Fisheries Ecology Division
110 McAllister Way
Santa Cruz, CA 95060

[5]National Marine Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Blvd. East
Seattle, WA 98112-2097

May 17, 2019

# I. Background and Model Structure

Given the goals of improving the reliability of water supply and improving the ecosystem health in California's Central Valley, NMFS-SWFSC is developing simulation models to evaluate the potential effects of water project operations and habitat restoration on the dynamics of Chinook salmon populations in the Central Valley. These life cycle models (LCMs) couple water planning models (CALSIM II), physical models (HEC-RAS, DSM2, DSM2-PTM, USBR river temperature model, etc.) and Chinook salmon life cycle models to predict how various salmon populations will respond to suites of management actions, including changes to flow and export regimes, modification of water extraction facilities, and large-scale habitat restoration. In this document, we describe a winter-run Chinook salmon life cycle model (WRLCM). In the following sections, we provide the general model structure, the transition equations that define the movement and survival throughout the life cycle, the life cycle model inputs that are calculated by external models for capacity and smolt survival, and the steps to calibrate the WRLCM.

## Winter-run Life Cycle Model (WRLCM)

The WRLCM is structured spatially to include several habitats for each of the life history stages of spawning, rearing, smoltification (physiological and behavioral process of preparing for seaward migration as a smolt), outmigration, and ocean residency. We use discrete geographic regions of Upper River, Lower River, Floodplain, Delta, Bay, and Ocean (Figure 1). The temporal structure of winter-run Chinook is somewhat unique, with spawning occurring in the late spring and summer, the eggs incubating over the summer, emerging in the fall, rearing through the winter and outmigrating in the following spring (Figure 2). We capture these life-history stages within the WRLCM by using developmental stages of eggs, fry, smolts, ocean sub-adults, and mature adults (spawners). The goal of the WRLCM is consistent with that of Hendrix et al. (2014); that is, to quantitatively evaluate how Federal Central Valley Project (CVP) and California State Water Project (SWP) management actions affect Central Valley Chinook salmon populations.

In 2015, the WRLCM was reviewed by the Center for Independent Experts (CIE). In response to recommendations from the CIE, the following modifications were implemented in the WRLCM: 1) divided the River habitat to encompass above Red Bluff Diversion Dam (Upper River) and below Red Bluff Diversion Dam (Lower River); 2) incorporated hatchery fish into the WRLCM; 3) used 95% of observed density as an upper bound for calculation of habitat capacity; 4) re-parameterized the Beverton-Holt function; 5) used appropriate spawner sex-ratios for model calibration to account for bias in Keswick trap capture; 6) modified the WRLCM to a state-space form to incorporate measurement error and process noise; and 7) designed metrics and simulation studies to evaluate model performance. Hendrix et al. (2014) indicated that future work would use DSM2's enhanced particle tracking model to track salmon survival, which is currently being developed yet is not ready to incorporate into this version of the model.

Additional comments received in the CIE review that have not been incorporated yet include: 1) expanding spatial structure for spring and fall-run; 2) tracking additional categories of juveniles (e.g., yearling) for applying an LCM to spring-run Chinook; 3) implementing shared capacity for fall and spring-run Chinook; 5) tracking monthly cohorts through the model; and 6) evaluating multiple model structural forms. We are actively working on improving the WRLCM and developing the spring-run LCM (SRLCM) and fall-run LCM (FRLCM). Many of the CIE recommendations will be implemented with subsequent versions of these models.

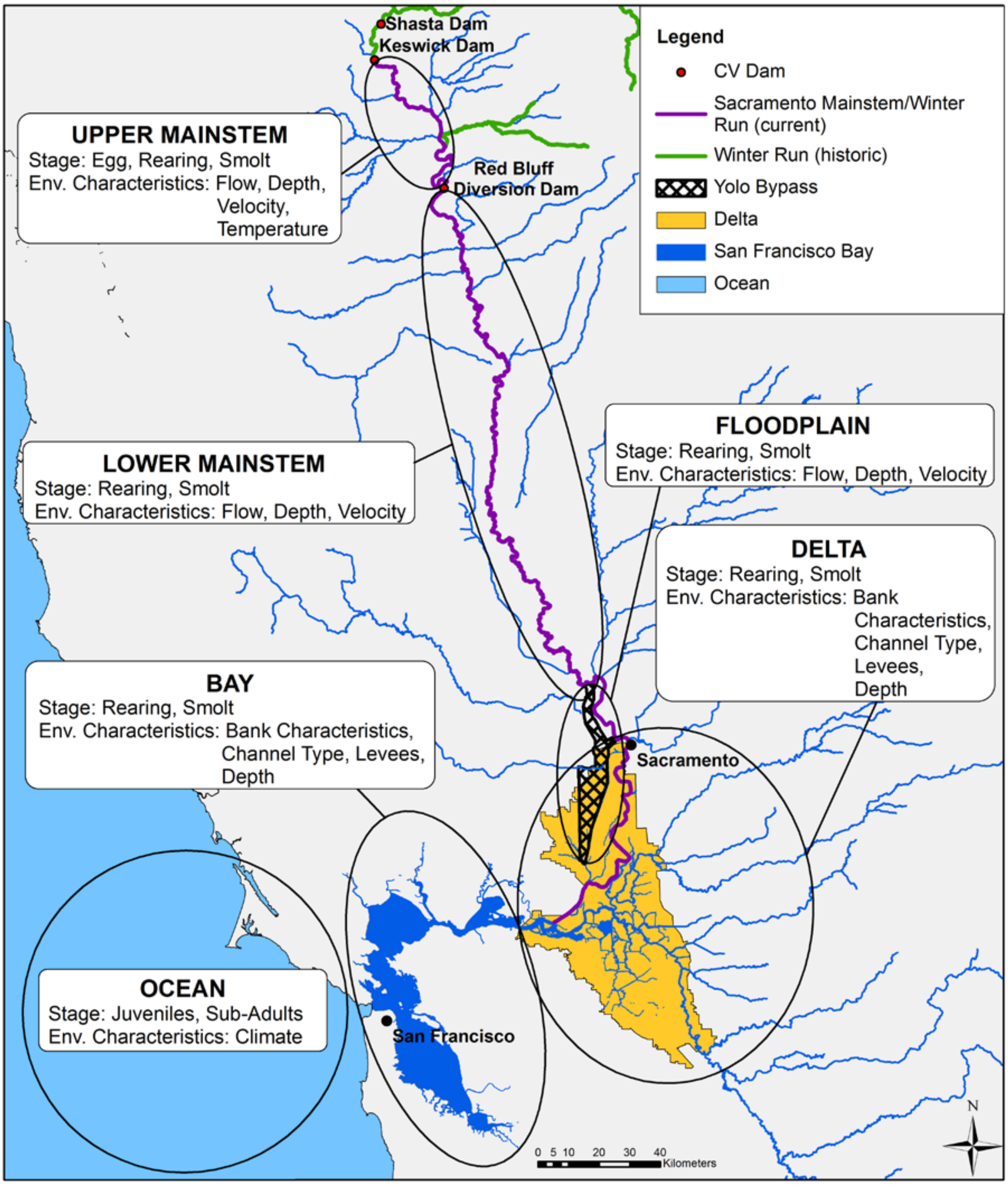



**Figure 1. Geographic distribution of Chinook life stages and examples of environmental characteristics that influence survival.**

The quantity and quality of rearing and migratory habitat are viewed as key drivers of reproduction, survival, and migration of freshwater life stages. Various life stages have velocity, depth, and temperature preferences and tolerances, and these factors are influenced by water project operations and climate.

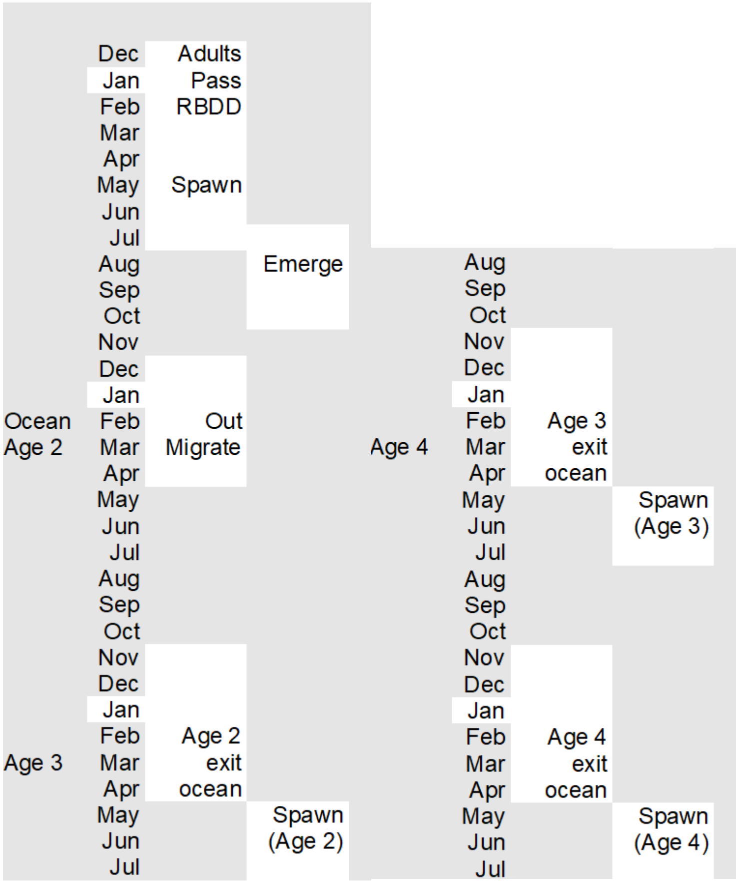



**Figure 2. Temporal structure of the winter-run Chinook salmon, each cohort begins in March of the brood year. Figure from Grover et al. (2004).**

Hydrology (the amount and timing of flows) is modeled with the California Simulation Model II (CALSIM II). Hydraulics (depth and velocity) and water quality is modeled with the Delta Simulation Model II (DSM2) and its water quality sub-model QUAL, the Hydrologic Engineering Centers River Analysis System (HEC-RAS), the U.S. Bureau of Reclamation's (USBR) Sacramento River Water Quality Model (SRWQM), and other temperature models. Many of the stage transition equations describing the salmon life cycle are directly or indirectly functions of water quality, depth, or velocity, thereby linking management actions to the salmon life cycle. The combination of models and the linkages among them form a framework for analyzing alternative management scenarios (Figure 3).

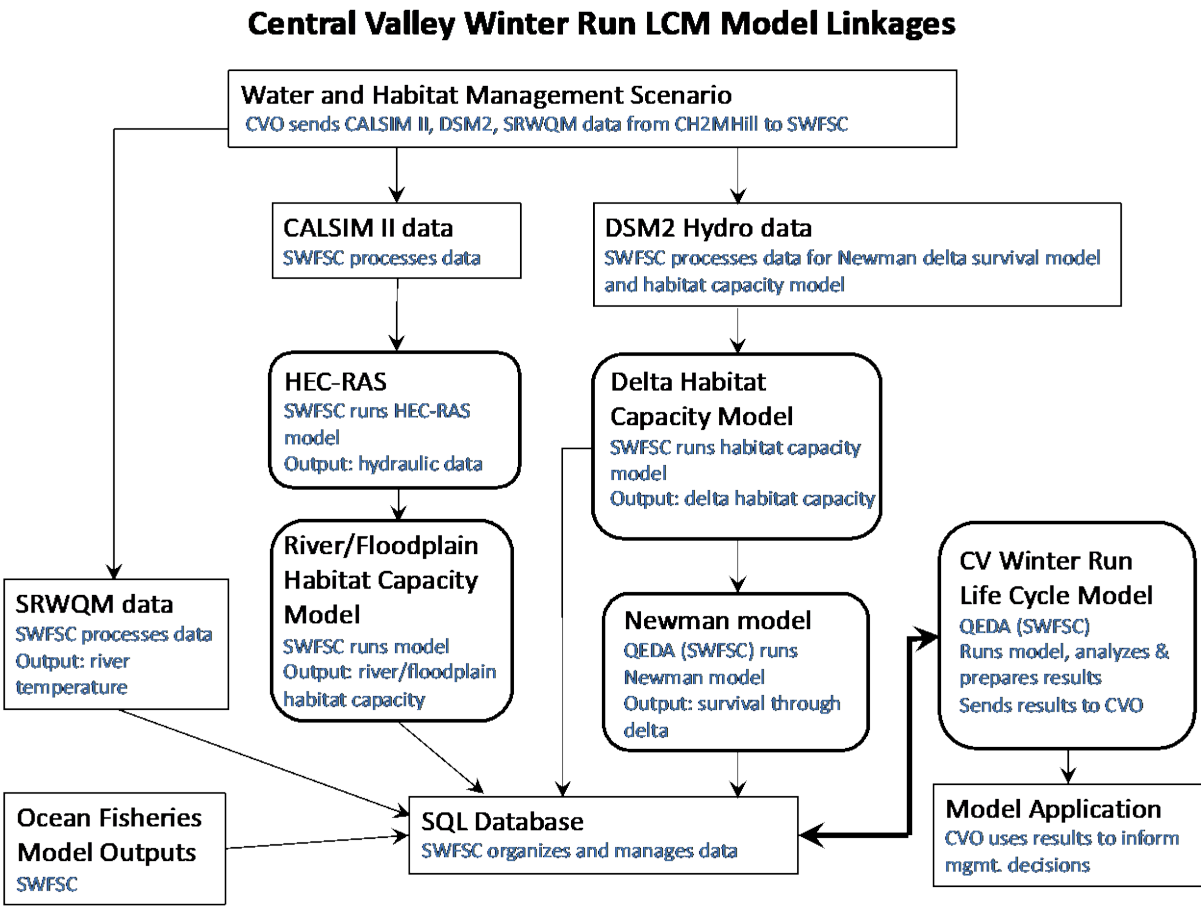



**Figure 3. Submodels that support and provide parameter inputs that feed into the life cycle model.**

The life cycle model is a stage-structured, stochastic life cycle model. Stages are defined by development and geography (Figure 1), and each stage transition is assigned a unique number (Figure 4).

## II. Model Transition Equations

This section is divided into two parts. In the first part, we explain each of the transitions for the natural origin winter-run Chinook, which are described by the life cycle diagram (Figure 4). In the second part, we explain the transitions for hatchery origin fish. The transitions are described for an annual cohort; however, in most cases we have not included a subscript for the cohort brood year to simplify the equations. For those transitions in which there are multiple cohorts, such as the production of eggs in transition 22, a subscript to distinguish cohort is included in the equation. Note that all parameters used in the model are defined in Appendix B.

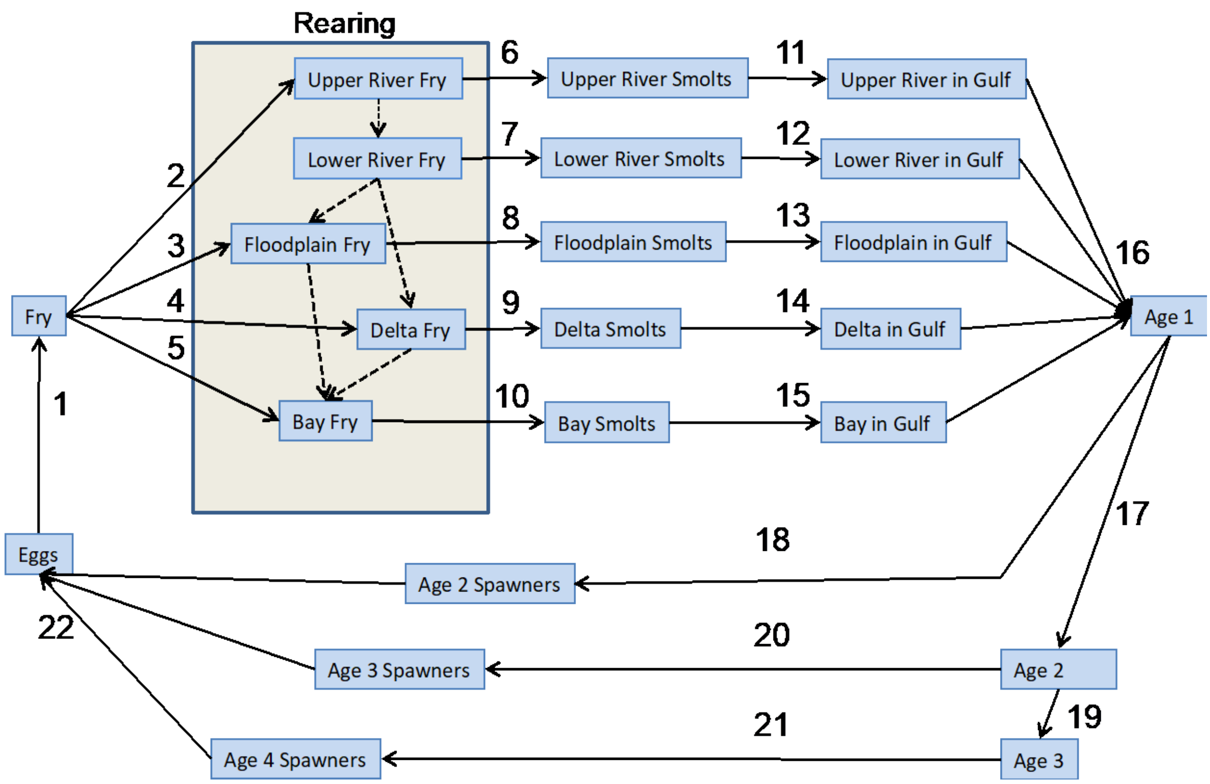



**Figure 4. Central Valley Chinook transition stages. Each number represents a transition equation through which we can compute the survival probability of Chinook salmon moving from one life stage in a particular geographic area to another life stage in another geographic area.**

## *Natural Origin Chinook*

### Transition 1

*Definition*: Survival from Egg to Fry

$Fry_{m+2} = Eggs_m * S_{eggs,\,m}$

$$\text{Logit}(S_{eggs,m}) = \begin{cases} B0_1\,, & TEMP \le t.crit \\ B0_1 + B1_1(TEMP_m - t.crit), & TEMP > t.crit \end{cases}$$

where $S_{eggs,m}$ is the survival rate of fry as a function of the coefficients $B0_1$, $B1_1$ and *t.crit* (model parameter representing the critical temperature at which egg survival begins to be decline), the covariate $TEMP_m$ (the average of the month of spawning $m$ and the following 2 months), logit(x) = log(x/[1-x]) is a function that ensures that the survival rate is within the interval [0,1], for months $m$ = (2, ..., 6) corresponding to April to August.

### Transition 2

*Definition*: Fry emerged in a given month either remain in the Upper River (UR) as Rear Fry ($RearFry_{UR,m}$) or disperse downstream as Tidal Fry ($TidalFry_m$) to the $h$ habitats = Floodplain ($FP$), Delta ($DE$), and Bay ($BA$) in months $m$ = (4, ..., 8) corresponding to June to October.

$TidalFry_{m,} = P_{TF,} * Fry_m$

$RearFry_{UR,m} = (1 - P_{TF}) * Fry_m$

where $P_{TF}$ is the proportion of fry moving out of the Upper River as tidal fry, and $RearFry_{UR,m}$ are the number remaining in the Upper River habitat ($UR$) as rearing fry.

## Transitions 3 - 5

*Definition*: Dispersal of tidal fry to the $h$ habitats = Lower River ($LR$), Floodplain ($FP$), Delta ($DE$), and Bay ($BA$) arriving in the month following emergence $m$ = (5, …, 9) corresponding to July to December.

*Floodplain Tidal Fry (Transition 3)*

Whenever there are flows into the Yolo Bypass, a proportion of the Tidal Fry move into the floodplain habitat:

$TidalFry_{FP,m} = S_{TF,FP} * TidalFry_m * P_{FP,m}$

where $P_{FP,m}$ is the proportion of fry (including tidal fry) that move into the Floodplain habitat, and $S_{TF,FP}$ is the monthly survival of tidal fry in the floodplain. The $P_{FP,m}$ is modeled as a function of the expected flow onto the Floodplain habitat due to proposed modifications of the Fremont Weir.

$$P_{FP,m} = \begin{cases} min.p\,, & y.flow_m < 100 \\ min.p + \dfrac{(y.flow_m - 100) * (0.5 - min.p)}{5900}\,, & 100 \le y.flow_m \le 6000 \\ inv.logit\left(\dfrac{p.rate * (y.flow_m - 6000)}{1000}\right), & y.flow_m > 6000 \end{cases}$$

where $P_{FP,m}$ is the proportion of fry moving into the Floodplain as a function of the coefficients *min.p* and *p.rate*, and the covariate $y.flow_m$. The function inv.logit(x) = $e^x/(1+ e^x)$ ensures that the proportion of fry moving into the Floodplain is within the interval [0,1]. The covariate $y.flow_m$ represents the monthly average flow rate (cfs) at the entrance to Yolo Bypass (CALSIM node D160). The relationship between $P_{FP,m}$ and flow is depicted in Figure 5.

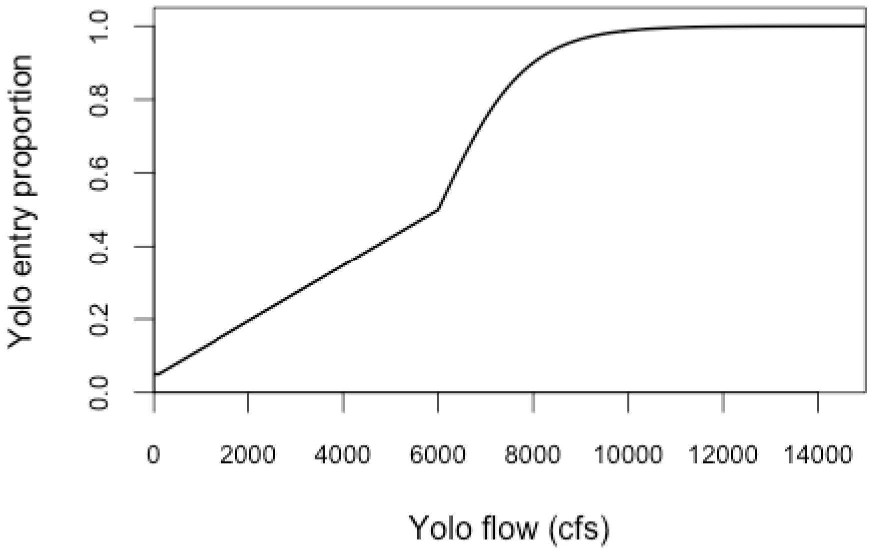



**Figure 5. The relationship of Floodplain entry (Yolo bypass) entry proportion ($P_{FP}$) as a function of Yolo flow.**

*Delta and Bay Tidal Fry (Transition 4 and 5)*

$TidalFry_{DE,m} = TidalFry_m * (1- P_{FP,m}) * (1 - P_{TF, BA,m}) * S_{TF,DE,m}$

$TidalFry_{BA,m} = TidalFry_m * (1- P_{FP, m}) * P_{TF, BA,m} * S_{TF,DE,m} * S_{TF,DE-BA}$

where $S_{TF,DE,m}$ is the survival to the Delta by Tidal Fry.

$\text{logit}(S_{TF,DE,m}) = B0_4 + B1_4*DCC_m$

where $B0_4$ and $B1_4$ are model parameters, and $DCC_m$ is the proportion of the transition month that the DCC gate is open.

$P_{TF,Bay,m}$ is the proportion of fish moving to the Bay from the Delta

$\text{logit}(P_{TF,Bay,m}) = B0_5 + B1_5*Q_{RioVista,m}$

where $B0_5$ and $B1_5$ are model parameters, and $Q_{RioVista,m}$ is the flow anomaly (subtract mean and divide by standard deviation). The mean and standard deviation were calculated from 1970-2014 data at Rio Vista, which was the period of model calibration.

### *Rearing*

*Definition*: Fry rear among Upper River, Lower River, Floodplain, Delta, and Bay habitats according to a density dependent movement function in months $m$ = (5, …, 17) corresponding to July to the following July (brood year + 1).

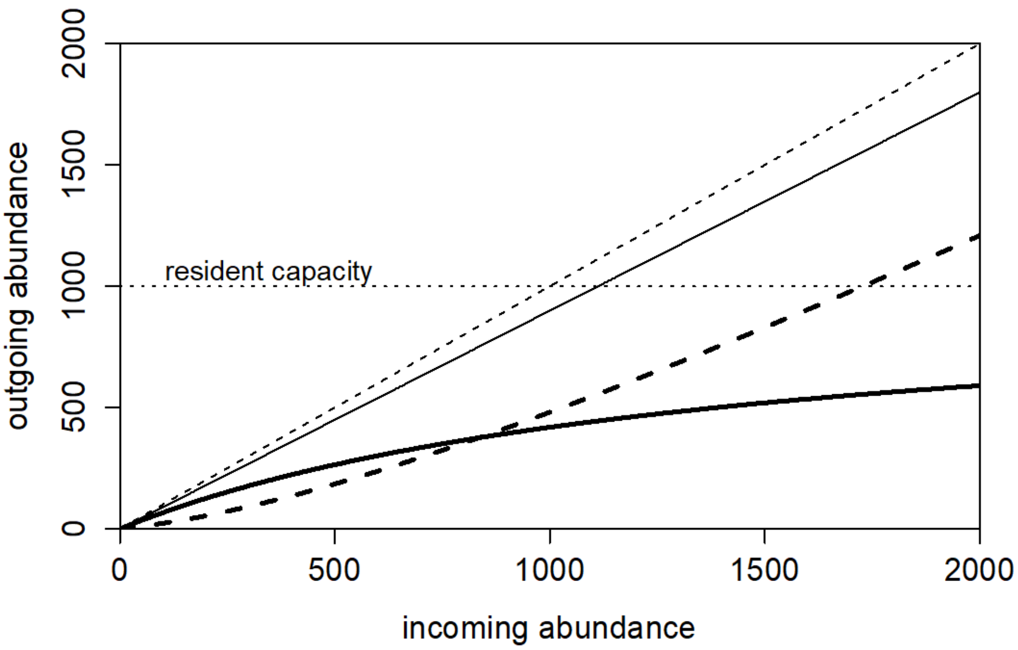



**Figure 6. Example of the Beverton-Holt movement function in which the outgoing abundance (thin solid black line) is split between migrants (thick dashed line) and residents (solid dark line), that are affected by the resident capacity (thin dotted line). The 1:1 line (thin dashed line) is also plotted for reference. Parameter values used in the plotted relationship are survival, *S* = 0.90; migration, *m* = 0.2; and capacity, *K*= 1000.**

While Transitions 2-5 calculate the number of fry that seed specific habitats immediately following emergence, the density dependent movement function follows how numbers of fish move downstream through each habitat during the entire fry rearing period. Specifically, the density dependent movement function calculates the total number of fish in a given habitat and month ($Residents_{h,m}$) versus the number of fish that will migrate to downstream habitats ($Migrants_{h,m}$). The number of residents and migrants in the month is calculated from the following equations (Figure 6):

$$Residents_{h,m} = S_{FRY,h,m} * (1 - mig_{h,m}) * N_{h,m} / (1 + S_{FRY,h,m} * [1 - mig_{h,m}] * N_{h,m}/K_{h,m})$$

$$Migrants_{h,m} = S_{FRY,h,m} * N_{h,m} - Residents_{h,m}$$

where $S_{FRY,h,m}$ is the survival rate in the absence of density dependence, $N_{h,m}$ is the pre-transition abundance composed of *Migrants* from upstream habitats in $m-1$ and *Residents* from the current habitat (Figure 7) in $m-1$, $K_{h,m}$ is the capacity for habitat type $h$ and $mig_{h,m}$ is the migration rate in the absence of density dependence in month $m$.

The migration rate in the Lower River is modeled as a function of a flow threshold at Wilkins Slough

$$\text{logit}(mig_{LR,m}) = B0_M + B1_M * I(Q_{Wilkins,\,m} > 400\ m^3s^{-1})$$

whereas in all other habitats and months the migration rate $mig_{h,m}$ is a constant value. Survival of resident and migrant fry $S_{FRY,h,m}$ are also constant over habitats and months.

**Transitions 6 - 10**

*Definition:* Smolting of *Residents* in the Upper River, Lower River, Floodplain, Delta, and Bay habitats in months $m$ = (11, … ,17) corresponding to January to July in the calendar year after spawning.

$Smolts_{h,m} = P_{SM,m} * Residents_{h,m-1}$

where $P_{SM,m}$ is the probability of smolting in month $m$ which is assumed to be the same across habitats, by the *Residents* from the previous month ($m$-1) in that habitat.

The probability of smolting is modeled as a proportion ordered logistic regression model of the form:

$\text{logit}(P_{SM,\, m}) = Z_k$

where $-\infty < Z_1 < Z_2 \ldots < Z_k < \infty$ are the monthly rates of smoltification based on photoperiod (k = 1, …, 7 encompassing January to July).

Note that during months where smoltification occurs (in months $m$ = 11, … ,17) smolts are removed from the total number of fish in a given habitat before the movement function is applied. The model performs the following steps during the months in which smoltification occurs:

1. Smoltification of Resident fry
2. Accumulation of the Migrant fry from the upstream habitats and Resident fry from the current habitat remaining from the previous month that did not smolt
3. Survival and movement of the fry calculated in step 2

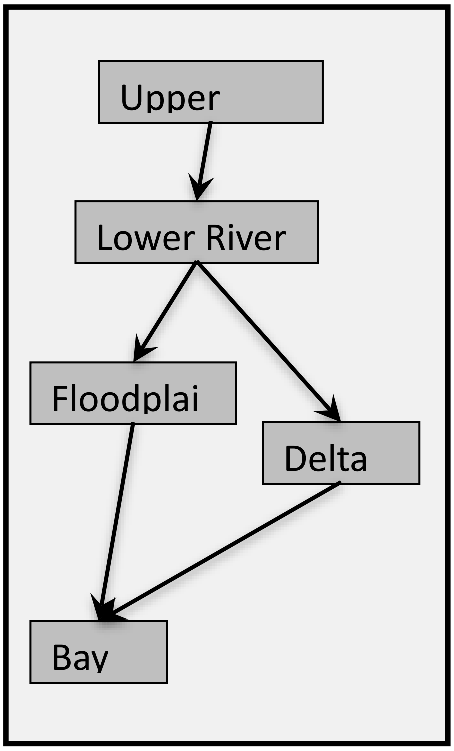



**Figure 7. Connectivity among habitats for winter-run Chinook fry. Connections between the Lower River and Floodplain occur due to flooding of the Yolo bypass and are thus ephemeral.**

### Transitions 11 & 12

*Definition*: Smolts that reared in the Upper River and Lower River habitats migrate to the Gulf of the Farallones in months $m$ = (12, … ,18) corresponding to February to August.

*Upper River smolt outmigration (Transition 11)*

$$Gulf_{UR,m} = S_{11,UR,m-1} * S_{G1} * Smolts_{UR,m-1} * \exp(\varepsilon_y - \sigma_\varepsilon^2/2)$$

*Lower River smolt outmigration (Transition 12)*

$$Gulf_{LR,m} = S_{12,LR,m-1} * S_{G1} * Smolts_{LR,m-1} * \exp(\varepsilon_y - \sigma_\varepsilon^2/2)$$

where survival $S_{T,h,m}$ is the smolt survival rate from transition $T$ (11, ..., 15) in habitat $h$ ($UR, LR, FP, DE, BA$) in month $m$. The rates $S_{11.UR,m}$ and $S_{12,LR,m}$ are composed of three components: A) survival rate from the Upper or Lower River to the Sacramento River near Sacramento; B) survival through the Delta to Chipps Island; and C) survival from Chipps Island to Golden Gate. The survival rate $S_{G1}$ is the survival rate of smolts originating from the Upper River, Lower River, and Floodplain habitats during ocean entry at the Gulf of Farallones. Finally, the transition to the ocean from all habitats includes a random effect term $\varepsilon_y$ that is specific to each year $y$ and is distributed as a normal random variable, that is $\varepsilon_y \sim \mathrm{N}(0, \sigma_\varepsilon^2)$. The formulation used here is a biased-corrected form so the expected value of the random effects equals 0.

$$S_{11.UR,m} = {}^{A}S_{11,UR,m} * {}^{B}S_{12,LR,m} * {}^{C}S_{11}$$
$$S_{12,LR,m} = {}^{A}S_{12,LR,m} * {}^{B}S_{12,LR,m} * {}^{C}S_{11}$$

The first smolt survival component is modeled as a function of flow at Bend Bridge

$$\mathrm{logit}({}^{A}S_{11,UR,m}) = B0_{11,UR} + B1_{11} * q.bb_m$$
$$\mathrm{logit}({}^{A}S_{12,LR,m}) = B0_{12,LR} + B1_{11} * q.bb_m$$

where $B0_{11,UR}$, $B0_{12,LR}$ and $B1_{11}$ are model parameters, and $q.bb_m$ is monthly flow at Bend Bridge which is the closest station to the Red Bluff Diversion Dam standardized relative to historic Bend Bridge flows from 1970-2014.

$${}^{B}S_{12.LR,m} = Newman_{LR,m}$$

where $Newman_{LR,m}$ is a mean monthly survival rate for smolts originating from the Sacramento River through the Delta to Chipps Island as calculated by the Newman model. The value ${}^{C}S_{11}$ is a model parameter representing survival from Chipps Island to Golden Gate and is applicable to smolts originating from all habitats.

**Transition 13**

*Definition*: Smolts that reared in the Floodplain migrate to the Gulf of the Farallones in months $m$ = (12, … ,18) corresponding to February to August.

$$Gulf_{FP,m} = S_{13,FP,m-1} * S_{G1} * Smolts_{FP,m-1} * \exp(\varepsilon_y - \sigma_\varepsilon^2/2)$$

The rate $S_{13,FP,m}$ is composed of three components: A) survival rate from the Floodplain to the Delta; B) survival through the Delta to Chipps Island; and C) survival from Chipps Island to Golden Gate.

$$S_{13,FP,m} = {}^{A}S_{13,FP,m} * {}^{B}S_{13,FP,m} * {}^{C}S_{11}$$

where ${}^{A}S_{12,FP,m}$ is survival in the Floodplain until the Newman equation is applied for survival through the Delta

$${}^{B}S_{13.FP,m} = Newman_{FP,m}$$

where $Newman_{FP,m}$ is a mean monthly survival rate for smolts originating from the Floodplain through the Delta to Chipps Island as calculated by the Newman equation.

**Transition 14**

*Definition*: Smolts that reared in the Delta migrate to the Gulf of the Farallones in months $m$ = (12, … ,18) corresponding to February to August.

$$Gulf_{DE,m} = S_{14,DE,m-1} * S_{G2} * Smolts_{DE,m-1} * \exp(\varepsilon_y - \sigma_\varepsilon^2/2)$$

The rate $S_{14,DE,m}$ is composed of two components: A) survival through the Delta to Chipps Island; and B) survival from Chipps Island to Golden Gate.

$$S_{14,DE,m} = {}^{A}S_{14,DE,m} * {}^{C}S_{11}$$

where ${}^{A}S_{14,DE,m} = Newman_{DE,m}$

The survival rate $S_{G2}$ is the survival rate of smolts in the nearshore from Delta and Bay habitats relative to the survival rate in the nearshore of Upper River, Lower River, and Yolo habitats.

$$S_{G2} = \text{logit}(\text{inv.logit}(S_{G1}) + D_{G2})$$

**Transition 15**

*Definition*: Smolts that reared in the Bay migrate to the Gulf of the Farallones with an associated migration survival in months $m$ = (12, … ,18) corresponding to February to August.

$$Gulf_{BA,m} = S_{15,BA} * S_{G2} * Smolts_{BA,m-1} * \exp(\varepsilon_y - \sigma_\varepsilon^2/2)$$

where $S_{15,BA}$ is the survival from the Bay habitat to the Golden Gate.

### Transition 16

The total number of Age 1 fish entering the Gulf of the Farallones from all habitats arriving in a given month can be calculated by summing across each of the individual rearing areas. Furthermore, earlier arriving fish are retained in the Age 1 stage and an ocean survival rate is applied to those fish that were already in the Age 1 stage in the previous month. Fish arrive into the Age 1 stage in months $m$ = (12, …, 21) corresponding to February through October.

$$Age1_{m} = Gulf_{UR,m} + Gulf_{LR,m} + Gulf_{FP,m} + Gulf_{DE,m} + Gulf_{BA,m} + Age1_{m-1} * S_{17}^{1/4}$$

### Transition 17

*Definition*: Survival in the ocean from Age 1 to Age 2 (for Chinook that remain in the ocean)

$$Age2 = Age1_{m=21} * (1 - M_2) * S_{17}$$

where $S_{17}$ is a model parameter representing the survival rate of Age 1 fish in the ocean to Age 2 and $M_2$ is a model parameter representing the maturation rate that leads to 2-year old spawners. The model transitions from a monthly time step (used for months 1 through 20) to an annual time step (used for Age 2, Age 3 and Age 4 fish) in this transition, thus the $S_{17}$ survival represents a 4-month survival rate from 21 months to 24 months.

### Transition 18

*Definition*: Maturation and migration for Age 2 males and females that will spawn as 2-year olds

$$Sp_{2,F} = Age1_{m=21} * S_{17} * M_2 * Fem_{Age2} * S_{sp2}$$
$$Sp_{2,M} = Age1_{m=21} * S_{17} * M_2 * (1 - Fem_{Age2}) * S_{sp2}$$

where $S_{17}$ and $M_2$ are model parameters for maturation and survival as described in Transition 17. $Fem_{Age2}$ is a model parameter representing the proportion of Age 2 spawners that are female, and $S_{sp2}$ is a model parameter representing the natural survival rate of Age 2 spawners from the ocean to the spawning grounds.

### Transition 19

*Definition*: Survival in the ocean from Age 2 to Age 3 (for Chinook that remain in the ocean)

$$Age3 = Age2 * (1 - I_3) * S_{19} * (1 - M_3)$$

where $I_3$ is the fishery impact rate for Age 3 fish, $S_{19}$ is a model parameter representing natural survival rate for fish between Age 2 and Age 3, and $M_3$ is a model parameter representing maturation rate of Age 3 fish.

**Transition 20**

*Definition*: Maturation and migration for Age 3 males and females that will spawn as 3-year olds

$Sp_{3,F} = Age2 * (1 - I_3) * S_{19} * M_3 * Fem_{Age3} * S_{sp3}$
$Sp_{3,M} = Age2 * (1 - I_3) * S_{19} * M_3 * (1 - Fem_{Age3}) * S_{sp3}$

where $I_3$ is the Age 3 fishery impact rate, and $M_3$ and $S_{19}$ are the Age 3 maturation and survival rates as described in Transition 19. $Fem_{Age3}$ is a model parameter representing the proportion of Age 3 and 4 spawners that are female, and $S_{sp3}$ is a model parameter representing the natural survival rate of Age 3 spawners from the ocean to the spawning grounds.

**Transition 21**

*Definition*: Maturation and migration for Age 3 males and females that will spawn as 4 year olds

$Sp_{4,F} = Age3 * (1 - I_4) * S_{21} * Fem_{Age3} * S_{sp4}$
$Sp_{4,M} = Age3 * (1 - I_4) * S_{21} * (1 - Fem_{Age3}) * S_{sp4}$

where $I_4$ is the Age 4 fishery impact rate, $S_{21}$ is a model parameter representing survival rate from Age 3 to Age 4, $Fem_{Age3}$ is a model parameter representing the proportion of Age 3 and 4 spawners that are female, and $S_{sp4}$ is a model parameter representing the natural survival rate of Age 4 spawners from the ocean to the spawning grounds.

**Transition 22**

*Definition*: Number of eggs produced by spawners of Ages 2 – 4 in months $m$ = (2, …, 6) corresponding to April to August.

$$Eggs_m = \frac{\sum_{j=2}^{4} TSp_{j,F} * P_{SP,m} * V_{eggs,j}}{1 + \frac{\sum_{j=2}^{4} P_{SP,m} * TSp_{j,F} * V_{eggs,j}}{K_{Sp,m}}}$$

where $TSp_j$ are the total number of female spawners of age $j$ = 2, 3, 4 (composed of both natural and hatchery origin), $V_{eggs,j}$ is the number of eggs per spawner of age $j$ = 2, 3, 4, $K_{Sp,m}$ is the capacity of eggs in the spawning grounds per month, and $P_{SP,m}$ is the proportion of spawning that occurs in month $m$ and is a function of April average temperature at Keswick Dam. Because the April temperature can vary among years, the monthly distribution varies as well to reflect observed patterns in spawn timing among the years from 1999 to 2012. Please see Appendix A for description of the analysis of historical patterns in spawn timing.

$TSp_{2,F} = Sp_{2,F} + Sp_{2,F,Hatchery}$

$TSp_{3,F} = Sp_{3,F} + Sp_{3,F,Hatchery} - hat.f$

$TSp_{4,F} = Sp_{4,F} + Sp_{4,F,Hatchery}$

$hat.f = 0.15 * Sp_3$ (min = 10; max = 60)

where $hat.f$ is the number of spawning females removed for use as hatchery broodstock, and $Sp_{j,Hatchery}$ for $j$ = (2,3,4) is the spawners of age $j$ hatchery origin, which are described below in the *Hatchery Origin Chinook* section.

***Hatchery Origin Chinook***

### Transition 1H

*Definition*: Survival of hatchery fish from eggs to Age 2

$Age2_{Hatchery} = hat.f * 3000 * H_{S1}$

$H_{S1} = 2.3 * Age2_{Natural} / Fry_{Natural}$

where $H_{S1}$ is the hatchery-origin survival rate from pre-smolt at release to Age 2 in the ocean, $Age2_{Natural}$ is the number of natural-origin Chinook that survived to Age 2 and remained in the ocean, and $Fry_{Natural}$ is the number of natural origin emerging Fry (see Transition 1 for Natural Origin Chinook). The multiplier of 3000 hatchery smolts per spawner was obtained from Winship et al. (2014). The multiplier of 2.3 was used to equate hatchery origin survival to the end of age 2 to natural origin survival to the end of age 2 as described in Winship et al. (2014). Note this transition includes the total number of Age 2 hatchery fish, including fish that remain in the ocean and Age 2 spawners.

### Transition 2H

*Definition*: Maturation and spawning for hatchery origin Age 2

$Sp_{2,F,Hatchery} = Age2_{Hatchery} * M_2 * Fem_{Age2} * S_{sp2}$
$Sp_{2,M,Hatchery} = Age2_{Hatchery} * M_2 * (1 - Fem_{Age2}) * S_{sp2}$

where the coefficients are described under Transition 18.

### Transition 3H

*Definition*: Survival of hatchery origin fish in the ocean from Age 2 to Age 3 (for Chinook that remain in the ocean)

$Age3_{Hatchery} = Age2_{Hatchery} * (1 - I_3) * S_{19} * (1 - M_3)$

where the coefficients are described under Transition 19.

### Transition 4H

*Definition*: Maturation and spawning for hatchery origin Age 3

$Sp_{3,F,Hatchery} = Age2_{Hatchery} * (1 - I_3) * S_{19} * M_3 * Fem_{Age3} * S_{sp3}$
$Sp_{3,M,Hatchery} = Age2_{Hatchery} * (1 - I_3) * S_{19} * M_3 * (1 - Fem_{Age3}) * S_{sp3}$

where the coefficients are described under Transition 20.

### Transition 5H

*Definition*: Survival and maturation rate for hatchery origin Age 4

$Sp_{4,F,Hatchery} = Age3_{Hatchery} * (1 - I_4) * S_{21} * Fem_{Age3} * S_{sp4}$
$Sp_{4,M,Hatchery} = Age3_{Hatchery} * (1 - I_4) * S_{21} * (1 - Fem_{Age3}) * S_{sp4}$

where the coefficients are described under Transition 21.

***Fishery Dynamics***

To simulate the winter-run population dynamics under alternative hydrologic scenarios, we include fishery dynamics that are consistent with the current fishery control rule (NMFS 2012) (Figure 8). For each year of the simulation, the impact rate for age 3 ($I_3$) was calculated from the control rule by obtaining the 3-year trailing geometric average of spawner abundance. The age-4 impact rate ($I_4$) in that year was calculated as double the instantaneous age-3 impact rate (Winship et al. 2014).

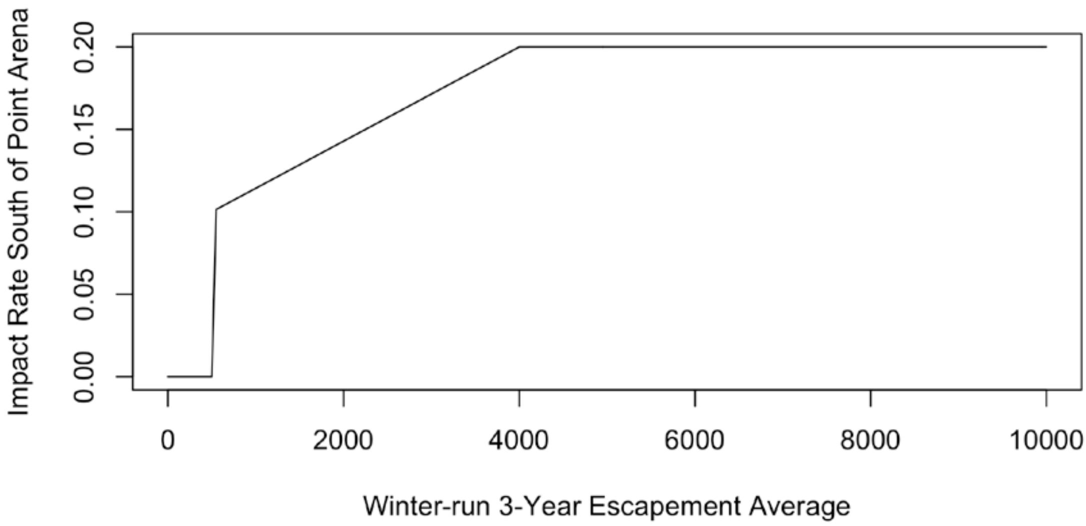



**Figure 8. Fishery control rule determining the level of Age 3 impact rate as a function of trailing 3-year geometric mean in winter-run escapement.**

# III. Inputs to the Winter-run life-cycle model

## Water Temperature

The life cycle model (LCM) incorporates monthly average temperature below Keswick Dam into the definition of egg to fry survival. The water temperature can be obtained from water quality gages on the Sacramento River (for model calibration) or from a forecasted water temperature model, such as the as the Sacramento River Water Quality Model (SRWQM).

## Fisheries

Estimates of impact rates on vulnerable age classes of Chinook salmon are computed as part of the Pacific Fisheries Management Council (PFMC) annual forecast of harvest rates and review of previous years' observed catch rates. For runs that are not actively targeted, such as winter-run and spring-run Chinook, analyses of coded wire tag (CWT) groups are used to infer impact rates for these races (e.g., O'Farrell et al. 2012).

## Habitat Capacity

Juvenile salmonids rear in the mainstem Sacramento River, delta, floodplain, and bay habitats (Figure 1). The model incorporates the dynamics of rearing fry by using density-dependent movement out of habitats as a function of capacity for juvenile Chinook. The capacities of each of the habitats are calculated in each month using a series of habitat-specific models that relate habitat quality to a spatial capacity estimate for rearing juvenile Chinook salmon. Habitat quality is defined uniquely for each habitat type (mainstem, delta, etc.) with the goal of reflecting the unique habitat attributes in that specific habitat type. For example, the mainstem habitat quality is a function of velocity and depth (Beechie et al. 2005). Higher quality habitats are capable of supporting higher densities of rearing Chinook salmon, with the range of densities being determined from studies in the Central Valley and in river systems in the Pacific Northwest where appropriate.

*Defining habitat capacity*. For each habitat type (Upper River, Lower River, Floodplain, Delta, and Bay), capacity was calculated each month as:

$$K_i = \sum_{j=1}^{n} A_j d_j$$

where $K_i$ is the capacity for a given habitat type $i$, $n$ is the total number of categories describing habitat variation, $A_j$ is the total habitat area for a particular category, and $d_j$ is the maximum density attributable to a habitat of a specific category. Three variables were determined for each habitat, the ranges of each were divided into high and low quality, and all combinations were examined, resulting in a total of eight categories (2 x 2 x 2) of habitat quality for each habitat type (Table 1). In the Upper River, Lower River, and Floodplain, there were 4 categories (2x2) of habitat quality. Ranges of high and low habitat quality were based on published studies of habitat use by Chinook salmon fry across their range and examination of data collected by USFWS within the Sacramento-San Joaquin Delta and San Francisco Bay.

*Defining maximum densities*. Determining maximum densities for each combination of habitat variables is complicated by the fact that most river systems in the Central Valley are now hatchery-dominated with fish primed for outmigration. In addition, the Central Valley river system is at historically low natural abundance levels compared to expected or potential density levels. Because of this deficiency in the Central Valley system, salmon fry density data from the Skagit River system were used, which in contrast has very low hatchery inputs, has been monitored in mainstem, delta, and bay habitats, and exhibits evidence of reaching maximum density in years of high abundance (Greene et al. 2005; Beamer et al. 2005). These data from the Skagit River were compared with Central Valley density estimates calculated by USFWS. For each of these data sets, the upper 90 to 95 percentile levels of density defined a range of maximum density levels, assuming that the highest five percentile of density levels were sampling outliers. The comparison indicated that Skagit River values represented conservative estimates of maximum density (Figure 9).

**Table 1. Habitat variables influencing capacity for each habitat type. Mainstem includes Upper River, Lower River and Floodplain habitats.**

| Habitat type | Variable | Habitat quality | Variable range |
|---|---|---|---|
| Mainstem | Velocity | High | <= 0.15 m/s |
| | | Low | > .15 m/s |
| | Depth | High | > .2 m, <= 1 m |
| | | Low | <= 0.2 m, > 1 m |
| Delta | Channel type | High | Blind channels |
| | | Low | Mainstem, distributaries, open water |
| | Depth | High | > .2 m, <= 1.5 m |
| | | Low | <= 0.2 m, > 1.5 m |
| | Cover | High | Vegetated |
| | | Low | Not vegetated |
| Bay | Shoreline type | High | Beaches, marshes, vegetated banks, tidal flats |
| | | Low | Riprap, structures, rocky shores, exposed habitats |
| | Depth | High | > .2 m, <= 1.5 m |
| | | Low | <= 0.2 m, > 1.5 m |
| | Salinity | High | <= 10 ppt |
| | | Low | > 10 ppt |

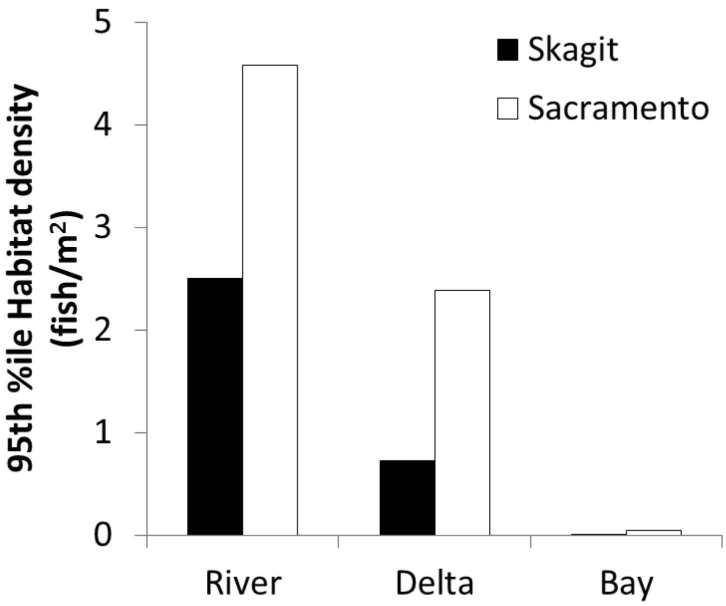



**Figure 9. 95th percentile values of densities in river, delta, and bay habitats in the Skagit and Sacramento Rivers. Skagit data are based on electroshocking in mainstems and beach seining in delta and bay habitats (Beamer et al. 2005), while Sacramento data are based on beach seining across all habitat types (USFWS, 2005).**

*Determining habitat areas*. Two approaches were used to map the spatial extents of different combinations of habitat variables. In the mainstem and floodplain, the HEC-RAS model divides the river into units based on multiple cross-sections defining depth ranges (Figure 10). Each unit defined by the cross-sections has velocity parameters associated with it. Different levels of flow in a given month or year change the distribution of velocity and depth.  Total habitat area in each of the eight classes is calculated by integrating over the river channels modeled by HEC-RAS.

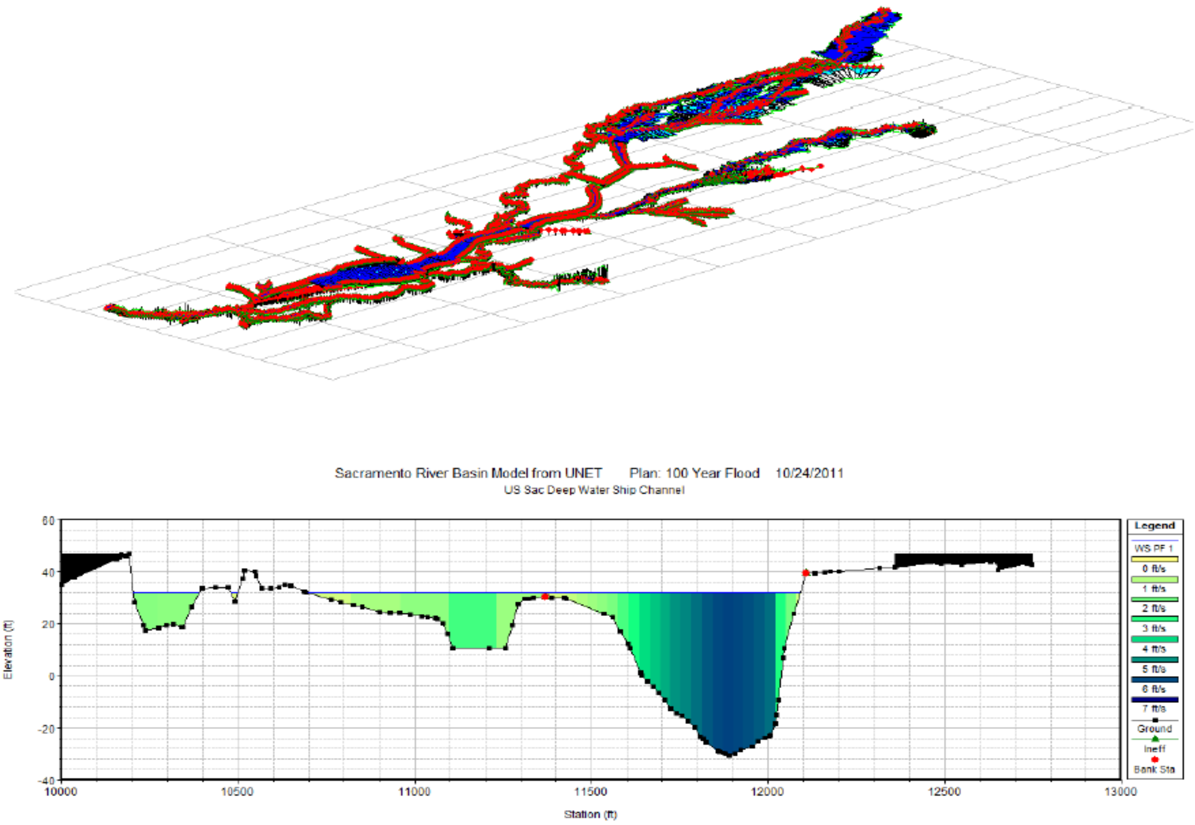



**Figure 10. HEC-RAS model cross sections of the Sacramento River mainstem and floodplain (upper panel), and a visualization of a single cross-section, showing depth and velocity differences (lower panel).**

For the delta and bay, channel type, depth, cover, salinity, and shoreline type were mapped from existing delta and bay Geographic Information Systems (GIS) products (Figure 11). Delta and bay polygons[1] were classified into high quality habitat types (blind tidal channels) and low quality habitat types (mainstem, distributaries, large water bodies, and bay). For the channel typing, several datasets comprised the base GIS layers, including National Wetlands Inventory (NWI) wetland polygons, San Francisco Estuary Institute's Bay Area Aquatic Resource Inventory's (BAARI) stream lines and polygons, Hydro24ca channel polygons (USBR 2006, Mid-Pacific Region GIS Service Center), aerial photos and Google Earth. The Hydro24ca channel data included channel types such as major river, slough, lake and several other types. When channel type could not be defined for a given reach, aerial photos and attributes from surrounding channels were used to estimate channel type. National Wetland Inventory (NWI) GIS data served as base channel and wetland data. NWI data provides comprehensive data coverage as well as detailed wetland categories that were required. However, NWI data did not have enough information to distinguish accessibility for juveniles. Thus,

[1] A closed shape used in GIS mapping that is defined by a connected sequence of x, y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique.

Bay Area Aquatic Resource Inventory (BAARI) data were used as a reference to identify accessible wetlands from NWI polygons. For the areas that BAARI data did not cover, levee GIS layers were overlain to estimate accessible wetland habitat.

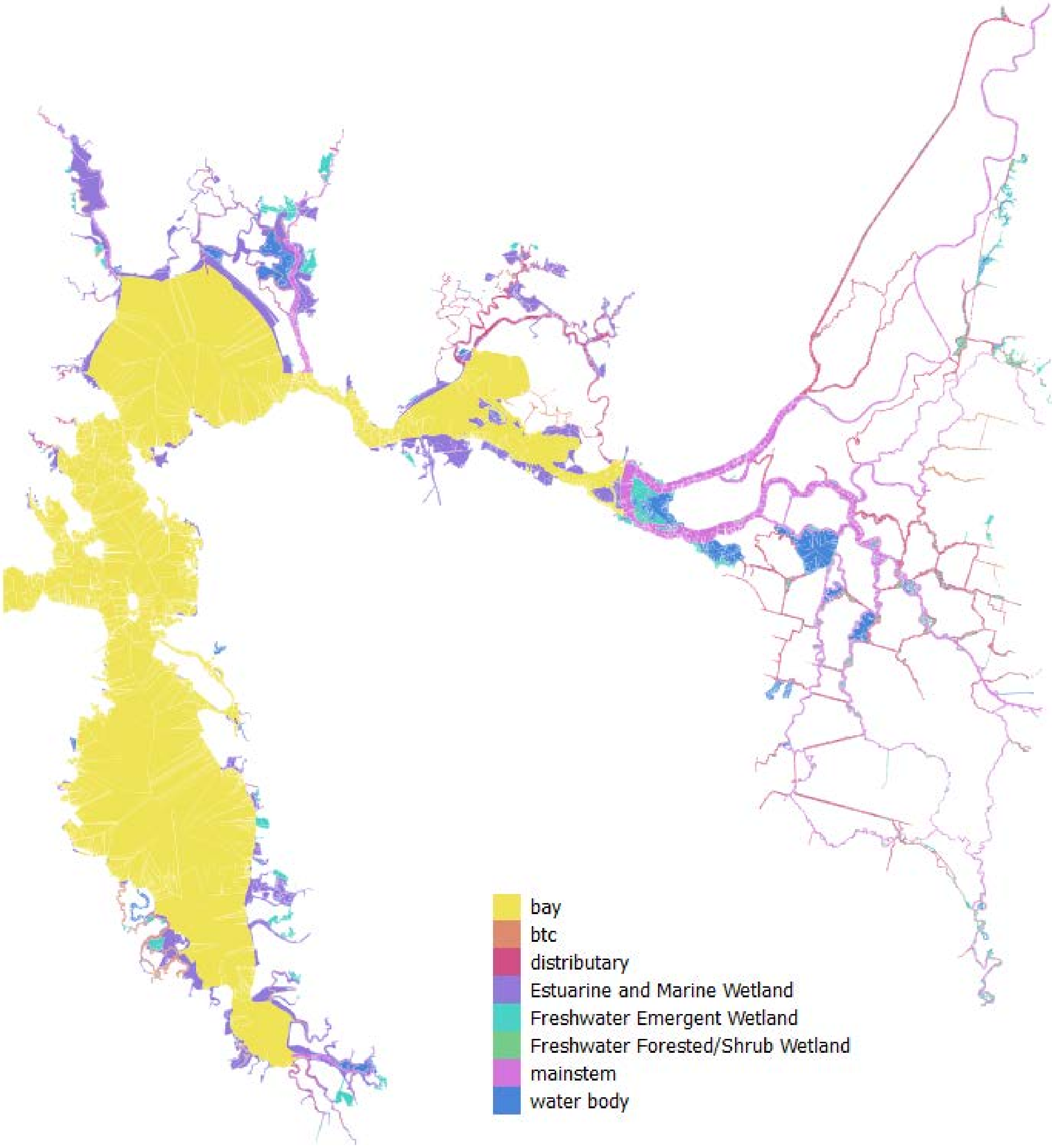



**Figure 11. Habitat types delineated for the Sacramento Delta and San Francisco Bay. The abbreviation "btc" stands for blind tidal channel.**

Most channel types could be mapped using these datasets except for the blind tidal channels. Instead of directly mapping blind tidal channels, we estimated these areas using allometric relationships between wetland areas and blind tidal channel areas. We tested allometric equations developed in the Skagit River by Beamer et al. (2005) and Hood (2007) to determine which equations were best suited to apply to the Central Valley and chose an allometric equation that returned conservative estimation results:

$$BTC\ (ha) = 0.0024 * Wetland(ha)^{1.56}$$

We also applied the minimum area requirement (0.94 ha) to form blind tidal channels in a wetland from Hood (2007).

Salinity is another factor influencing habitat availability for juvenile Chinook salmon that can vary with water flow. The X2 position describes the distance from Golden Gate Bridge to the 2 ppt isohaline position near the Sacramento Delta (Jassby et al. 1995). This distance predicts amount of suitable habitat for various fish and other organisms. Based on observations of high likelihood of fry presence in water with salinity of up to 10 ppt in both Skagit River and San Francisco Bay fish monitoring data, we defined the low-salinity zone for Chinook as salinity < 10 ppt (i.e., habitats upstream of X10). We calculated X10 values as 75 percent of X2 values (Monismith et al. 2002, Jassby et al. 1995), and mapped these across San Francisco Bay.

Another axis used to evaluate habitat is vegetated cover along river banks. Areas associated with cover were assumed to be higher quality habitats because they provide protection from predators (Semmens 2008) and offer subsidies of terrestrial insect prey. Such habitats are preferred in other systems by Chinook salmon (Beamer et al. 2005, Semmens 2008). The extent of these areas was estimated using Coastal Change Analysis Program (C-CAP) Land Use/Land Cover (LULC) layers. We defined sheltered habitat as forested or shrub covered areas and assumed that other areas, such as urban and bare land, did not provide sheltered habitat.

*Restricting habitat areas based on connectivity*. Our first analysis of habitat areas assumed all regions of the Delta were equally accessible to Chinook salmon fry. This assumption may be incorrect, however, because much of the fish monitoring has shown that fry do not inhabit certain areas in the Delta. Therefore, a spatial connectivity mask, or exclusion zone, was developed to exclude certain areas from the habitat mapping. This exclusion zone was produced using month- and year-specific fish monitoring data (Figure 12). Poisson regression models were used to predict fish counts based on the relationships between fish counts in beach seine datasets and several covariates including river system (Sacramento or San Joaquin), distance of sampling site to its mainstem (m), physical channel depth (m), physical channel width (m), and DSM2 water stage (m). We selected these parameters based on Akaike's Information Criterion (AIC) analysis of the Poisson regression models with various combinations of the parameters. The resulting Poisson model equation was used to produce a presence-absence map for the entire delta (Figure 12). Restricted capacity estimates were generated by summing habitat areas with predicted fry presence.

*Modeling capacity for preferred and no action alternatives*. The geospatial tools described above were used to make predictions of capacities of preferred and no action alternatives by routing Calsim2 runs of alternatives through HEC-RAS and DSM2 models. Model changes for these runs included the lowering of the diversion for the Yolo Bypass in HEC-RAS for both alternatives and the diversions and underground tunnels in DSM2 for the preferred alternative.

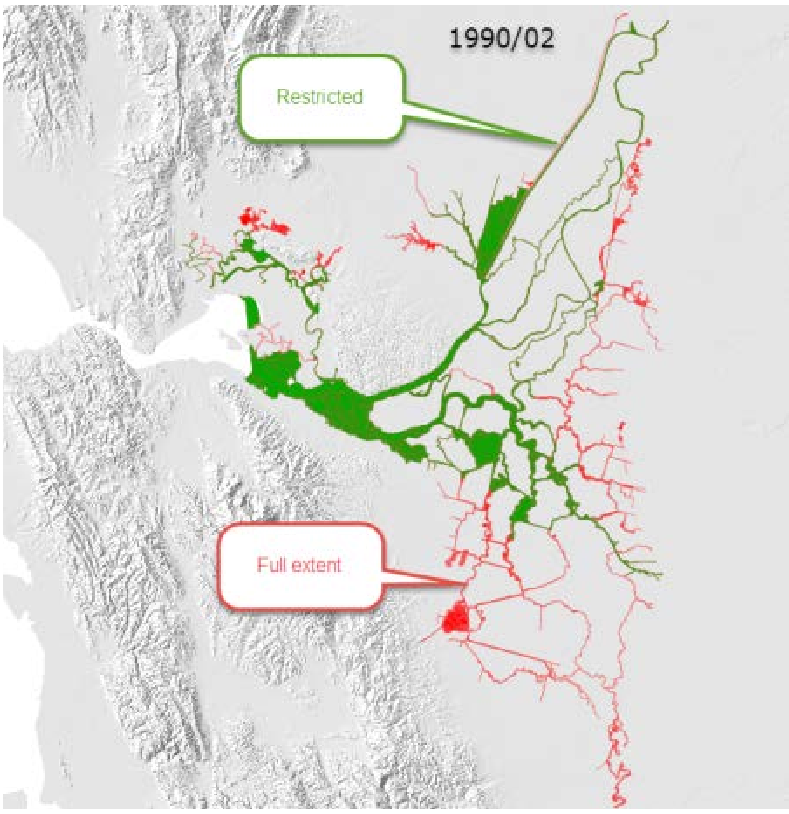



**Figure 12. Example results of reduced connectivity applied to the February (02) 1990 map. The presence/absence prediction for connected habitat areas is designated as "Restricted" (green), a smaller area than the full extent of the Sacramento Delta (red).**

## Newman Equations for Smolt Survival

The survival rate of juvenile Chinook salmon smolts within and migrating through the Delta is modelled using an approach developed by Newman (2003). The Newman survival model is a nonlinear hierarchical model that incorporates biotic covariates, environmental covariates and random effects to estimate survival of juvenile Chinook salmon in the delta. Although more recent models such as the enhanced Particle Tracking Model (ePTM, Sridharan et al. 2015) and the Survival, Travel time, And Routing Simulation (STARS) model (Perry et al. 2018) have been developed to improve the delta survival estimates generated by Newman (2003), the Newman delta survival model remained the preferred model for this version of the WRLCM for two important reasons. First, the ePTM is currently undergoing development and is not ready for incorporation into the WRLCM at this time. Second, the STARS model does not include exports as a covariate, thus could not inform how differences in levels of exports under the COS and PA scenarios affect smolt survival in the delta. Therefore, the Newman survival model was used for this version of the WRLCM because it was the most complete model available that was sensitive to changes in exports.

The Newman model estimates survival through the delta by comparing survival of juvenile hatchery coded-wire-tagged fall-run Chinook salmon released at several locations upstream and downstream of the delta (Newman 2003). Upstream releases were located in the lower Sacramento River (near the cities of Sacramento, Courtland, and Ryde), and thus required juveniles to transit the delta before reaching the ocean. Lower releases were located just west of Chipps Island (near Port Chicago and Benicia), and thus represented juveniles that did not transit the delta. Survival was estimated from coded-wire tag recoveries in the freshwater by operating a midwater trawl located near Chipps Island following releases (upstream releases only) and in the ocean as released fish reached 2 to 5 years of age and were captured from commercial and recreational fisheries (both upstream and downstream releases). The relative differences in survival between release groups allowed for delta-specific survival estimates.

Several biotic and abiotic variables are included as covariates in the Newman model of delta survival. Covariates in the model include fish length, log transformed median river flow during the outmigration period, water salinity, river water temperature and hatchery water temperature at release, magnitude of the tide, median volume of exports during the outmigration period, indicator for position of the DCC gate located below Courtland (1 = open; 0 = closed), and water turbidity (Newman 2003). Because all of the covariates were standardized in the Newman analysis, we can set the values of the unused covariates to 0 (the mean value during the study) and those terms drop from the equation. Generically, the following equation was employed in the WRLCM to calculate smolt survival (for more details on the model and description of covariates, see Newman (2003)).

$$Newman_{h,m} = B0_{Newman} + B1_{Newman}size_{h,m} + B2_{Newman}temp_{h,m} + B3_{Newman}flow_{h,m} + B4_{Newman}exports_{h,m} + B5_{Newman}DCC_{h,m} + B6_{Newman}SacIndicator_{h,m}$$

where $Newman_{h,m}$ is the Newman model estimate for survival in the delta for fish originating from a given habitat $h$ and month $m$. The covariate $SacIndicator$ is an indicator value and set to 1 when modeling survival from the Sacramento release locations. For all other release locations, $SacIndicator$ is set to 0. For this version of the WRLCM, we did not include covariates of salinity, release temperature, hatchery temperature, tide, or turbidity because these were not available for evaluation of the operational scenarios. All parameter values included in the Newman model are listed in Appendix B.

The WRLCM adjusted input data into the Newman model to generate specific delta survival estimates for juveniles depending on their habitat of origin. Delta survival for fish originating from the upper or lower river ($Newman_{LR,m}$) used the above equation with the $SacIndicator$ term set to 1. Delta survival from fish originating in the delta ($Newman_{DE,m}$) used the above equation with the $SacIndicator$ term set to 0. Finally, Delta survival from fish in the floodplain ($Newman_{FP,m}$) used the above equation with the $SacIndicator$ term set to 0 and the average length increased by 10mm to account for the higher growth rates in the Yolo Bypass (Takata et al. 2017, Sommer et al. 2001).

## Caveats

The Newman survival results are based on a statistical model and environmental covariates that occurred over the time-frame 1979-1995. Furthermore, the Newman model was developed using fall-run juvenile Chinook salmon reared in hatcheries and released in April and May, which is later than the peak outmigration for winter-run Chinook salmon. As a result, the use of the Newman model for predicting absolute estimates of survival for winter-run Chinook salmon must be considered with caution. The authors expect future versions of the WRLCM to incorporate delta survival from updated models that are developed for winter-run Chinook salmon outmigration timing and are sensitive to exports and other water operations that may influence delta survival. The Newman model does appear capable of reflecting relative changes in survival as a function of important management drivers, however. Due to the short time frame under which this analysis had to be conducted, the Newman model became the only option, despite its limitations. It is important to note that the WRLCM is being applied to understand the relative differences between scenarios, and relative model outputs may be less sensitive to these caveats. The Newman model should be considered as an assumption of how smolt survival rates would vary as a function of management drivers with these assumptions being applied equally to the scenarios under evaluation.

# IV. Model Calibration

The WRLCM framework is flexible in that it may be used to generate many different trajectories of abundance and spatial patterns of habitat use by varying the parameters of the model. The WRLCM should reflect historical trends and spatial patterns in abundance, however. As a result, we calibrated the WRLCM to multiple winter-run abundance indices by fixing some model parameters and estimating other parameters with a statistical fitting algorithm.

One goal of the WRLCM was to construct a model that was sensitive to alternative hydromanagement actions in the Central Valley; thus the model was structured such that it is sensitive to hydrologic drivers. An unintended consequence of this approach is that the statistical properties of the model are not optimal. In particular, some model parameters are not uniquely identifiable; that is, the same abundance can occur through several different parameter combinations. Because this property of the LCM makes statistical estimation difficult, the values of some parameters must be constrained using biological information, previous studies, or expert opinion, so that other parameters can be estimated. We provide the parameters that were constrained and provide justification for their values before moving to the statistical estimation of the remaining parameters.

## Fixed parameters and their justifications

### Spawn timing parameters

Historically, the spawning of winter-run Chinook has not been uniform among the months April to August. Instead, higher proportions of winter-run spawned in June and July relative to April, May, and August. In addition, the proportions of winter-run that spawned in each month were not constant across years, but instead varied annually. We analyzed the historical proportion spawning among each month from 2003 – 2014 using carcass counts (assuming a 2-week period between spawning and senescence), and estimated the proportion of winter-run spawning in each month as a function of April temperatures at Keswick (Appendix A). We compared this model to one that used a static proportion among years, and found that the model based on April temperatures outperformed the static model. The general relationship identified through this multinomial regression model was that hotter April temperatures caused later initiation of spawning in winter-run Chinook. This may be explained mechanistically if the female spawners were laying their eggs to target an emergence time. Hotter temperatures in April indicated that a shorter incubation window was needed, whereas cooler temperatures indicated a longer incubation window. Please see Appendix A for additional information on this analysis.

These equations provided a method of shifting spawning distribution among months as a function of April temperatures (Appendix A). The April water temperatures were standardized in the analysis and thus need to be standardized for use in the simulation model.

### Tidal fry related parameters

Winter-run Chinook generally have not had a high tidal fry proportion (on the order of less than 5%). Furthermore, the location of tidal fry has varied among years, and they have been susceptible to movement downstream in the Sacramento River under high flow conditions (Pat Brandes, USFWS *personal communication*). The WRLCM parameters for the fry stage reflected these assumptions (Table 2).

**Table 2. Fixed parameter values related to the tidal fry stage.**

| Parameter | Value | Description |
|---|---|---|
| $P_{TF,\,m}$ | 0.047 | Proportion tidal fry |
| $S_{TF,FP}$ | 0.731 | Survival tidal fry in floodplain |
| $P_{FP,m}$ | 0.881 | Proportion to Floodplain if flooding |
| $B0_4$ | 0.5 | Average survival tidal fry to delta intercept |
| $B1_4$ | -1.0 | Effect of DCC gate (value is in logit space)* |
| $B0_5$ | 0.5 | Average proportion of tidal fry to bay intercept |
| $B1_5$ | 2.0 | Effect of Rio Vista flow (value is in logit space)* |

*Values in logit space are the untransformed values used in the logit function of the transition equation

### Smoltification timing parameters

The timing of smoltification of winter-run Chinook salmon historically begins in January with a majority of winter-run sized smolts outmigrating by March (delRosario et al. 2013). In the WRLCM, all fry are assumed to have smolted by April and migrating in May (Table 5). The timing of smoltification in the WRLCM has been parameterized to coincide with winter-run sized Chinook salmon in Chipps Island trawl data (delRosario et al. 2013) and by using Chipps Island abundance indices as described below in the *Parameter Estimation* section.

**Table 3. Smoltification timing parameters for winter-run Chinook.**

| Parameter | Value | Description |
|---|---|---|

| | | |
|---|---|---|
| $Z_1$ | 0.269 | January smolt probability |
| $Z_2$ | 0.5 | February smolt probability |
| $Z_3$ | 0.953 | March smolt probability |
| $Z_4$ | 1 | April smolt probability |
| $Z_5$ | 1 | May smolt probability |
| $Z_6$ | 1 | June smolt probability |
| $Z_7$ | 1 | July smolt probability |

### Maturation rate probabilities

The age-specific maturation probabilities for winter-run Chinook salmon were fixed to values based on analysis of coded wire tagged hatchery fish (Grover et al. 2004). The probability of maturation of age 2 fish was 0.10 ($M_2$), the conditional probability of maturation at age 3 was 0.90 ($M_3$), and the conditional probability of maturation at age 4 was 1.0.

Age-specific sex ratios were applied to obtain age and sex specific escapement values. Males dominate age-2 escapement, thus the female sex ratio for age-2 fish ($Fem_{Age2}$) was set at 0.01. Estimates of the proportion of age-3 female spawners ($Fem_{Age3}$) may vary among years, and we accounted for this historical annual variability by using an annual sex spawner ratio value calculated from Keswick trap counts 2001 – 2014 (mean = 0.595, sd = 0.077). These values were also used in the annual calculation of natural origin escapement from carcass surveys over the period 2001 – 2014 (Doug Killam, CDFW Redding, CA, *personal communication*). In the absence of an estimate of the age-3 sex ratio, a value of 0.5 was assumed for 1970 – 2000.

Egg production per age-2 female ($V_{eggs,2}$) was 3200 for age 2 females (Newman and Lindley, 2006) and production per age-3 and age-4 female ($V_{eggs,3}$ and $V_{eggs,4}$) was 5000 (Winship et al. 2014).

### Smolt survival

The Newman equation (Newman 2003) calculates month and year-specific delta smolt survival probabilities; however, some survival probabilities were needed to move the smolts from their areas of rearing to the location in which the Newman survival rates were applied. Smolt survival from the Lower River to the Delta ($B0_{11,LR}$) was fixed at 0.8 (estimates of survival ranged from 0.73 - 0.875 Colusa to Sacramento in the 2012-2015 WR acoustic tag data, Arnold Ammann, SWFSC NMFS Santa Cruz *personal communication*). Smolt survival from the Upper River to the Delta ($B0_{10,UR}$) was fixed at 0.4 (estimates of survival averaged 0.456 from release to Sacramento in the 2012-2015 WR acoustic tag data, Arnold Ammann, SWFSC NMFS Santa Cruz *personal communication*). Smolt survival from the Yolo bypass to the location where the Newman survival rates were applied (${}^{A}S_{13,FP}$) was assumed to be 0.924 per month.

Survival of smolts from Chipps Island to the Golden Gate bridge (${}^{c}S_{11}$) was assumed to be 0.82, and survival of smolts that reared in the Bay to the Golden Gate bridge ($S_{15,BA}$) was assumed to be 0.5.

### Ocean survival

Survival of smolts that reared in the Upper River, Lower River, and Yolo habitats, River and Yolo habitats ($S_{G1}$) which is estimated (see below in the *Parameter Estimation* section).

Survival during the first four months in the ocean ($S_{17}$) was assumed to have a rate of 0.79, which equates to an annual survival of 0.5, whereas annual survival in the ocean for age-3 and age-4 ($S_{19}$ and $S_{21}$) was assumed to be 0.8. These annual natural survival rates are consistent with winter-run reconstruction conducted annually as part of the fishery management of Sacramento River salmon (Grover et al. 2004, O'Farrell et al. 2012). Annual impact rates of age-3 ($I_3$) and age-4 ($I_4$) were obtained from estimated harvest rates over the 1970- 2014 period (O'Farrell and Satterthwaite 2015). Survival of age-2 ($S_{sp2}$), age-3 ($S_{sp3}$), and age-4 ($S_{sp4}$) through the freshwater prior to spawning is assumed to be 0.9 to incorporate in-river harvest, which historically included levels of approximately 7 percent (Grover et al. 2004) and pre-spawn mortality.

### Formulation of the Floodplain habitat access for calibration

To reflect the historical dynamics of access to the Floodplain habitat (Yolo bypass), the following transition equation was used to describe the proportion of Tidal Fry that enter the floodplain habitat ($P_{FP,m}$)

$$P_{FP,m} = B1_{FP} * \mathrm{I}(Q_{Verona,m} > 991.1\ \mathrm{m^3 s^{-1}})$$

where $Q_{Verona,m}$ was the Sacramento River flow at Verona in month $m$, $\mathrm{I}(\,)$ is an indicator function that equates to 1 when the condition in the parenthesis is met, and $B1_{FP}$ is the proportion of fry that enter the Yolo under flooding conditions, which was 0.881.

## Statistical estimation

One of our objectives is to ensure that the WRLCM is capable of reflecting the historical patterns in winter-run Chinook population dynamics in the Sacramento River. In order to meet this objective, we calibrated the LCM to observed winter-run indices of abundance throughout the life cycle (Table 4). Not all indices of abundance were available for the entire period of model calibration of 1970-2014. This data limitation is not a problem for fitting the WRLCM, however. The WRLCM can be fit to the specific indices of abundance for the period over which they were available by pairing observed indices of abundance with WRLCM predictions over the appropriate period. Then, the sampling distribution provided a likelihood function by which the model predictions were statistically evaluated given the observed data (Hilborn and Mangel 1997).

This type of model, in which multiple data sources are used to inform multiple life-history stages, is called an integrated population model and has notable advantages over piece-wise model composition (Newman et al. 2014). In particular, the model parameter estimates can utilize all of the available data simultaneously, which can improve the parameter estimates by allowing the model to "fill in the gaps" over portions of the life cycle that are unobserved (Newman et al. 2014).

**Table 4. Indices of abundance used to calibrate the winter-run life cycle model.**

| Data | Date | Coefficient of Variation | Sampling Distribution | Data time step |
|---|---|---|---|---|
| Natural Escapement | 1970-2014 | 1.0 (1970-1986)<br>1.5 (1987-2000)<br>1.0 (2001-2014) | lognormal | Annual |
| RBDD monthly juvenile counts | 1996-1999, 2002-2014 | | lognormal | Monthly |
| Knights Landing monthly catches | 1999 - 2008 | NA | multinomial | Monthly |
| Chipps Island monthly juvenile abundance | 2008 - 2011 | 1.5 | lognormal | Monthly |

## Maximum Likelihood Estimation

Given the fixed parameter values described above, the remaining parameters were estimated in a statistical fitting framework. An initial evaluation of model complexity (not shown) indicated that 10 parameters could possibly be estimated in the mechanistic portion of the model, depending upon which parameters were chosen. Previous calibrations of the model indicated that there were high correlations among several of those parameters, however. Due to the short time frame under which to calibrate the WRLCM using the Newman equation for smolt survival, we estimated 4 population dynamics parameters (and calculated an empirical estimate for the variance of the random effects) in addition to 45 annual random effects (i.e, the $\varepsilon_y$) in the model calibration.

These parameters were estimated by maximizing the likelihood (the likelihood specified by the sampling distribution) of observing the winter-run abundance indices (Hilborn and Mangel 1997). That is, parameter combinations can be used to make predictions on the escapement in each year, the number of juveniles passing RBDD in each month, the catches at Knights Landing, and monthly abundance estimates at Chipps Island. Some parameter combinations provide predictions that are closer to the observed abundance indices than others. The parameter combination that provides the closest fit to the observed indices is the one that maximizes the likelihood, and is thus called the maximum likelihood estimate (MLE).

Model parameters were estimated using a Monte-Carlo Expectation-Maximization (MCEM) algorithm (Wei and Tanner 1990, Levine and Casella 2001). In our case we used two blocks of parameters: 1) parameters associated with the mechanistic population dynamics and 2) the annual random effects. The specific implementation of the algorithm uses Monte Carlo draws so that parameter estimates that describe the winter-run population dynamics integrate across the annual random effects. The algorithm switches between a) maximizing the likelihood of the parameters given a set of random effects (the maximization step) and b) drawing sets of random effects given a fixed set of parameter values. (the expectation step). The algorithm iterates between these two steps until the parameter estimates become stable.

In practice, the expectation step can be difficult to implement when the model is complex. Approaches to overcome this difficulty have included using Markov Chain Monte Carlo (MCMC) to draw values of the random effects given the current estimates of the model parameters (McCullough 1997). Levine and Casella (2001) extended this approach by drawing many vectors of random effects via MCMC initially, e.g., 4000 vectors of annual random effects, each vector with 45 elements. Each of the random effects vectors is then reweighted at each iteration of the algorithm to reflect the likelihood of that random effects vector given the current values of the model parameters. We employed the Levine and Casella (2001) implementation of the MCEM here to estimate the WRLCM model parameters.

### Fits to abundance indices

Fits to the abundance indices generally followed patterns in the observed data. Annual patterns in natural origin escapement were well estimated by the model (Figure 13), as were monthly patterns in juvenile abundance estimates at RBDD (Figure 14).

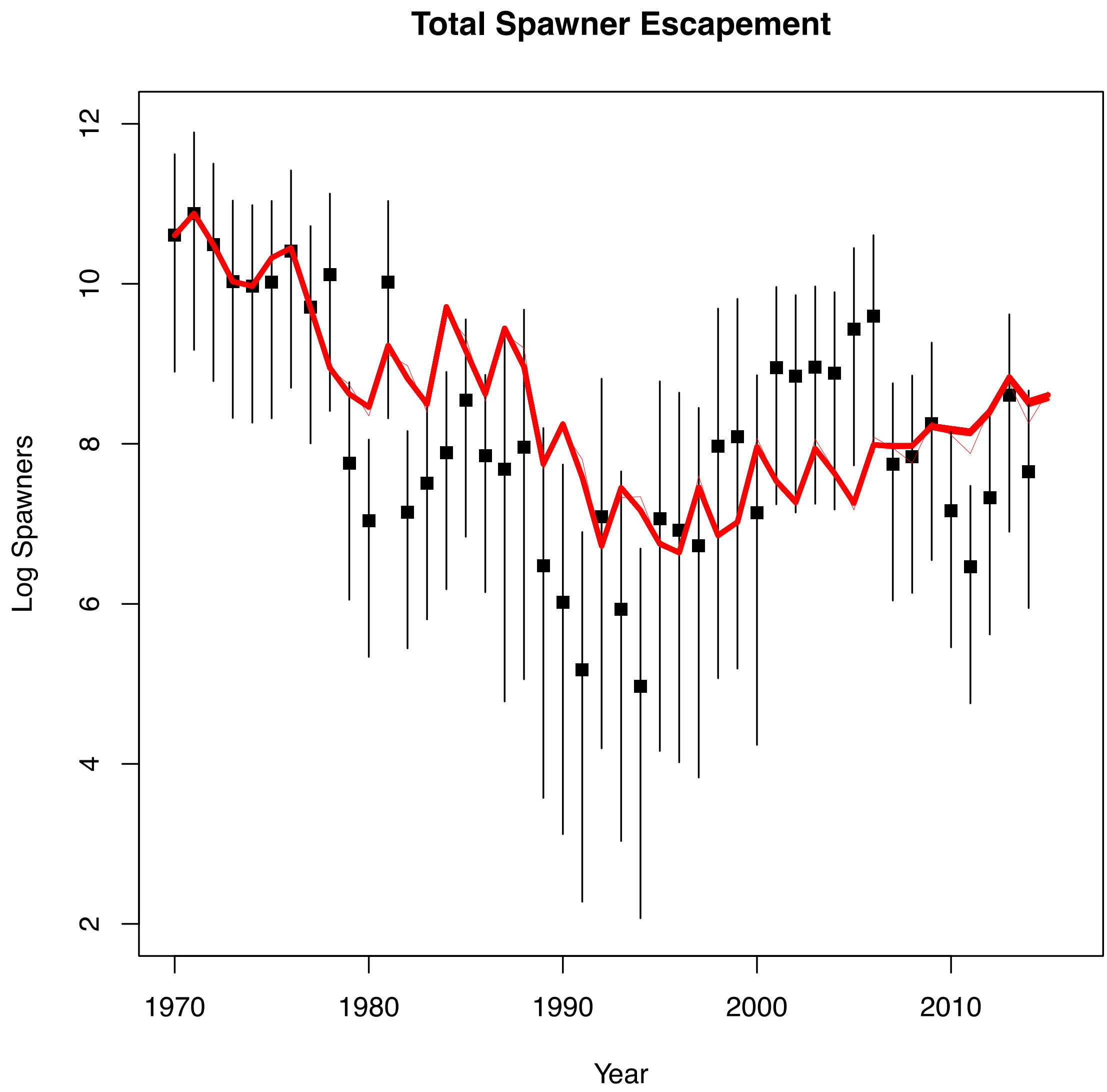



**Figure 13. Model fits (red lines under different random effects vectors with the width of the line related to the weight of the random effects vector) to log natural origin escapement data (squares) with 95% interval on measurement error (vertical lines).**

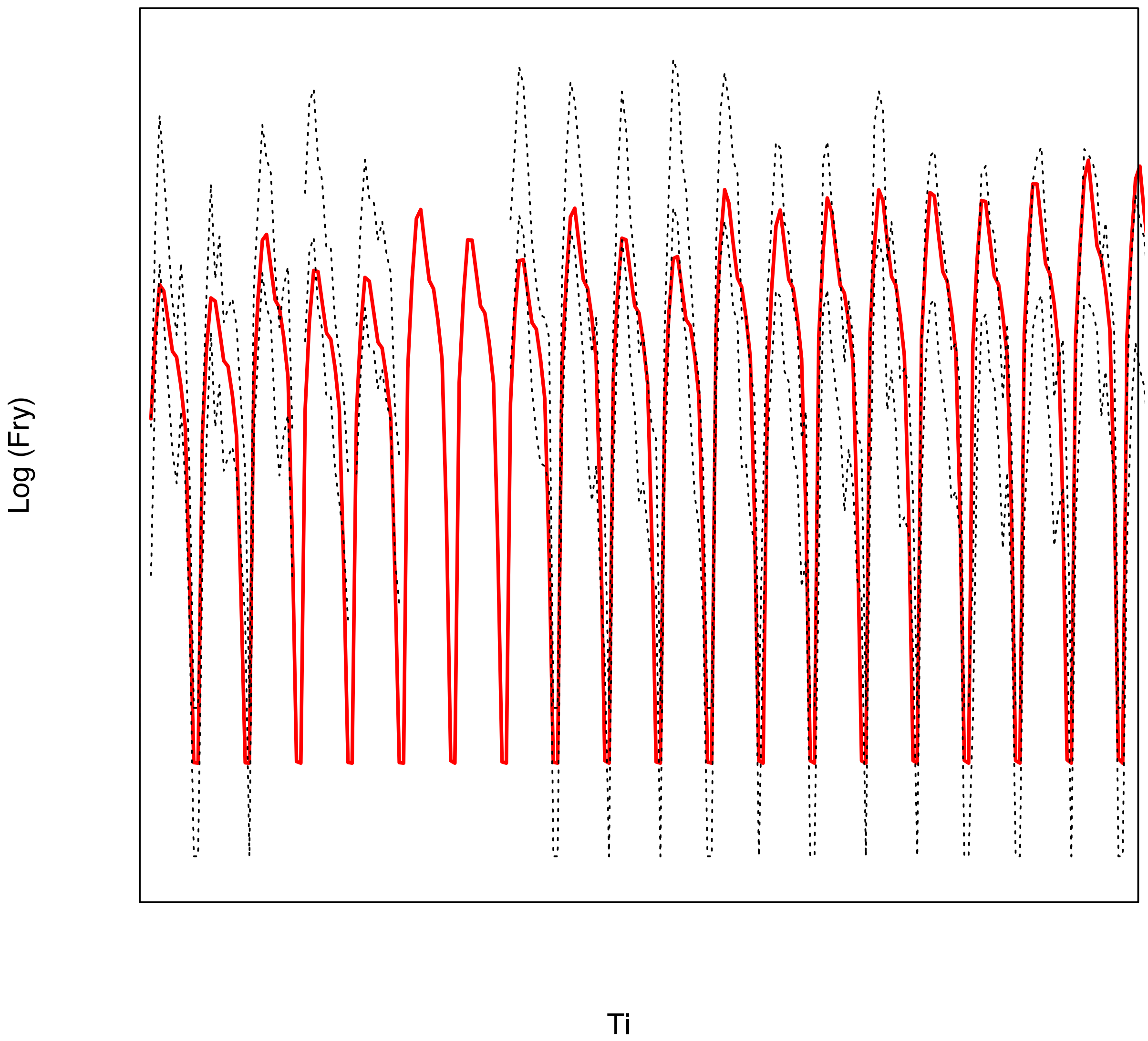
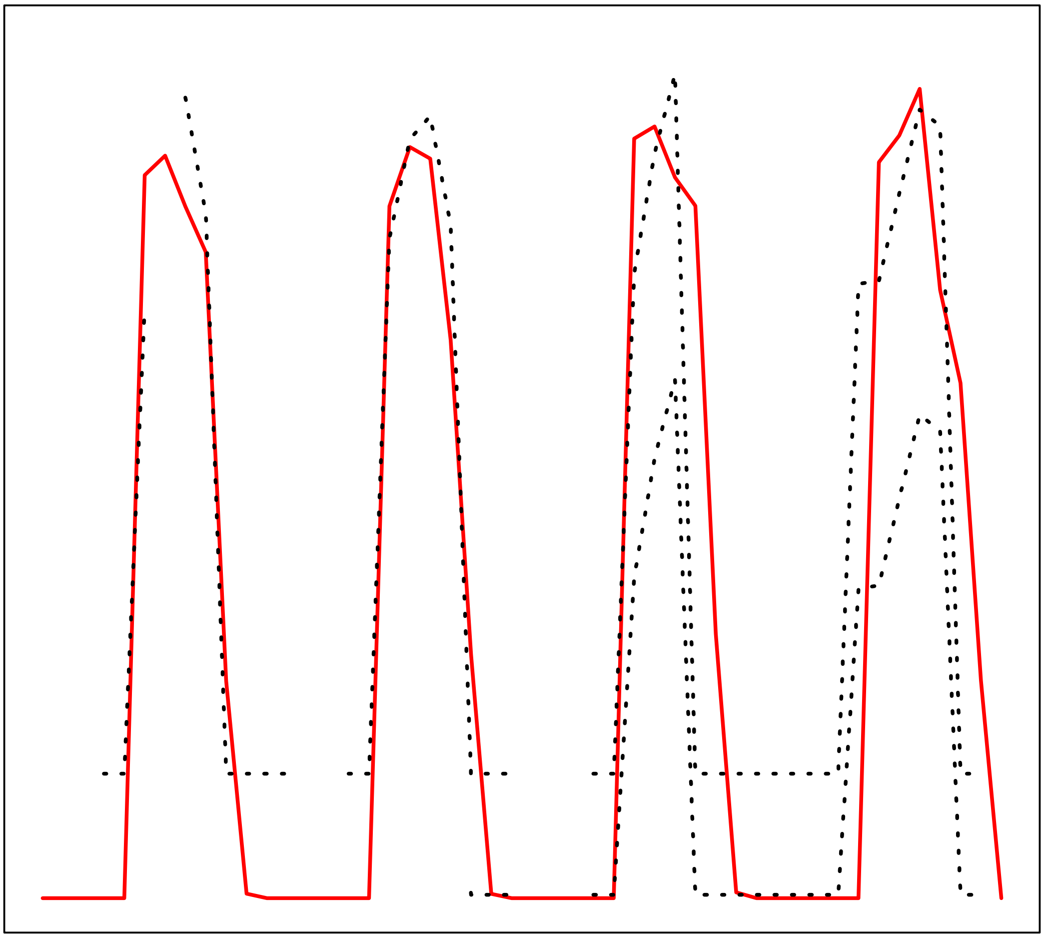



**Figure 14. Model fit (red line) to monthly juvenile abundance estimates at Red Bluff Diversion Dam from 1996 to 2014 (squares) with 95% interval on measurement error (dashed lines).**

Finally, the WRLCM was able to capture the monthly patterns in Chipps Island abundance trends from 2008 – 2011, reflecting the outmigration patterns of winter-run from each of the rearing habitats (Figure 15).



Ti

**Figure 15. Model fits (red line) to monthly Chipps Island abundance estimates (black squares) from 2008 to 2011 with 95% interval on measurement error (dashed lines).**

*Comparison of model to Knights Landing Catch*

Although catches at Knights Landing were not used to estimate the parameters of the WRLCM, we calculated the proportion of fish predicted by the model to the observed total catches in a given year. The WRLCM used the flow triggers at Wilkins Slough (Rearing transition) of greater than 400 $m^3s^{-1}$ to move fish past Knights Landing, and the model was able to capture the general patterns in movement among years as a function of the flow trigger (Figure 16 and 17).

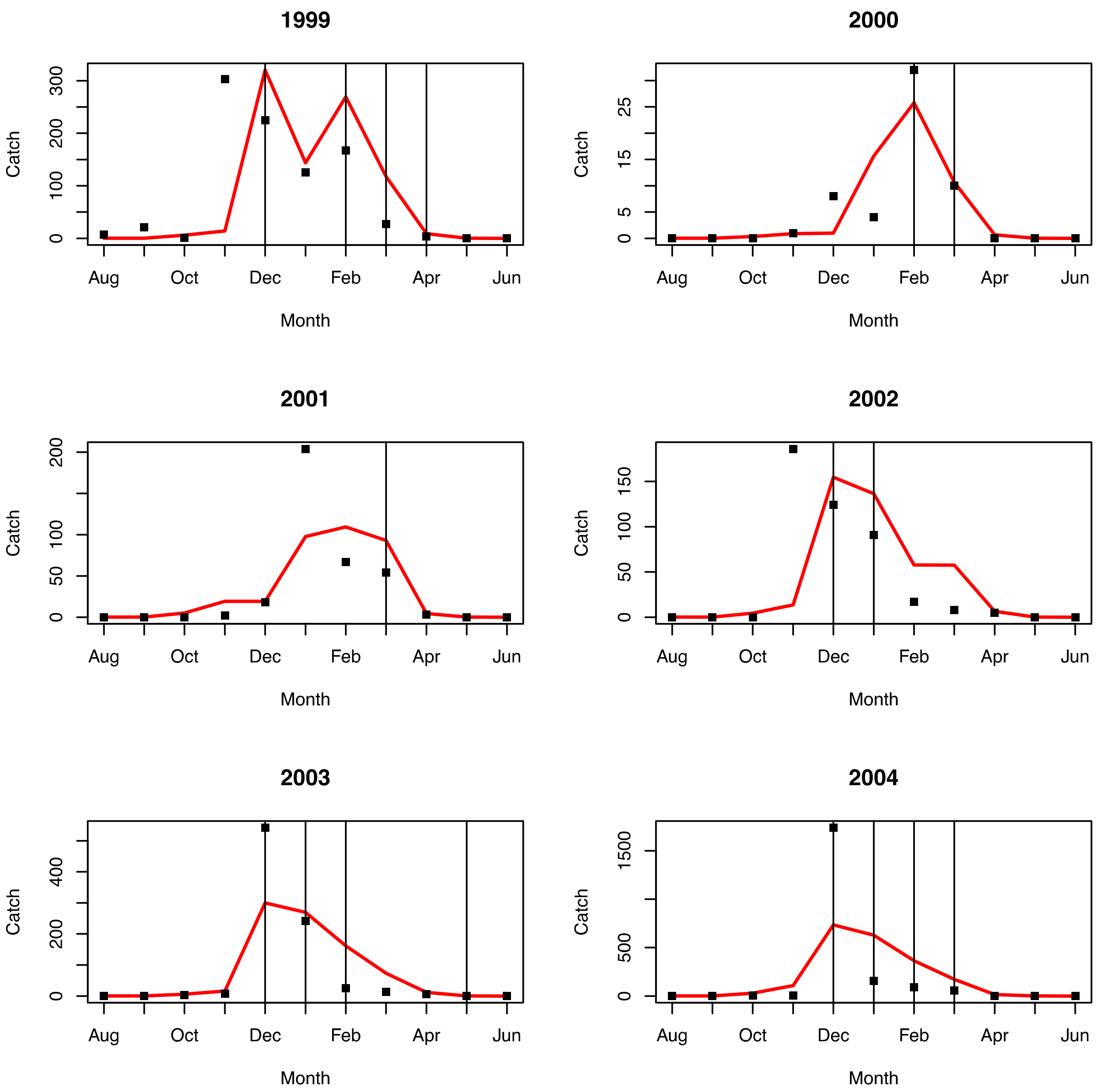



**Figure 16. Model predictions (red line) to Knights Landing catch data (black squares) from 1999 to 2004. Vertical lines indicate months in which the average flow at Wilkins Slough was greater than 400 $m^3s^{-1}$.**

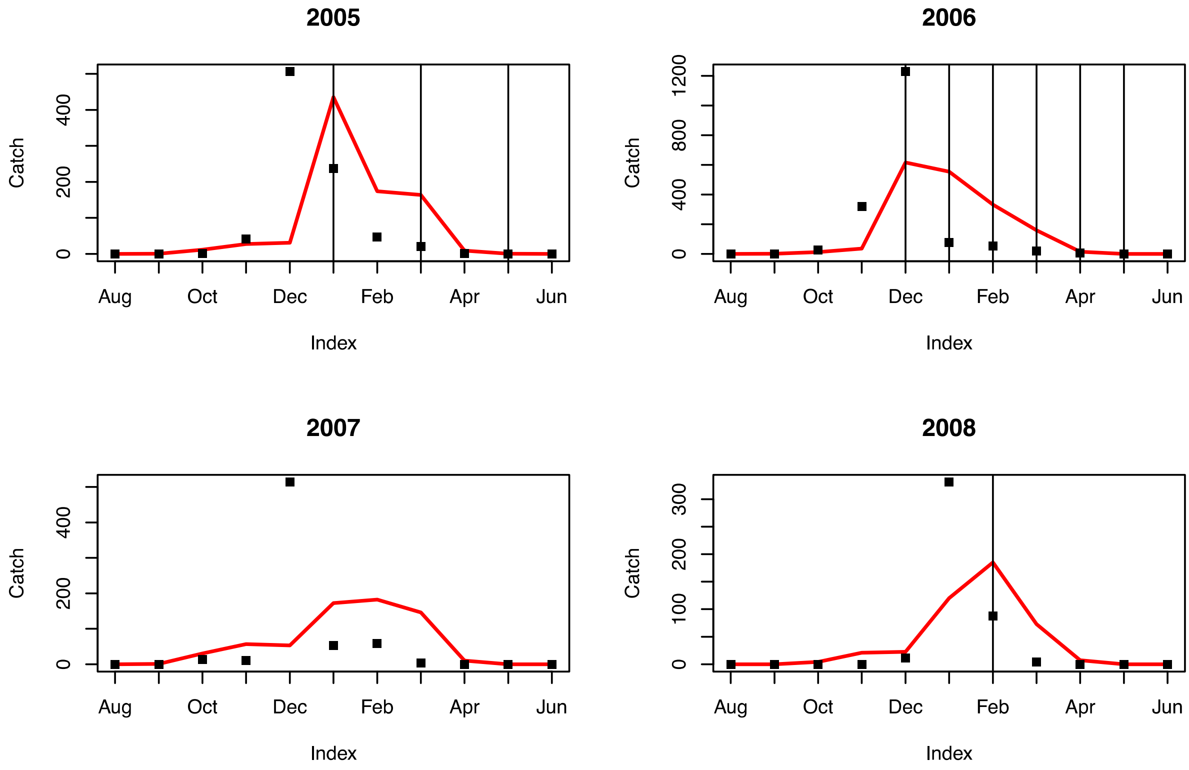



**Figure 17. Model predictions (red line) to Knights Landing catch data (black squares) from 2005 to 2008. Vertical lines indicate months in which the average flow at Wilkins Slough was greater than 400 $m^3s^{-1}$.**

The estimated parameter values from the MCEM algorithm are provided in Table 5. The table provides the parameter estimate, the standard deviation of the estimate (SD), a transformed value of the parameter estimate, and a note defining the parameter. We attempted to estimate all parameters of the survival of egg to fry as a function of temperature (Transition 1); however, there was strong correlation among the three parameters that caused problems with parameter identifiability. We assumed that the survival rate from egg to fry in the absence of thermal mortality was 0.321, which is consistent with historical estimates of egg to fry survival values (Poytress et al. 2014). The 3-month trailing average (spawn month and trailing 2 months) threshold ($t.crit$) was 13.5 $^0$C (56.3 $^0$F). The survival of egg to fry below this critical temperature was 0.321 ($B0_1$) for the 3-month period, whereas above this threshold the survival was reduced by $B1_1$ for each degree of centigrade (within the logistic regression). The monthly fry survival rate ($S_{FRY}$) was estimated to have a rate of 0.761 per month, and the proportion of fry in the Upper River that were estimated to move to the Lower River per month was 0.327. Finally, flow at Bend Bridge was found to have a positive effect on survival of smolts originating in the Upper River (Table 5).

The MCEM algorithm can be used to make an empirical calculation of the variance of the random effects. We used the 4000 vectors of random effects and their associated weights to calculate the empirical weighted variance of the random effects. The range of the random effects was restricted such that the annual random effect parameters ($\varepsilon_y$) had values of approximately $\pm$ 1. These parameter values corresponded to a range in annual variability in survival of (0.36, 2.7) due to the lognormal structure of the random effects.

**Table 5. WRLCM parameter estimates from the model calibration to winter-run indices of abundance (Table 4).**

| Parameter | Estimate | SD | Transformed Value | Notes |
|---|---|---|---|---|
| $B0_1$* | -0.75 | 0 | 0.321 | Survival below critical temperature value (logit space) |
| *t.crit** | 13.5 | 0 | 13.5 | Critical temperature (C) at which egg to fry survival is reduced |
| $S_{FRY}$ | 1.16 | 0.002 | 0.761 | Winter run fry survival (logit space) |
| $mig_{LH}$ | -0.721 | 0.003 | 0.327 | Proportion of fry in upper river migrating to lower river per month (logit space) |
| $B1_{10}$ | 0.211 | 0.005 | NA | River smolt survival from flow effect |
| $\sigma_{\varepsilon}^2$** | 0.207 | | | Variance of annual random effects in process noise |

* parameters fixed in estimation but are relevant for the estimation portion of the model
** empirical estimate from weighted random effects vectors

Using the Hessian matrix (second derivative of parameter estimates with respect to the likelihood surface at the maximum likelihood estimate), we were able to calculate the Fisher information matrix, and obtain estimates of the standard deviation of the model parameters (Table 5) and the correlation among estimated model parameters (Table 6). Several parameters had high correlations. Correlation among the estimated parameters was less than $\pm$ 0.7 with the highest correlation occurring between fry survival and the rate of decline in egg to fry survival as a function of thermal mortality ($B1_1$). The correlation was negative indicating that similar abundances could be obtained due to a decrease in fry survival or an increase in thermal mortality due to surpassing the critical temperature of 13.5 $^0$C.

**Table 6. Correlation matrix for estimated parameters in the WRLCM calibration.**

| | $B1_1$ | $S_{FRY}$ | $mig_{LH}$ | $B1_{10}$ |
|---|---|---|---|---|
| $B1_1$ | 1 | -0.654 | -0.115 | 0.290 |
| $S_{FRY}$ | -0.654 | 1 | -0.508 | -0.462 |
| $mig_{LH}$ | -0.115 | -0.508 | 1 | -0.006 |
| $B1_{10}$ | 0.290 | -0.462 | -0.006 | 1 |

## Developing parameter sets for Monte Carlo simulations

To compare alternative hydromanagement actions, Monte Carlo simulations should be run under each of the actions. We have obtained estimates of parameter uncertainty and correlation (Table 6) in the model calibration from the Hessian matrix to incorporate into the Monte Carlo simulation. For those parameters that were estimated, Monte Carlo parameter values were drawn from multivariate normal distribution centered on the maximum likelihood estimates (MLE) and using the covariance matrix estimated from the Hessian obtained at the MLE. The draws from the multivariate normal distribution incorporated the relative uncertainty in the estimated parameters and preserved the correlation structure among several of the life cycle model parameters that were identified in the correlation matrix of the parameter estimates (Table 5). In addition, we used samples from the posterior distributions for the coefficients of the Newman model (Appendix B). For the random effects, iid normal N(0, $\sigma_\varepsilon^2$) random variables were drawn to reflect the annual random effects in the process noise. All other parameters were set to their fixed values as described above. Please see Appendix B for a list of all parameter values.

## V. References

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. L. Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: Linking estuary restoration to wild Chinook salmon populations. Appendix D of the Skagit Chinook Recovery Plan, Skagit River System Cooperative, LaConner, WA. Available at: www.skagitcoop.org.

Björnsson, B. T., S. 0. Stefansson, and S. D. McCormick. 2011. Environmental endocrinology of salmon smoltification. General and Comparative Endocrinology 170(2):290-298.

del Rosario, R. B., Y. J.Redler., K. Newman, P. L. Brandes, T. Sommer, K. Reece, and R. Vincik. 2013. Migration patterns of juvenile winter-run-sized Chinook salmon (*Oncorhynchus tshawytscha*) through the Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science 11(1).

Greene, C.M., D.W. Jensen, E. Beamer, G.R. Pess, and E.A. Steel. 2005. Effects of environmental conditions during stream, estuary, and ocean residency on Chinook salmon return rates in the Skagit River, WA. Transactions of the American Fisheries Society, 134:1562-1581.

Grover, A., A. Lowe, P. Ward, J. Smith, M. Mohr, D. Viele, and C. Tracy. 2004. Recommendations for developing fishery management plan conservation objectives for Sacramento River winter Chinook and Sacramento River spring Chinook. Interagency Workgroup Progress Report. February 2004.

Hendrix, N., Criss, A., Danner, E., Greene, C.M., Imaki, H., Pike, A., and Lindley, S.T. 2014. Life cycle modeling framework for Sacramento River Winter run Chinook salmon, NOAA Technical Memorandum 530, National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, Ca.

Hilborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press.

Jassby, A. D., W.J. Kimmerer, S.G. Monismith, C. Armor, J.E. Cloern, T.M. Powell, J.R. Schubel, and T.J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5: 272-289.

Levine, R.A. and G. Casella. 2001. Implementations of the Monte Carlo EM Algorithm. Journal of Computational and Graphical Statistics, 10(3): 422-439.

McCulloch, C. E.1997. Maximum Likelihood Algorithms for Generalized Linear Mixed Models. Journal of the American Statistical Association, 92: 162–170.

Monismith, S.G., W. Kimmerer, J.R. Burau, and M.T Stacey. 2002. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. Journal of Physical Oceanography, 32: 3003-3019.

National Marine Fisheries Service (NMFS) 2012. Final Implementation of the 2010 Reasonable and Prudent Alternative Sacramento River winter-run Chinook Management Framework for the Pacific Coast Salmon Fishery Management Plan. National Marine Fisheries Service, Southwest Region.

Newman, K.B. 2003. Modelling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon. Stat. Modelling **3**: 157–177. doi: 10.1191/1471082X03st055oa.

Newman, K., S.T. Buckland, B. Morgan, R. King, D.L. Borchers, D. Cole, P. Besbeas, O. Gimenez, and L. Thomas. 2014. Modelling population dynamics. Springer.

O'Farrell, M. R., M. S. Mohr, A. M. Grover, and W. H. Satterthwaite. 2012. Sacramento River winter Chinook cohort reconstruction: analysis of ocean fishery impacts. NOAA Technical Memorandum NOAA-TM-NMFS- SWFSC-491.

O'Farrell, M. and W. H. Satterthwaite. 2015. Inferred historical fishing mortality rates for an endangered population of Chinook salmon (Oncorhynchus tshawytscha). Fishery Bulletin, 113(3):341-352.

Perry, R.W., Pope, A.C., Romine, J.G., Brandes, P.L., Burau, J.R., Blake, A.R., Ammann, A.J., and Michel, C.J. 2018. Flow-mediated effects on travel time, routing, and survival of juvenile Chinook salmon in a spatially complex, tidally forced river delta. Can. J. Fish. Aquat. Sci. **75**: 1886–1901. doi: 10.1139/cjfas-2017-0310.

Poytress, W. R., J. J. Gruber, F. D. Carrillo and S. D. Voss. 2014. Compendium Report of Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Production Indices for Years 2002-2012. Report of U.S. Fish and Wildlife Service to California Department of Fish and Wildlife and US Bureau of Reclamation.

R Core Development Team (RCDT). 2016. R: A language and environment forstatistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Semmens, B. X. 2008. Acoustically derived fine-scale behaviors of juvenile Chinook salmon (Oncorhynchus tshawytscha) associated with intertidal benthic habitats in an estuary. Canadian Journal of Fisheries and Aquatic Sciences, 65: 2053-2062.

Sommer T, Nobriga ML, Harrell B, Batham W, and Kimmerer WJ. 2001. Floodplain rearing of juvenile chinook salmon: evi- dence of enhanced growth and survival. Can J. Fish Aquat Sci 58:325–333. doi:10.1139/f00-245

Sridharan V., Byrne B. 2015. Enhanced Particle Tracking Model (ePTM): status of model development and pilot application during WY 2015. Sacramento (CA): National Marine Fisheries Service, National Oceanographic and Atmospheric Administration. Report Submitted to the independent review committee of the delta Science Panel on the Long Term Operations and Biological Opinions [Internet]. 90 p. Available from: http://deltacouncil.ca.gov/sites/default/files/2015/10/Item%208%20WY%202015%20ePTM%20Report.pdf.

Takata L, Sommer T, Conrad JL, and Schreier, BM. 2017. Rearing and migration of juvenile Chinook salmon (Oncorhynchus tshawytscha) in a large river floodplain. Environmental biology of fishes, 100(9): 1105-1120.

U.S. Bureau of Reclamation. 2006. Hydro24ca - Selected hydrologic features 1:24,000-scale for California. http://projects.atlas.ca.gov/frs/?group_id=39&release_id=23

U.S. Fish and Wildlife Service. 2005. 2001-2005 annual progress report: "Abundance and survival of juvenile chinook salmon in the Sacramento-San Joaquin Estuary". Stockton, CA. https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_reports.htm

Wei, G. and Tanner, M. 1990. A Monte Carlo Implementation of the EM Algorithm and the Poor Man's Data Augmentation Algorithms. Journal of the American Statistical Association, Vol. 85, No. 411, pp. 699-704

Winship, A.J., M.R. O'Farrell and M.S. Mohr. 2014. Fishery and hatchery effects on an endangered salmon population with low productivity. Transactions of the American Fisheries Society, 143(4):957-971.

# Appendix A. Analysis of winter-run monthly spawn timing

To estimate the proportion of winter-run spawning among the months of April to August, we conducted an analysis of the numbers of winter-run carcasses detected in each of the months April to August. We were interested in understanding whether the proportions spawning among months were static across all years, or alternatively, whether the proportions varied among years due to the environmental conditions in that year. That is, whether there were some environmental conditions that caused shifts to earlier spawning in some years.

*Data*

Winter-run carcass observations by date were shifted two weeks earlier to generate "observed" number of fish spawning by date. These spawning numbers by date were coalesced by month to form $N.spawn_{m,t}$ the observed (based on carcass counts) number of winter-run Chinook spawning in month $m$ in year $t$.

To evaluate annual variability in the proportion spawning in a given month, we calculated a spawning proportion anomaly as the standardized proportion of fish spawning each month ($SP_{m,t}$). For example, the values of the standardized April values were

$$SP_{Apr,t} = \frac{P.spawn_{Apr,t} - mean(P.spawn_{Apr})}{std\ dev(P.spawn_{Apr})}$$

where the proportion spawning in each month for a given year $t$ (subscript suppressed) was calculated as

$$P.spawn_m = \frac{N.spawn_m}{\sum_m N.spawn_m}.$$

To understand how these annual anomalies varied as a function of water temperature, we calculated the Pearson's correlation coefficient between mean monthly temperature below Keswick Dam between January and June and the standardized proportions (Figure A1).

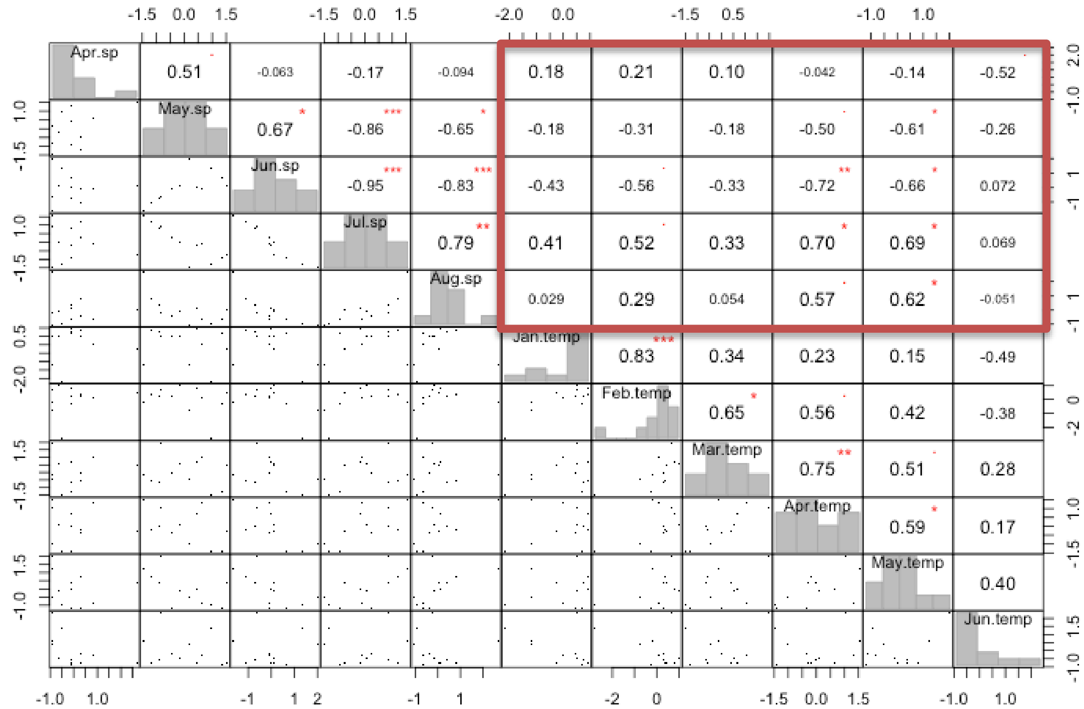



**Figure A1. Pearson correlation coefficients (upper triangle), histograms (diagonal) and scatter plots (lower triangle) for all combinations of monthly spawning proportion anomalies and Keswick water temperatures. The red box indicates the month by temperature correlations, and red asterisks indicate significant correlation coefficients.**

*Statistical analysis*

We fit a multinomial logistic regression using the *multinom* function from the *nnet* package in R to the number of winter-run Chinook spawning in each month, $N.spawn_{m,t}$. We evaluated the ability of April Keswick temperatures to explain annual variability in the spawning timing. We focused on April temperatures because April is the first month of spawning, and April would allow this physical variable to be used as a predictor of spawn timing for future years. The monthly average April temperatures at Keswick were standardized (subtracted mean and divided by standard deviation) for use in the multinomial model.

We fit a base model without the April temperature effect and we fit the model with the April effect and used Akaike Information Criterion (AIC) to compare the models. The AIC value for the base multinomial model was 75822, whereas the value for the multinomial model including April temperature as a covariate was 74209. The difference in AIC was 1613, providing strong support for the model with the April temperature covariate.

The model coefficients for the multinomial model with April covariate indicated increasing spawning in July and August (positive coefficient values) when April temperatures increased (Table A1 and Figure A2). The model coefficients (Table A1) can thus be used for making predictions of spawning proportions using standardized April temperatures as displayed in Figure A2.

**Table A1. Coefficient estimates of the multinomial model including April covariate. The effect of the April covariate is reflected in the B1 coefficient estimate.**

| | Estimate | | Standard Error | |
|---|---|---|---|---|
| Month | B0 | B1 | B0 | B1 |
| Apr | -4.145 | 0.054 | 0.06 | 0.062 |
| May | -1.796 | -0.203 | 0.02 | 0.02 |
| Jul | -0.332 | 0.385 | 0.012 | 0.012 |
| Aug | -3.443 | 0.792 | 0.044 | 0.045 |

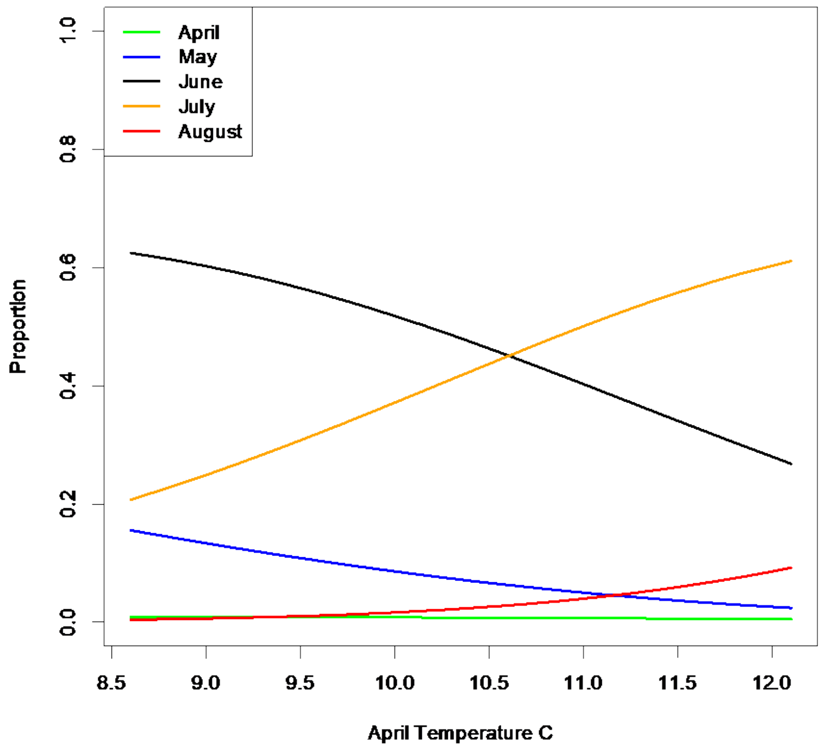



**Figure A2. Predictions of the proportion of winter-run Chinook spawning from the multinomial regression model using April temperatures at Keswick Dam as a predictor variable.**

# Appendix B. Table of parameter values for WRLCM

**Table B1. Parameter values, standard deviation (SD), transformed values, transition numbers in which parameters are found and brief description of parameter.**

| Name | Value | SD | Transformed Value | Transition | Description |
|---|---|---|---|---|---|
| *t.crit* | 13.5 | 0 | 13.5 | 1 | Critical temperature ( C ) at which egg to fry survival is reduced |
| $B0_1$ | -0.75 | 0 | 0.321 | 1 | Survival below critical temperature value (logit space) |
| $B1_1$* | -0.574 | 0.002 | NA | 1 | Rate of reduction in egg to fry survival (logit space) |
| $P_{TF, m}$ | -3 | 0 | 0.047 | 2 | Proportion tidal fry |
| $S_{TF,FP}$ | 1 | 0 | 0.731 | 3 | Survival tidal fry in floodplain |
| *min.p* | 0.05 | 0 | 0.05 | 3 | Minimum proportion entering Yolo bypass under flow < 100 cfs |
| *p.rate* | 1.1 | 0 | NA | 3 | Rate of increase in proportion entering Yolo bypass for flows > 6000 cfs |
| $B0_4$ | 0 | 0 | 0.5 | 4 | Average survival tidal fry to delta intercept |
| $B1_4$ | -1 | 0 | NA | 4 | Effect of DCC gate (value is in logit space)* |
| $B0_5$ | 0 | 0 | 0.5 | 5 | Average proportion of tidal fry to bay intercept |
| $B1_5$ | 2 | 0 | NA | 5 | Proportion tidal fry to bay - flow at Rio Vista effect |
| $S_{TF,DE-BA}$ | -1 | 0 | 0.269 | 5 | Survival of tidal fry from delta to bay |
| $S_{FRY}$* | 1.16 | 0.002 | 0.761 | Rearing | Winter run fry survival |
| $mig_{LH}$* | -0.721 | 0.003 | 0.327 | Rearing | Proportion of fry in upper river migrating to lower river per month |
| $B0_M$ | -6 | 0 | 0.003 | Rearing | Wilkins slough movement without trigger |
| $B1_M$ | 5.5 | 0 | NA | Rearing | Wilkins slough change in movement with flow trigger, movement rate under flow trigger is 0.377 |
| *mig* | -3 | 0 | 0.047 | Rearing | Probability of migration from habitats |
| $S_{FRY,BA}$ | -7 | 0 | 0.001 | Rearing | Survival of bay rearing fry pushed to gulf |
| $Z_1$ | -1 | 0 | 0.269 | 11 to 15 | January smolt probability |
| $Z_2$ | 0 | 0 | 0.5 | 11 to 15 | February smolt probability |
| $Z_3$ | 3 | 0 | 0.953 | 11 to 15 | March smolt probability |

| Name | Value | SD | Transformed Value | Transition | Description |
|---|---|---|---|---|---|
| $Z_4$ | 8 | 0 | 1 | 11 to 15 | April smolt probability |
| $Z_5$ | 10 | 0 | 1 | 11 to 15 | May smolt probability |
| $Z_6$ | 10 | 0 | 1 | 11 to 15 | June smolt probability |
| $Z_7$ | 10 | 0 | 1 | 11 to 15 | July smolt probability |
| $B0_{11,LR}$ | 1.39 | 0 | 0.801 | 12 | Smolt survival lower river to delta |
| $B0_{10,UR}$ | -0.4 | 0 | 0.401 | 11 | Survival of upper river fish to lower river |
| $B1_{10}$* | 0.211 | 0.005 | NA | 11,12 | River smolt survival from flow effect |
| ${}^{C}S_{11}$ | 1.5 | 0 | 0.818 | 11 - 14 | Survival smolt Chipps to ocean - assume 0.82 |
| ${}^{A}S_{13,FP,m}$ | 2.5 | 0 | 0.924 | 13 | survival from Yolo until Delta, assume 0.92 (at least until insertion point into smolt survival via Newman in Delta) |
| $S_{15,BA}$ | 0 | 0 | 0.5 | 15 | Survival of smolts bay to ocean |
| $S_{G1}$ | -2.2 | 0 | 0.0997 | 11, 12, 13 | Gulf entry survival for upper river, lower river, floodplain (delta and bay when $D_{G2I}=0$) |
| $D_{G2}$ | 0 | 0 | NA | 14, 15 | Gulf entry survival decrement for delta and bay (value in logit space) |
| $\sigma_{\varepsilon}^2$ | 0.207 | 0 | NA | 11-15 | Variance of annual random effects in process noise |
| $S_{17}$ | 1.35 | 0 | 0.794 | 17, 18 | Probability of survival age 1 to age 2 over 4 months |
| $M_2$ | -2.2 | 0 | 0.1 | 17,18 | Probability of maturation age 2 |
| $S_{sp2}$ | 2.2 | 0 | 0.9 | 18 | Survival ocean exit to spawning ground age 2 |
| $S_{19}$ | 1.4 | 0 | 0.802 | 19 | Probability of survival age 2 to age 3 |
| $M_3$ | 2.2 | 0 | 0.9 | 19, 20 | Conditional probability of maturation at age 3 |
| $S_{sp3}$ | 2.2 | 0 | 0.9 | 20 | Survival ocean exit to spawning ground age 3 |
| $S_{21}$ | 1.4 | 0 | 0.802 | 21 | Survival age 3 to age 4 |
| $S_{sp4}$ | 2.2 | 0 | 0.9 | 21 | Survival ocean exit to spawning ground age 4 |
| $V_{eggs,2}$ | 3200 | 0 | 3200 | 22 | Eggs per spawner age 2 |
| $V_{eggs,3}$ | 5000 | 0 | 5000 | 22 | Eggs per spawner age 3 |
| $V_{eggs,4}$ | 5000 | 0 | 5000 | 22 | Eggs per spawner age 4 |

| Name | Value | SD | Transformed Value | Transition | Description |
|---|---|---|---|---|---|
| $B0_{Apr}$ | -4.145 | 0 | NA | 22 | Intercept for proportion of spawners in April |
| $B1_{Apr}$ | 0.0538 | 0 | NA | 22 | Effect of temperature on proportion of spawners in April |
| $B0_{May}$ | -1.796 | 0 | NA | 22 | Intercept for proportion of spawners in May |
| $B1_{May}$ | -0.2031 | 0 | NA | 22 | Effect of temperature on proportion of spawners in May |
| $B0_{Jul}$ | -0.332 | 0 | NA | 22 | Intercept for proportion of spawners in July |
| $B1_{Jul}$ | 0.3852 | 0 | NA | 22 | Effect of temperature on proportion of spawners in July |
| $B0_{Aug}$ | -3.443 | 0 | NA | 22 | Intercept for proportion of spawners in August |
| $B1_{Aug}$ | 0.7921 | 0 | NA | 22 | Effect of temperature on proportion of spawners in August |
| $Fem_{Age2}$ | 0.01 | 0 | 0.01 | 18 | Proportion of age 2 spawners that are female |
| $Fem_{Age3}$ | 0.5 | 0 | 0.5 | 20 | Proportion of age 3 and 4 that are female |
| $K_{Sp,m}$ | 40000 | 0 | 40000 | 22 | Capacity in the spawning reaches by month |
| $B0_{Newman}$ | -1.02 | 0.1 | 0.26 | 11-14 | Baseline survival parameter in Newman (2003) |
| $B1_{Newman}$ | 0.1 | 0.05 | NA | 11-14 | Size parameter in Newman (2003) |
| $B2_{Newman}$ | -0.56 | 0.07 | NA | 11-14 | Temperature parameter in Newman (2003) |
| $B3_{Newman}$ | 0.56 | 0.09 | NA | 11-14 | Log Freeport flow parameter in Newman (2003) |
| $B4_{Newman}$ | -0.21 | 0.07 | NA | 11-14 | Exports parameter in Newman (2003) |
| $B5_{Newman}$ | -0.6 | 0.13 | NA | 11-14 | DCC gate position parameter in Newman (2003) |
| $B6_{Newman}$ | -0.24 | 0.13 | NA | 11-14 | Sacramento River indicator parameter in Newman (2003) |

*Estimated parameter values have associated standard deviations (SD)

# Appendix B

**Delta Passage Model (DPM), Interactive Object-Oriented Simulation (IOS), and SALMOD Model Documentation**

**(Note: Model descriptions extracted from California WaterFix Biological Assessment Appendix 5.D)**

### *5.D.1.2.2 Delta Passage Model*

This section discusses the details of the Delta Passage Model (DPM) and the methods for implementation in the effects analysis of the PA. Results are presented in Chapter 5, Section 5.4.1.3, *Assess Species Response to the Proposed Action*.

#### *5.D.1.2.2.1 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 has been completed to examine various aspects of uncertainty related to the model's inputs and parameters (see description of methods and results in Section 5.D.1.2.2.5, *Sensitivity Analysis*).

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 smolt survival model only, 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 BDCP 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 since then from various meetings of a workgroup consisting of agency biologists and consultants. This effects analysis uses the most recent version of the DPM as of September 2015. 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 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 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 NAA and PA 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 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.

#### *5.D.1.2.2.2 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 5.D-40). 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 5.D-35 for reach description).

Functional relationships are described in detail in Section 5.D.1.2.2.2.5, *Model Functions.*

##### 5.D.1.2.2.2.1 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). It is acknowledged that finer scale modeling with a shorter time step may match the biological processes governing fish movement better than a daily time step (e.g., because of diel activity patterns; Plumb et al. 2015) and that sub-daily differences in flow proportions into junctions make daily estimates somewhat coarse (Cavallo et al. 2015).

#### 5.D.1.2.2.2.2 Spatial Framework

The DPM is composed of nine reaches and four junctions (Figure 5.D-40; Table 5.D-35) 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. The entire Interior Delta region is treated as a single model reach[3]. 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 5.D-40, Table 5.D-35).

[3] It is acknowledged that reach-specific survival data for the various channels within the Interior Delta are becoming increasingly available (Buchanan et al. 2013; Delaney et al. 2014), which could allow model refinement in the future to account for reach-specific differences. At present, such effects are implicitly represented by the flow-survival relationships described in Section 5.D.1.2.2.2.5.5.

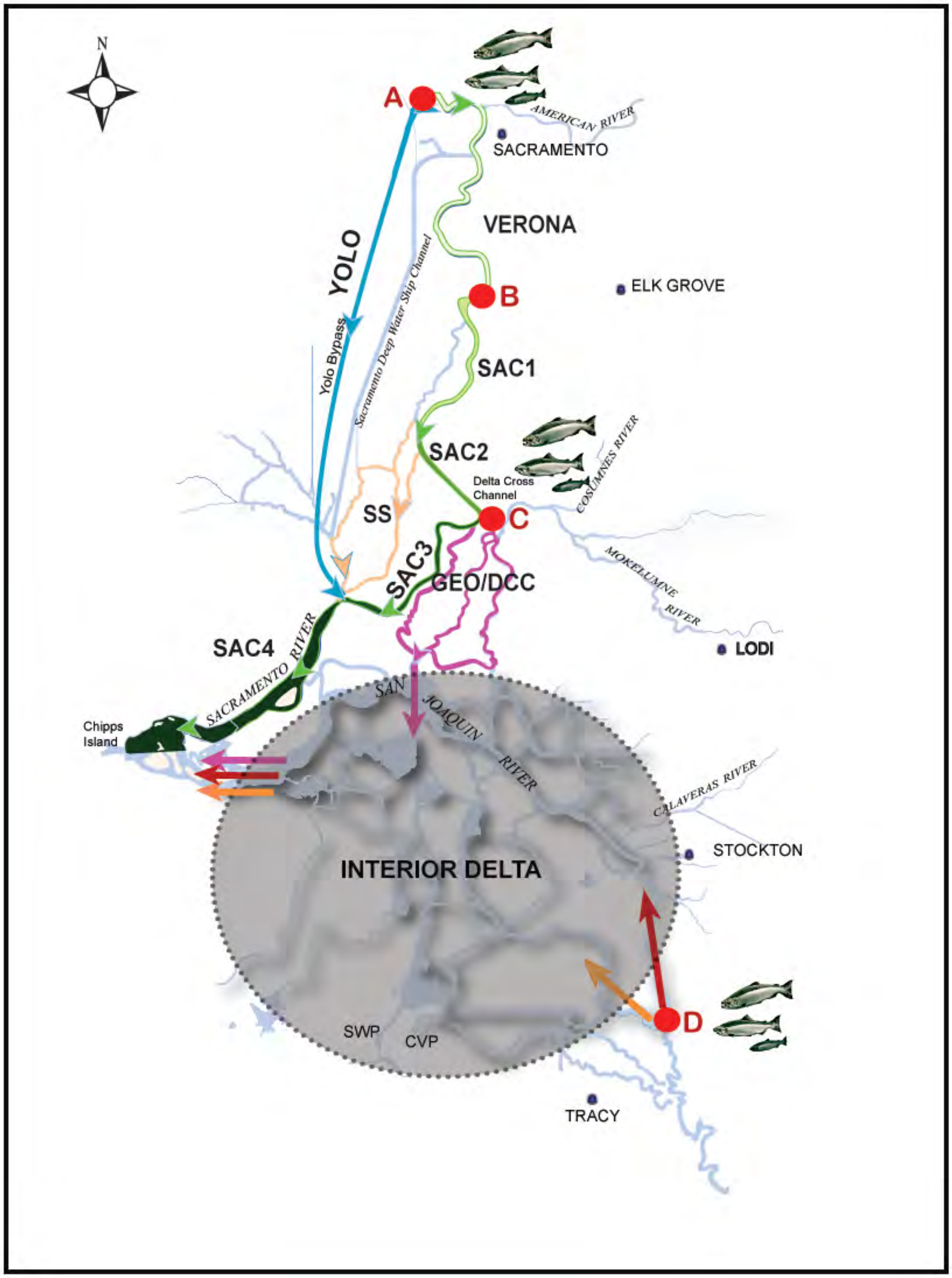
**Table 5.D-35. Description of Modeled Reaches and Junctions in the Delta Passage Model**

| 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. Smolts enter the Interior Delta from the Geo/DCC reach or from Junction D via Old River or from the 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 fish enter from the Sacramento River, Mokelumne River, the San Joaquin River, or Old River.

**Figure 5.D-40. Map of the Sacramento–San Joaquin River Delta Showing the Modeled Reaches and Junctions of the Delta Applied in the Delta Passage Model**

### 5.D.1.2.2.2.3 Flow Input Data

Water movement through the Delta 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/>) or from CALSIM-II. 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. 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 5.D-36. Technical details for DSM2-HYDRO and CALSIM II models are described in Appendix 5.A, *CALSIM Methods and Results,* and Appendix 5.B, *DSM Methods and Results.* DSM2 flow data output for the NAA and PA scenarios was used to inform the daily conditions experienced by migrating salmonids in the model.

**Table 5.D-36. 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 as part of Yolo Bypass enhancements, which were assumed to occur under NAA and PA.

In order to capture the effect of changed flows within the Sac1 reach being altered by the proposed NDD 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 NDD (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

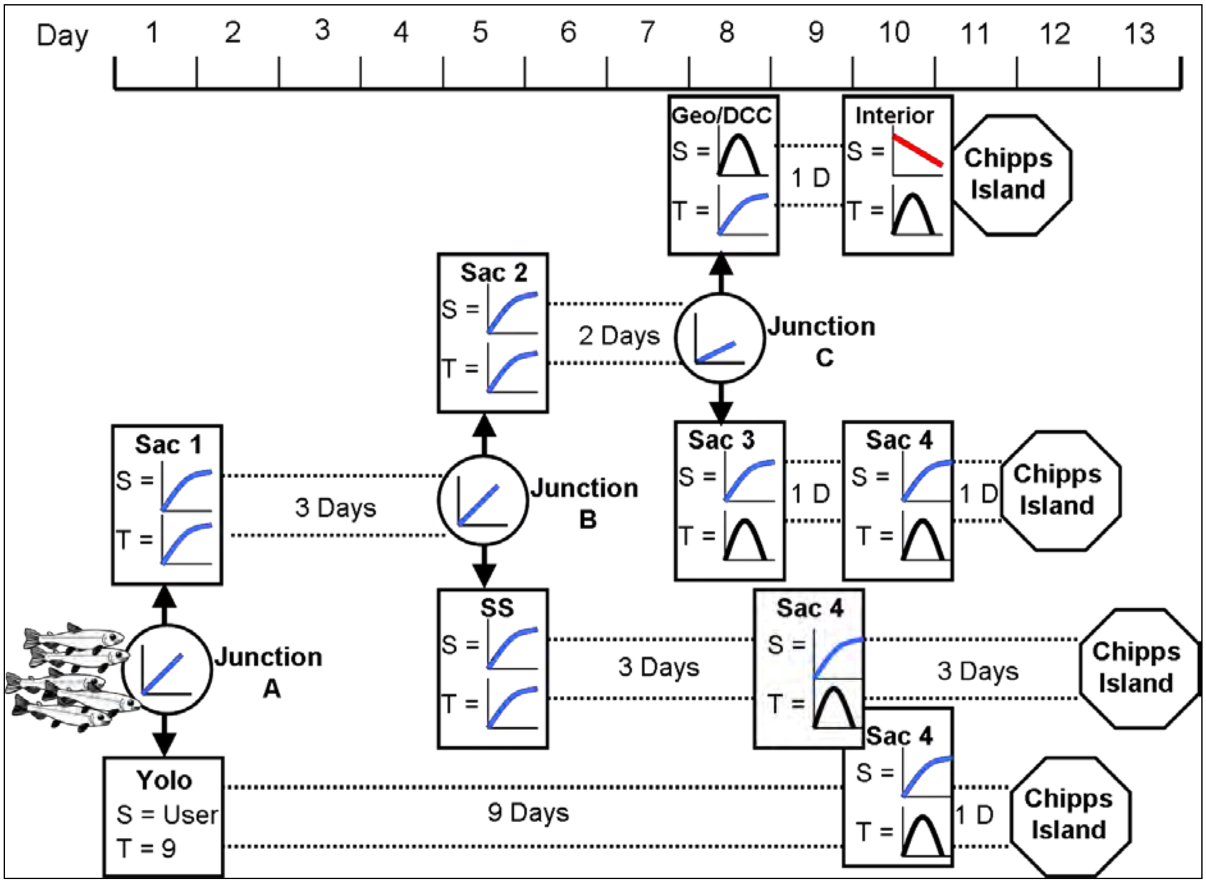
where flows into Sac1 are represented by DSM2 outputs from RSAC155 (Freeport) and flows at bottom of Sac1 are represented by DSM2 outputs from 418_mid (Sacramento River upstream of Sutter/Steamboat Sloughs and downstream of the north Delta intakes).

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:

$$\text{Modified Sac1 flows} = 0.56 \times 10{,}000 \text{ cfs} + 0.44 \times 8{,}000 \text{ cfs} = 9{,}120 \text{ cfs}.$$

#### 5.D.1.2.2.2.4 Illustrative Example

To help illustrate the series of operations performed by the DPM, Figure 5.D-41 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 Section 5.D.1.2.2.2.5, *Model Functions,* 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 5.D-41. Conceptual Diagram Depicting the "Migration" of a Single Daily Cohort of Smolts Entering from the Sacramento River and Migrating through the Delta Passage Model**

## 5.D.1.2.2.2.5 Model Functions

### *5.D.1.2.2.2.5.1 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 5.D-37). 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 95$^{th}$ 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 5.D-42). 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 was undertaken and showed that patterns in results would be expected to be similar for a range of entry distribution assumptions.

**Table 5.D-37. 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.

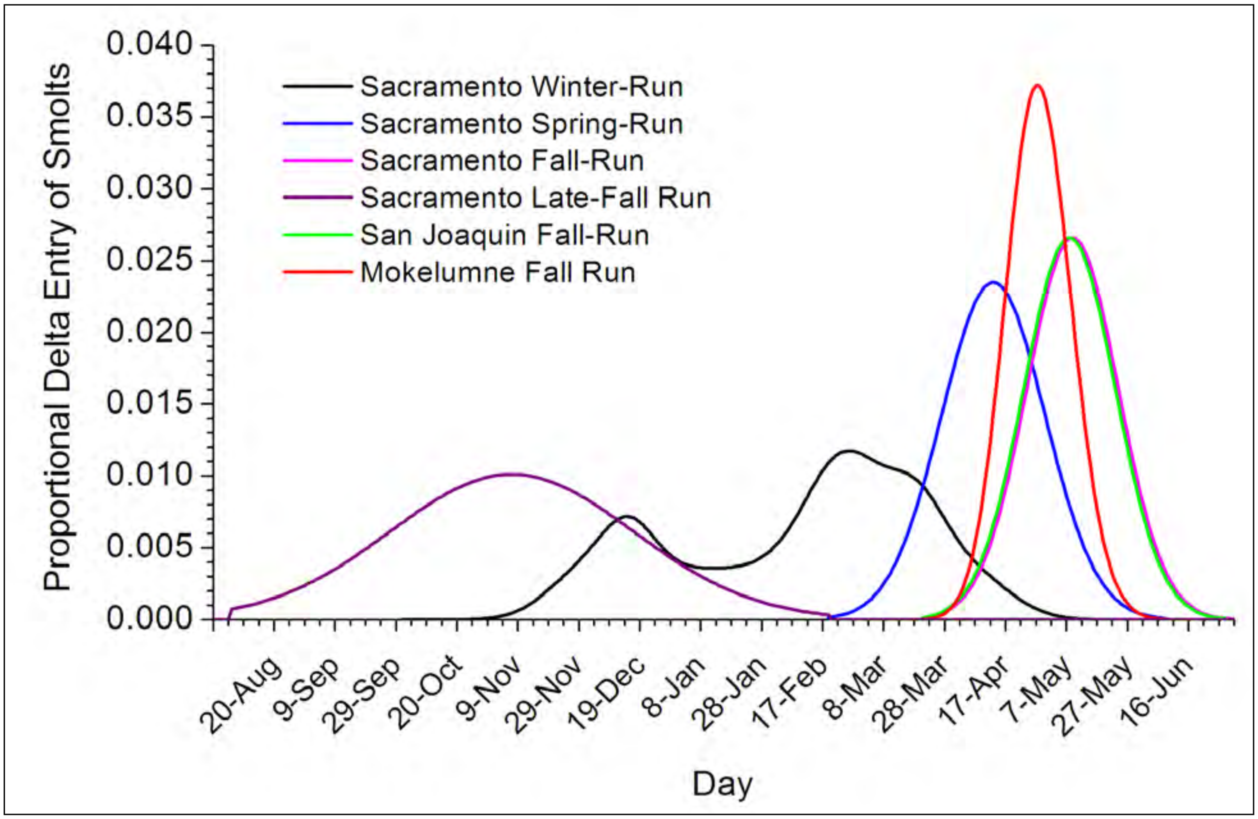



**Figure 5.D-42. Delta Entry Distributions for Chinook Salmon Smolts Applied in the Delta Passage Model for Sacramento River Winter-Run, Sacramento River Spring-Run, Sacramento River Fall-Run, Sacramento River Late Fall–Run, San Joaquin River Fall-Run, and Mokelumne River Fall-Run Chinook Salmon**

### *5.D.1.2.2.2.5.2 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 5.D-35) 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 $\beta_0$ is the slope parameter and $\beta_1$ 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 5.D-38). Flow data was queried from the DWR's California Data Exchange website (<http://cdec.water.ca.gov/>).

**Table 5.D-38. 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)**

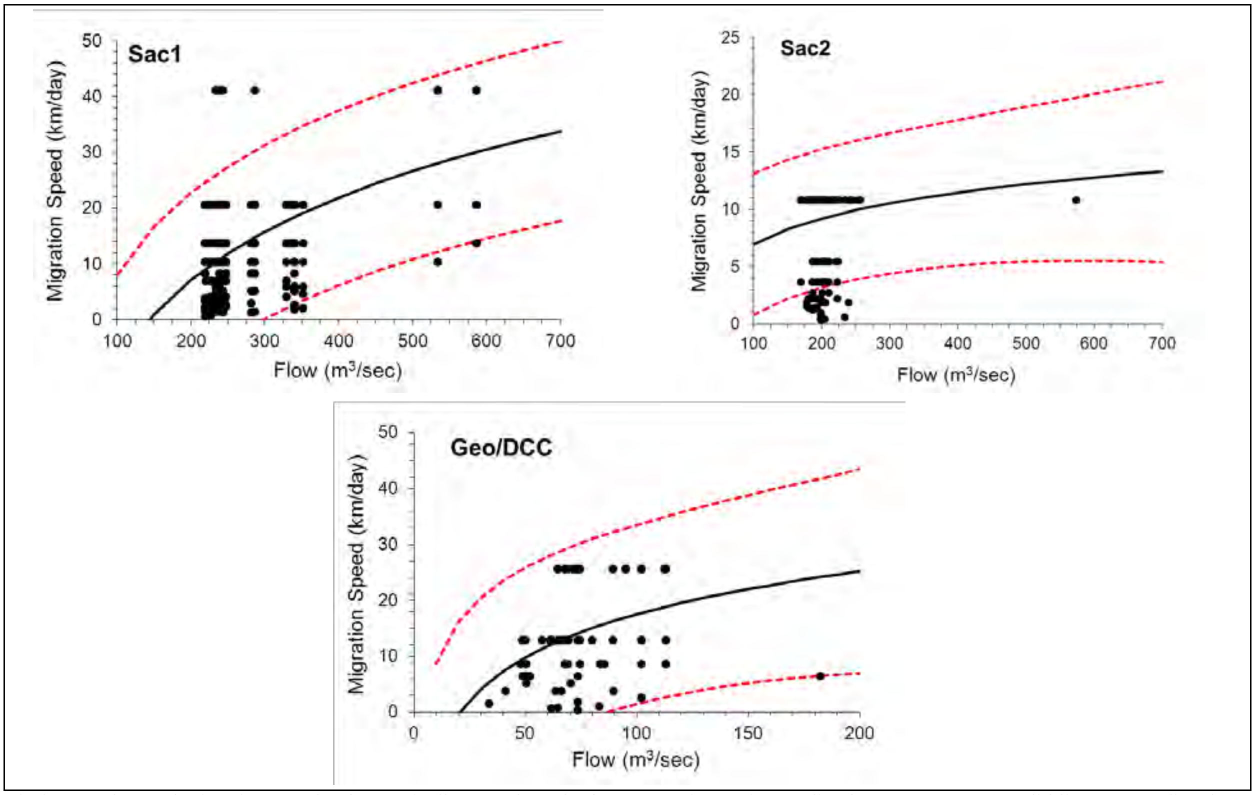
| Reach | Gauging Station ID | Release Dates | Sample Size | Speed (km/day) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Avg | Min | Max | SD |
| Sac1 | FPT | 12/05/06–12/06/06, 1/17/07–1/18/07, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09 | 452 | 13.32 | 0.54 | 41.04 | 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 5.D-39, Figure 5.D-43). Therefore, for reaches Sac1, Sac2, and Geo/DCC, the regression coefficients shown in Table 5.D-39 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 5.D-39). The flow-migration rate relationship that was used for Sac1 also was applied for the Verona reach.

**Table 5.D-39. Sample Size and Slope ($\beta_0$) and Intercept ($\beta_1$) 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 | $\beta_0$ | $\beta_1$ |
|---|---|---|---|
| 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 5.D-43. 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 5.D-38) 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 5.D-38).

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.

#### *5.D.1.2.2.2.5.3 Fish Behavior at Junctions (Channel Splits)*

For Junction A (entry into the Yolo Bypass at Fremont Weir), the following relationships were used.

- For Fremont Weir spills greater than 6,000 cfs (i.e., flows greater than the upper limit of flows through the notch proposed for Yolo Bypass enhancements, and included under NAA and PA scenarios): Proportion of smolts entering Yolo Bypass = Fremont Weir spill[4] / (Fremont Weir spill + Sacramento River at Verona flows).

- For Fremont Weir spills up to 6,000 cfs (i.e., flows through the notch for Yolo Bypass enhancements, included under NAA and PA scenarios): 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 et al. (2010) found that smolts generally entered downstream reaches in proportion to the flow being diverted. Therefore, smolts arriving at Junction B in the model were assumed to move proportionally with flow[5]. A proportional relationship between flow and fish movement for Junction D (San Joaquin River–Old River) also was applied[6]. Note that the operation of the Head of Old River gate proposed under the PA 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).

---

[4] 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.

[5] A subsequent analysis relating the proportion of fish entering important Delta junctions to the proportion of flow entering these junctions found that, across all junctions combined, the proportion of fish entering the junction was somewhat less than the proportion of flow (Cavallo et al. 2015). Therefore a somewhat lower proportion of fish may enter Sutter and Steamboat Sloughs than the proportion of flow.

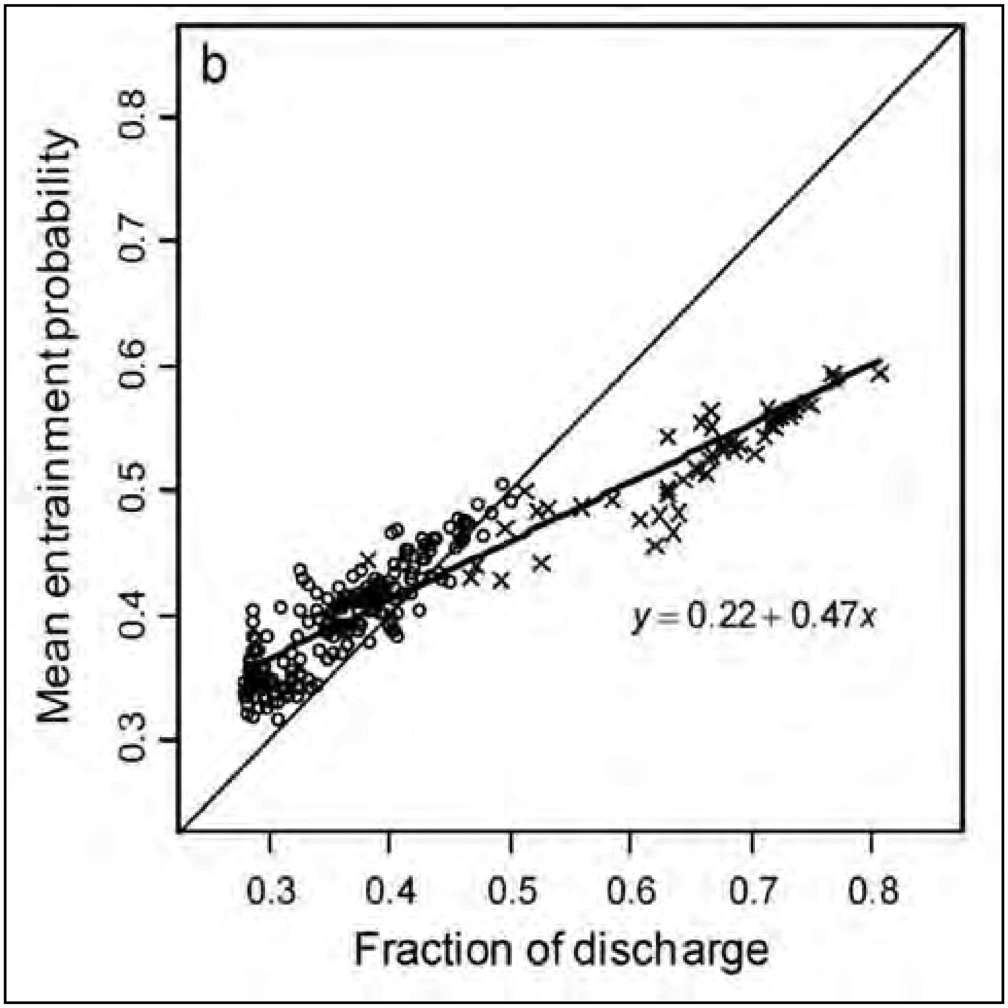
[6] As with Sutter/Steamboat Sloughs, the proportion of fish entering the junction may be somewhat less than the proportion of flow, based on the analysis by Cavallo et al. (2015).

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 5.D-44).

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.




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

**Figure 5.D-44. 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)**

### *5.D.1.2.2.2.5.4 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 5.D-40). 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 5.D-40. 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 5.D-40).

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 5.D-41). 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 (Myfanwy Johnston 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 5.D-40.

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 5.D-41. 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.

#### *5.D.1.2.2.2.5.5 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 5.D-45). 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*):

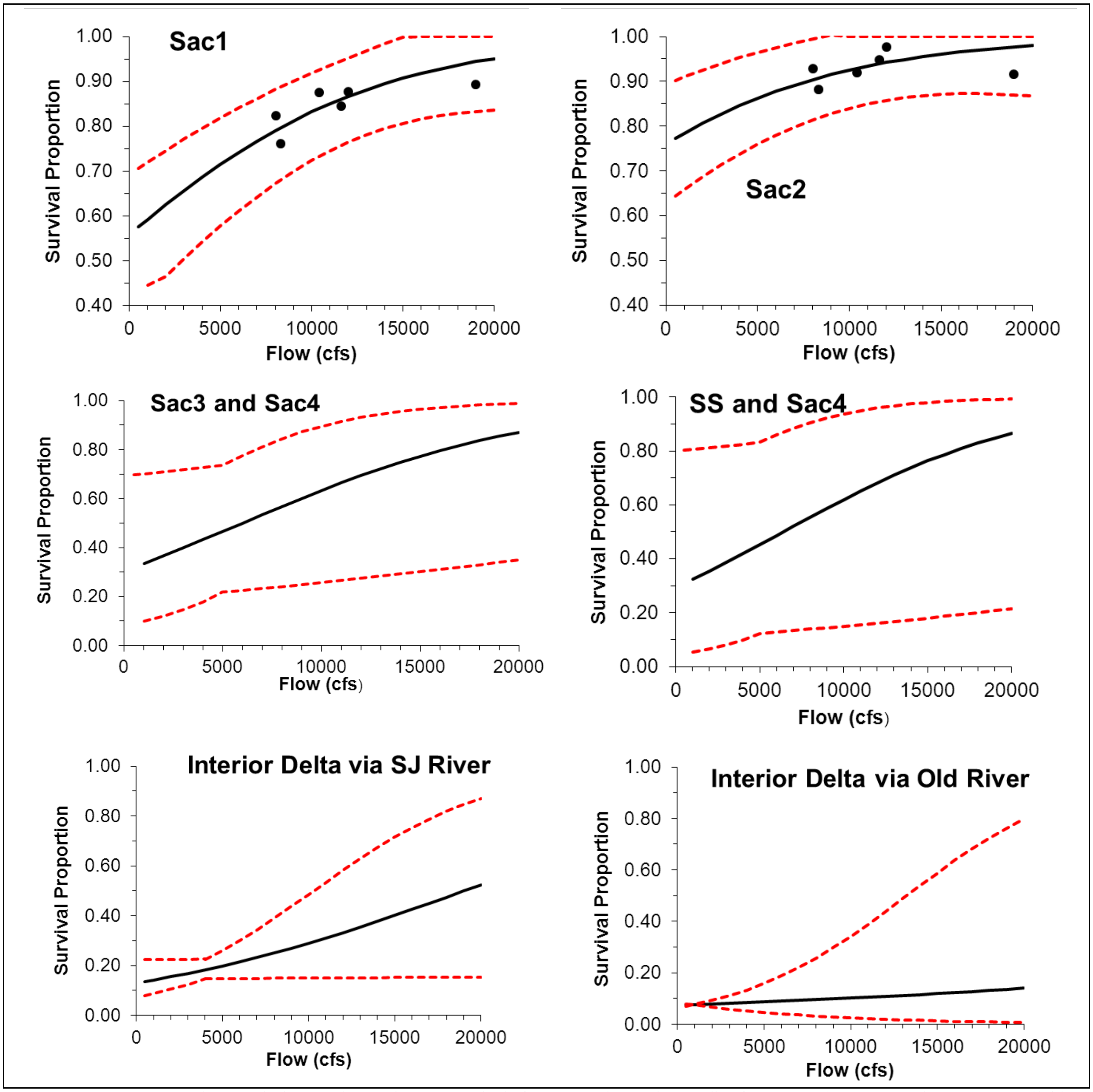
$$S = \frac{e^{(\beta_0 + \beta_1 flow)}}{1 + e^{(\beta_0 + \beta_1 flow)}}$$

where $\beta_0$ (SS and Sac4 = -0.175, Sac3 and Sac4 = -0.121) is the reach coefficient and $\beta_1$ (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[7] (Figure 5.D-45; Table 5.D-42). 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.

[7] Perry (2010) did not attempt to correlate survival to flow in these reaches because survival was generally high.




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 5.D-45. 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 5.D-42. 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 5.D-43; Figure 5.D-45). 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 5.D-43. 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) |

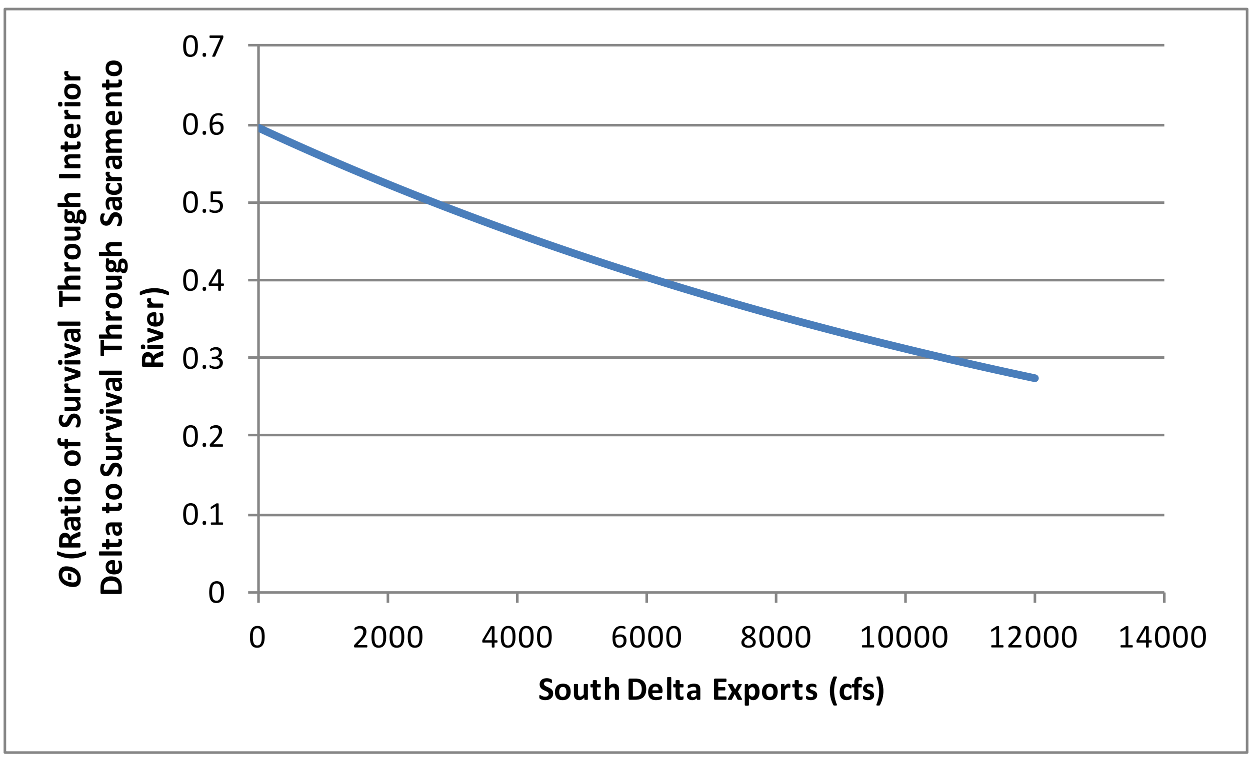
### *5.D.1.2.2.2.5.6 Export-Dependent Survival*

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 $\theta$ 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.

$\theta$ 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 5.D-46).




Source: Newman and Brandes 2010

**Figure 5.D-46. Relationship between θ (Ratio of Survival through the Interior Delta to Survival through Sacramento River) and South Delta Export Flows**

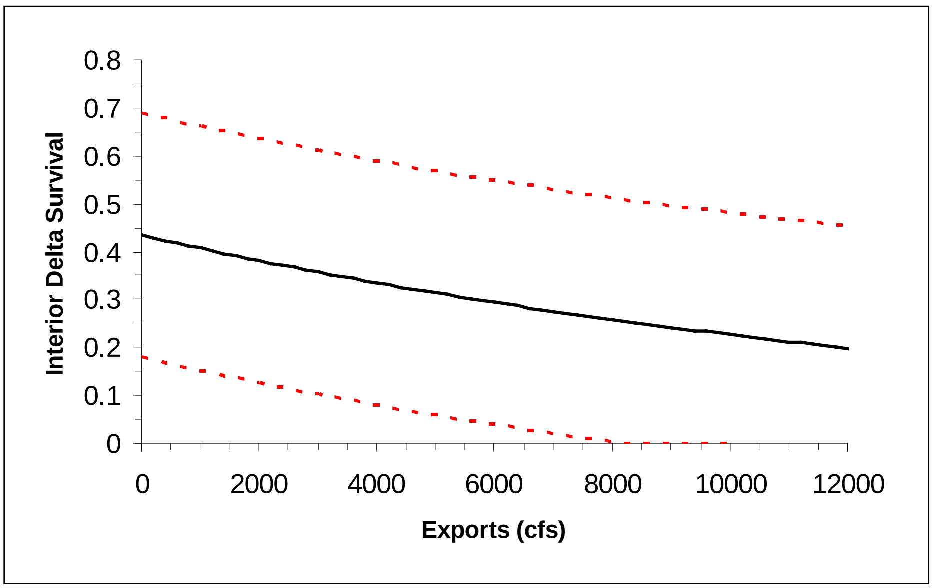
$\theta$ was converted from a ratio into a value of survival through the Interior Delta using the equation:

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

where $S_{ID}$ is survival through the Interior Delta, $\theta$ 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 5.D-47)[8].

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 Section 5.D.1.2.2.2.5.5, *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 5.D-47. 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**

[8] 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.

##### *5.D.1.2.2.3 Postprocessing of Model Outputs for Effects Analysis*

To facilitate the interpretation of overall DPM survival results in the effects analysis of the PA, 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 (1922–2003) 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 5.D-43 of Section 5.D.1.2.2.2.5.5, *Flow-Dependent Survival*. 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.

#### *5.D.1.2.2.4 Randomization to Illustrate Uncertainty*

As described previously, various DPM model functions incorporate uncertainty in relationships between fish response and physical parameters, e.g., survival in response to river flow; re-sampling from these relationships on each modeled day allows this uncertainty to be captured in the model effects. In order to illustrate the uncertainty in modeled annual estimates of through-Delta survival, 75 iterations of the DPM were run, each with different randomizations of the model functions. It was found that 75 iterations were sufficient to allow the error in the estimates to stabilize so that no additional iterations were required. The 75 iterations gave 75 estimates of through-Delta survival for each year in the simulation period, from which 95% confidence intervals (the $2.5^{th}$ and $97.5^{th}$ percentiles of the 75 iterations) were calculated for each annual estimate. The confidence intervals provided perspective on the range of uncertainty in each annual estimate, and allowed comparison of the number of years that the confidence intervals overlapped for the NAA and PA scenarios.

#### *5.D.1.2.2.5 Sensitivity Analysis*

A working group consisting of consultants and agency staff coordinated with the model developers to develop a sensitivity analysis in order to examine the influence of DPM structural uncertainty and parameter uncertainty on model outputs, in addition to demonstrating how changes in model inputs (flows and exports) influence model outputs. The methods and results for this sensitivity analysis are described in this section. Note that the sensitivity analysis was run using existing biological conditions DSM2 data (1976–1991) from the public draft BDCP DPM analysis and used the non-Fremont Weir notch implementation for entry into Yolo Bypass (i.e., Proportion of smolts entering Yolo Bypass = Fremont Weir spill / (Fremont Weir spill + Sacramento River at Verona flows); the entry timing was that of winter-run Chinook salmon.

##### 5.D.1.2.2.5.1 Methods

###### *5.D.1.2.2.5.1.1 Structural uncertainty*

Different forms of both winter run entry timing and Yolo survival in the Delta Passage Model were evaluated. To understand how variation in these functions affected model output, they were evaluated separately. Thus, each function had a "default" structure that was used when the other function was being evaluated. Table 5.D-44 lists the specific functions evaluated the candidate structures and the default value.

**Table 5.D-44. DPM Sensitivity Analysis Structural Uncertainty: Model functions with alternative structures that were evaluated and default structures that were used.**

| Function | Alternate structures | Default structure |
|---|---|---|
| Winter-run Chinook salmon entry timing | 1. One bimodal distribution | One bimodal distribution |
| | 2. Two bimodal distributions. One for Wet and above normal years and one for critical dry and below normal years. | |
| | 3. One bimodal distribution triggered by a 400 $m^3 * s^{-1}$ flow pulse. | |
| | | |
| Yolo survival | 1. Constant 80% survival | Constant 80% survival |
| | 2. Ted Sommer's new coded wire tag data by low flow year (<2000 $ft^3 * s^{-1}$ in Yolo) and high flow year (>2000 $ft^3 * s^{-1}$ in Yolo) | |
| | 3. Acoustic data from 2012 | |

For each candidate structure of a function, 1000 Monte Carlo simulations of the model were run for one year of model time. Flow and export inputs for this exercise were average daily flow and exports by water year type calculated from DSM2 data over 1976–1991. The water year type used for each Monte Carlo simulation was chosen based on their probability of occurrence over the last 100 years. The output evaluated was the percentage of fish surviving to Chipps Island. Output values were summarized by calculating the $5^{th}$ -$95^{th}$ percentile of output values for each structure and the percent overlap in output values among the three different structures.

##### *5.D.1.2.2.5.1.2 Parameter Uncertainty*

To understand how uncertainty in key model parameters affected model output, Sobol sensitivity indices were calculated. Sobol' indices provide a way to account for the direct effect of variation in individual parameters and their first order interactions on model output. A single model was used to calculate Sobol' indices that used the Yolo survival and winter run entry timing functions identified in the structural uncertainty analysis (a single bi-modal winter run entry distribution and acoustic survival estimates for Yolo Bypass survival).

Parameters examined in this analysis included water year-type and survival and travel time in all reaches including Verona, Sac1, Sac2, Steamboat/Sutter, Sac3, Geo/DCC and Interior Delta. This represents all model parameters that are resampled each day in the model. If the final model includes a stochastic function for Yolo survival, that parameter will also be included in the analysis. No other parameters can be examined with Sobol' indices because there is no variation in their values.

One thousand Monte Carlo simulations will be run to obtain data for the Sobol' analysis. Flows and exports will be randomly selected by water year type averages as described above. Once the data are obtained, they will be exported to the R statistical program and analyzed with the package "sensitivity". Two Sobol' indices will be calculated; a main index that describes the effect of an individual parameter on model output independent of all other parameters and a total index that incorporates first order interaction with other model parameters. The model output for this analysis will be total Delta survival. If confidence intervals of Sobol' indices do not include zero, they will be considered to have a significant effect on model output.

#### *5.D.1.2.2.5.1.3 Model Demonstration*

To demonstrate how changes in model inputs (flow and exports) affect model output, a model demonstration exercise was performed. The flow and export data described above were used to calculate 10, 20, 30, 40, 50, 60, 70, 80, and 90$^{th}$ percentile values in each water year-type. To demonstrate flow effects, exports were held at the 50$^{th}$ percentile value and 100 iterations of the model were run at each flow percentile from the 10$^{th}$ to the 90$^{th}$. Similarly, for the export effect demonstration, flow values in each reach were held at the 50$^{th}$ percentile value while 100 iterations of the model were run at each percentile of exports from the 10$^{th}$ to the 90$^{th}$.

### 5.D.1.2.2.5.2 Results and discussion

#### *5.D.1.2.2.5.2.1 Structural uncertainty*

Evaluation of winter run entry timing suggested that none of the alternative entry functions provided more explanatory power than the default bi-model distribution. When entry into the Delta was modeled as a function of water year-type, there was a 3.7% difference in through-Delta survival relative to the baseline. This was less than the 5% threshold for including this as the entry timing function. When entry timing was triggered by flow, there was a 0% difference in through-Delta survival. This also did not meet the criteria to replace the default bimodal function. Thus, no change was made to winter run entry timing.

Uncertainty in the Yolo survival function was evaluated with two alternate functions. The default function was a fixed survival value of 80%, which was based on professional opinion (Ted Sommer, personal communication). The alternative functions included; 1) the ratio of recoveries of coded wire tagged (CWT) fish released the Yolo Bypass and CWT fish released in the Sacramento River (relative survival) and 2) Estimates of survival for acoustically tagged late-fall run smolts released into the Toe Drain. Implementation of the CWT data resulted in a 0% difference in total through-Delta survival. Use of the acoustic survival data resulted in a 3.4% difference in total through-Delta survival. Although this value is below the 5% threshold to replace the function, the workgroup felt that the acoustic data was a better representation of survival that the 80% constant based on professional opinion. Thus, the fixed value was replaced with acoustic survival data.

#### *5.D.1.2.2.5.2.2 Parameter uncertainty*

The main index produced by Sobol’ sensitivity analysis characterizes the effect of individual parameters without considering interactions. The most influential parameters indicated by the main index were; 1) survival in reach Sac 3, 2) survival in the reach Steamboat/Sutter Sloughs, 3) the proportion of fish entering Steamboat/Sutter Sloughs and 4) survival in reach Sac2 (Figure 5.D-48). All other main index values were very low or the confidence interval overlapped with zero.

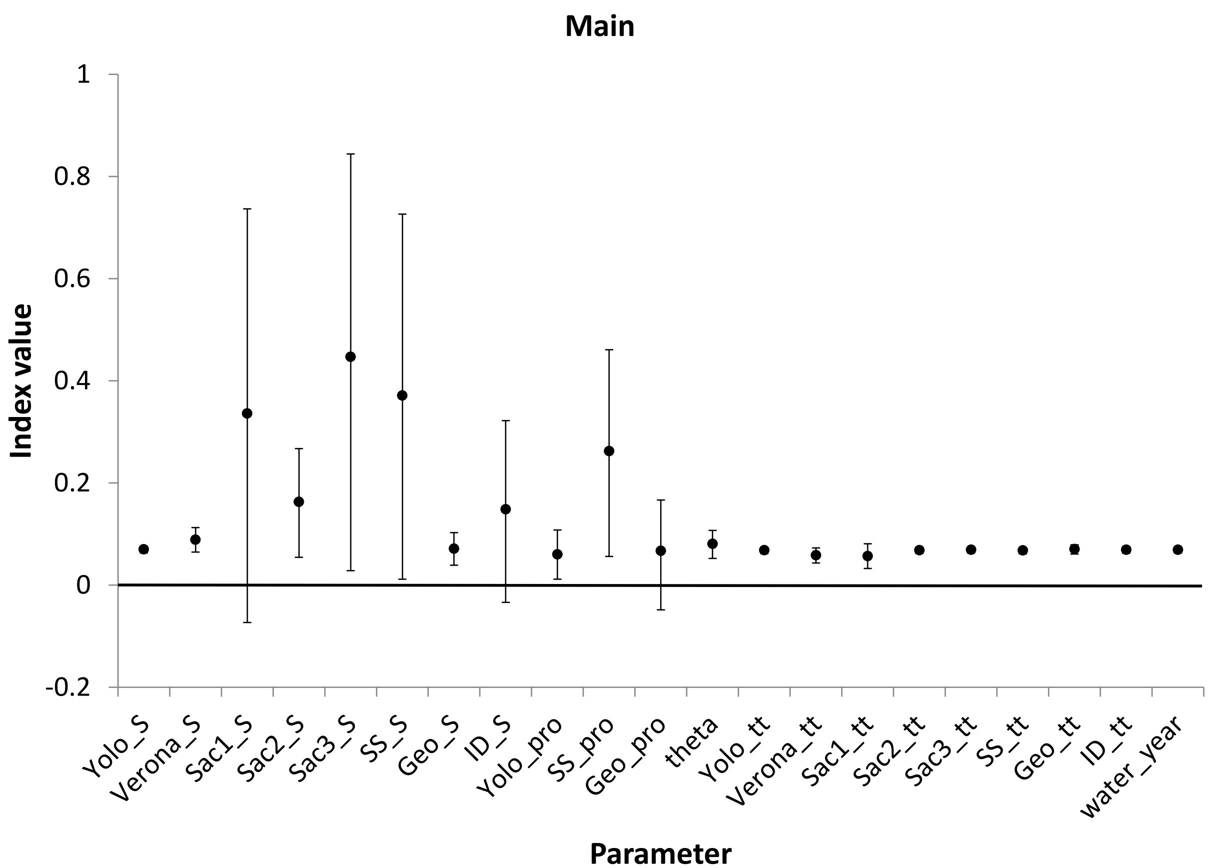



**Figure 5.D-48. DPM Sensitivity Analysis Parameter Uncertainty: Main index values from Sobol' sensitivity indices. Confidence intervals that cross zero indicate that parameter did not have a disproportionate effect of model output.**

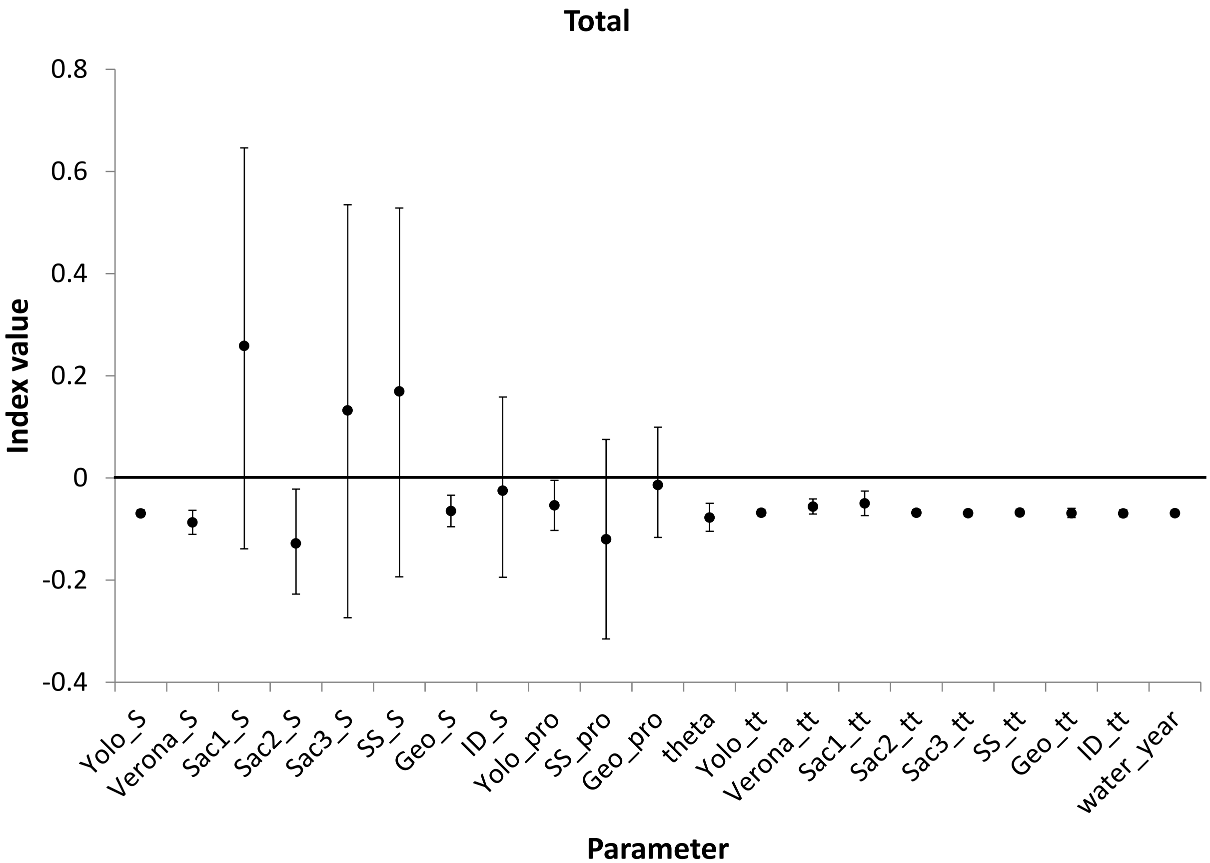



**Figure 5.D-49. DPM Sensitivity Analysis Parameter Uncertainty: Total index values from Sobol' sensitivity indices. Confidence intervals that cross zero indicate that parameter did not have a disproportionate effect of model output.**

The total index indicated that when first-order interactions were considered, none of the variables had a disproportionate influence on total through-Delta survival (Figure 5.D-49). Negative values for the total index were observed; however, negative values of Sobol' indices are interpreted as having no effect (Fieberg and Jenkins 2005).

### *5.D.1.2.2.5.2.3 Model demonstration*

Mean through-Delta survival for fish entering from the Sacramento River increased approximately 10% as flows increased from 10 to 90$^{th}$ percentile values in each water year (Figure 5.D-50). Initial screening of the survival values indicated the data were not normal so we employed the non-parametric Kruskal-Wallis test to determine if there were significant differences between the different percentile flow treatments. This test revealed significant differences between the treatment groups ($\chi^2 = 101.38$, $p < 0.001$). To determine where the differences existed, Wilcoxon's pairwise comparisons were performed. This comparison indicated that the first significant difference in survival occurred between the 10$^{th}$ and 20$^{th}$ percentile values. The increase in survival from the 10$^{th}$ to 20$^{th}$ percentile flow was greater than the increase between the 10$^{th}$ and 30$^{th}$ percentile value. This effect can happen because juvenile salmon are only affected by flow when they are present in the Delta. Thus, the timing of flows is just as important as the absolute magnitude. Even in years classified as "critical" or "dry" can produce high through-Delta survival values if pulses occurred during the time when salmon were passing through the Delta. Similarly, flows could be low during the migration period in a “wet” or “above normal” year and produce a relatively low survival value.

Variation in exports produced much less variation in through-Delta survival with a decline of less than 2.5% between the 10th and 90th percentile values (Figure 5.D-51). A Kruskal-Wallis test indicated a significant difference between the treatments ($\chi^2 = 30.63$, $P < 0.001$) and the Wilcoxon’s pairwise test revealed that the first significant difference was between the 10th and 90th percentile values. The lack of a large export effect is likely for several reasons. First, the total proportion of fish entering the interior Delta is low. Fish entering the model can enter the Yolo Bypass and the Steamboat/Sutter Slough route where they are no exposed to routes entering the interior Delta (Georgiana Slough, Delta Cross Channel). Second, the effect of exports on survival is weak and highly variable. Thus, there is unlikely to be a strong effect of exports on total survival of juvenile Chinook migrating through the Delta from the Sacramento River.

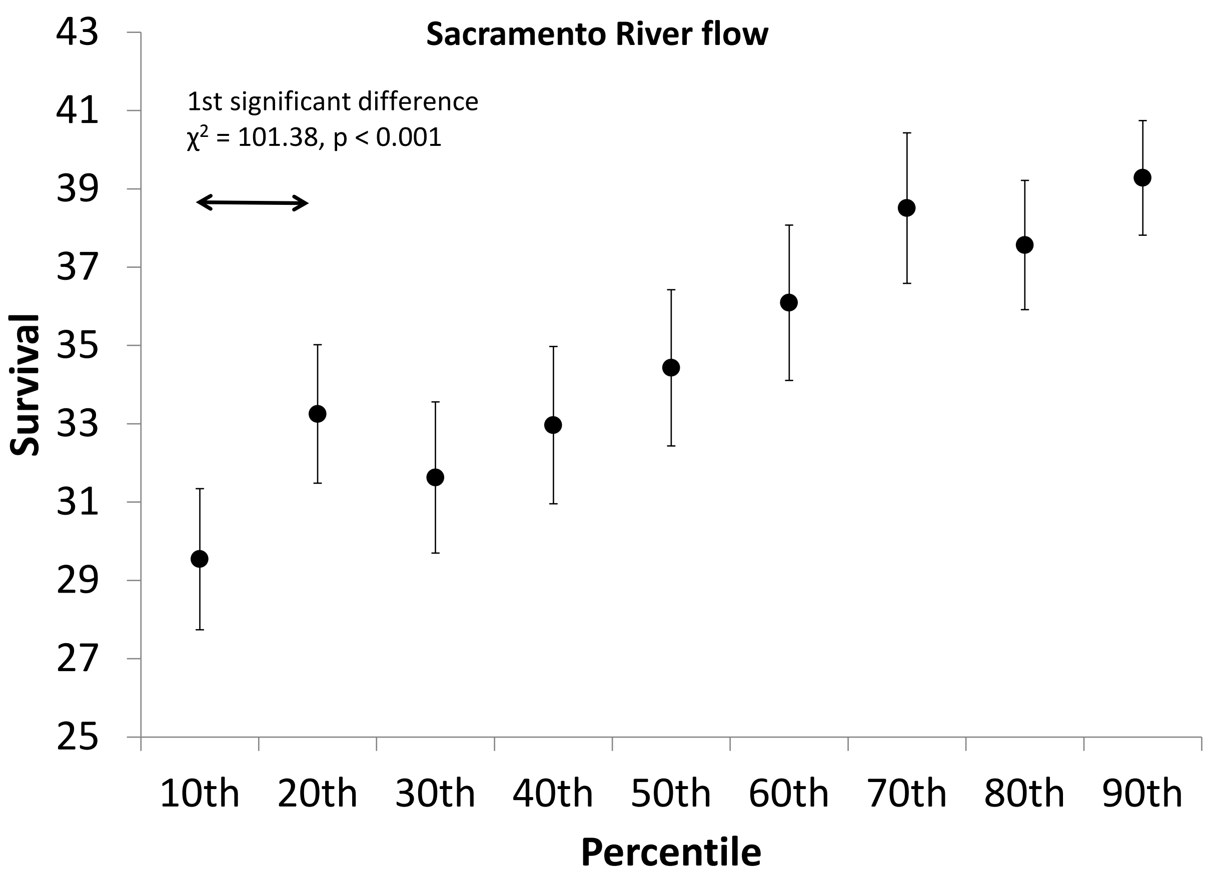



**Figure 5.D-50. Means and standard errors of total through-Delta survival for winter run Chinook salmon at 10th – 90th percentile flow values in each reach with exports held at the 50th percentile values.**

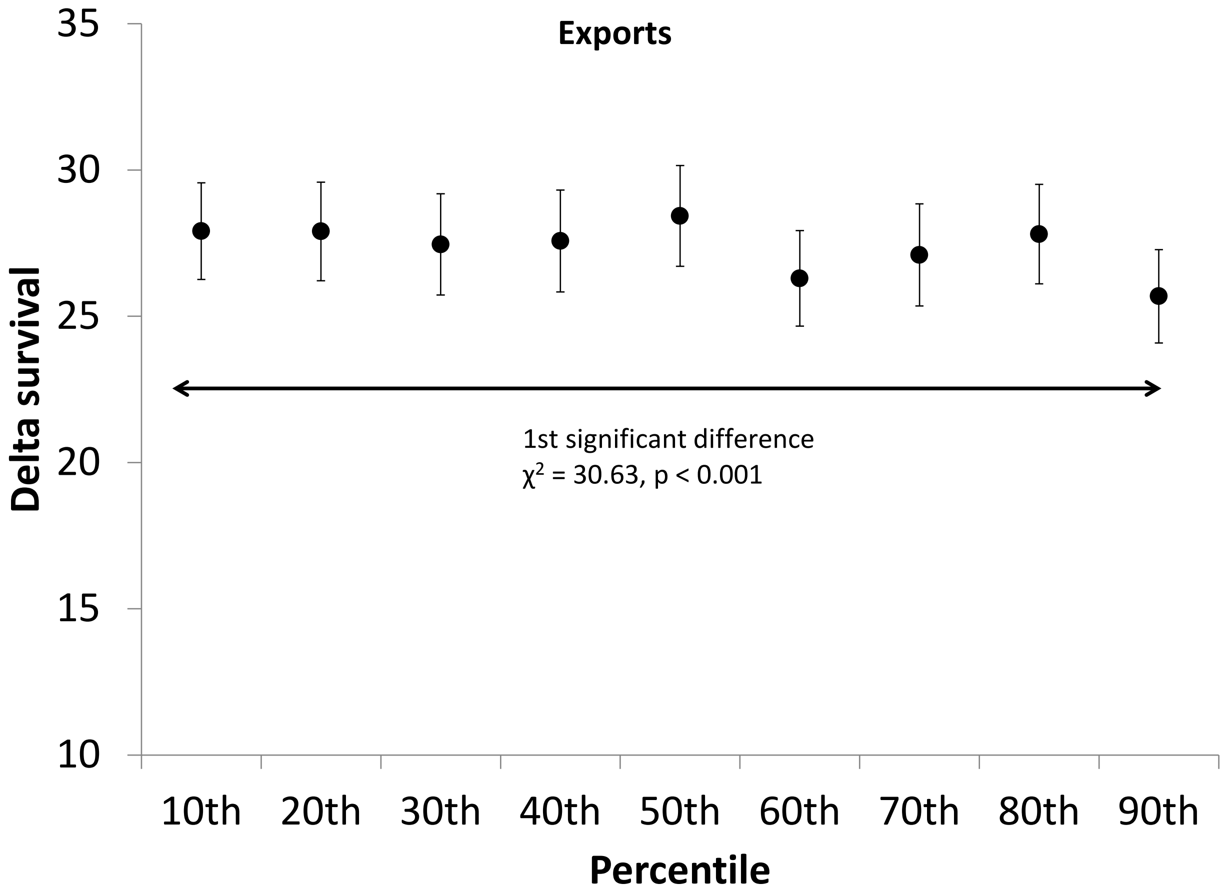



**Figure 5.D-51. Means and standard errors of total through-Delta survival for winter run Chinook salmon at 10th – 90th percentile export values in each reach with flows held at the 50th percentile values.**

To examine the flow and export ranges used in the sensitivity analyses, the 10th – 90th percentile values of flow in reach Sac 3 and exports were plotted for each water year type with the exception of years that were categorized as "Below Normal". This year-type was excluded because there was only one below normal year in the range of years used. Thus, percentile values could not be calculated and the flow and export values for this year type were always the same.

Examining the plots of each water year-type revealed that there was a considerably greater range between 10th and 90th percentile values in wet (Figure 5.D-52) and above normal (Figure 5.D-53) years relative to dry (Figure D_flow_sens) and critical (Figure C_flow_sens) years. Even in dry years, there were occasional flow pulses, whereas these were attenuated in critical years.

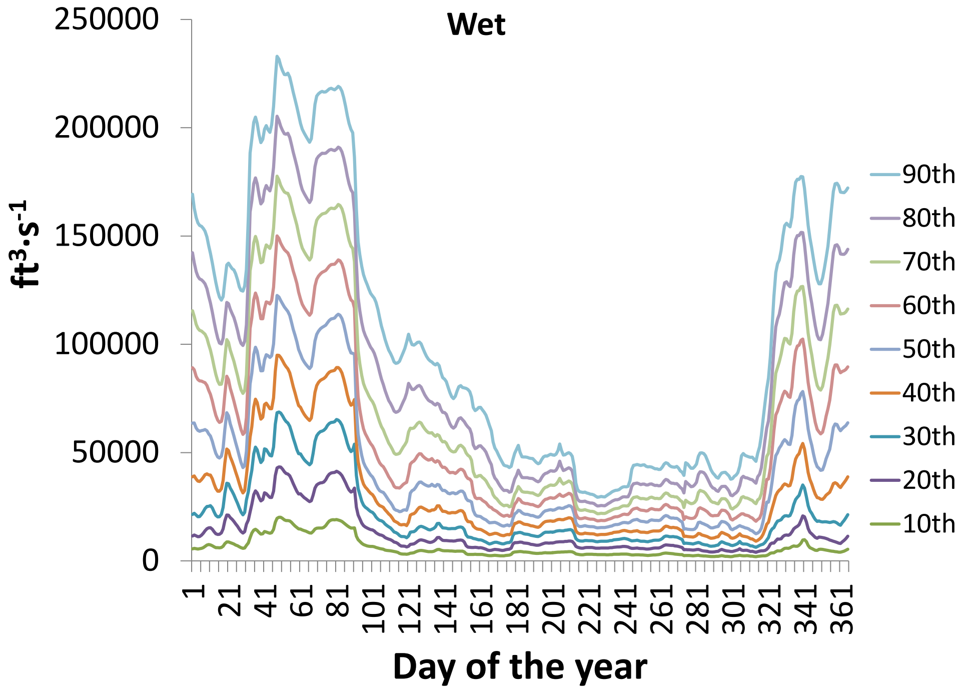



**Figure 5.D-52. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Wet Years, Used in the Sensitivity Analysis's Model Demonstration.**

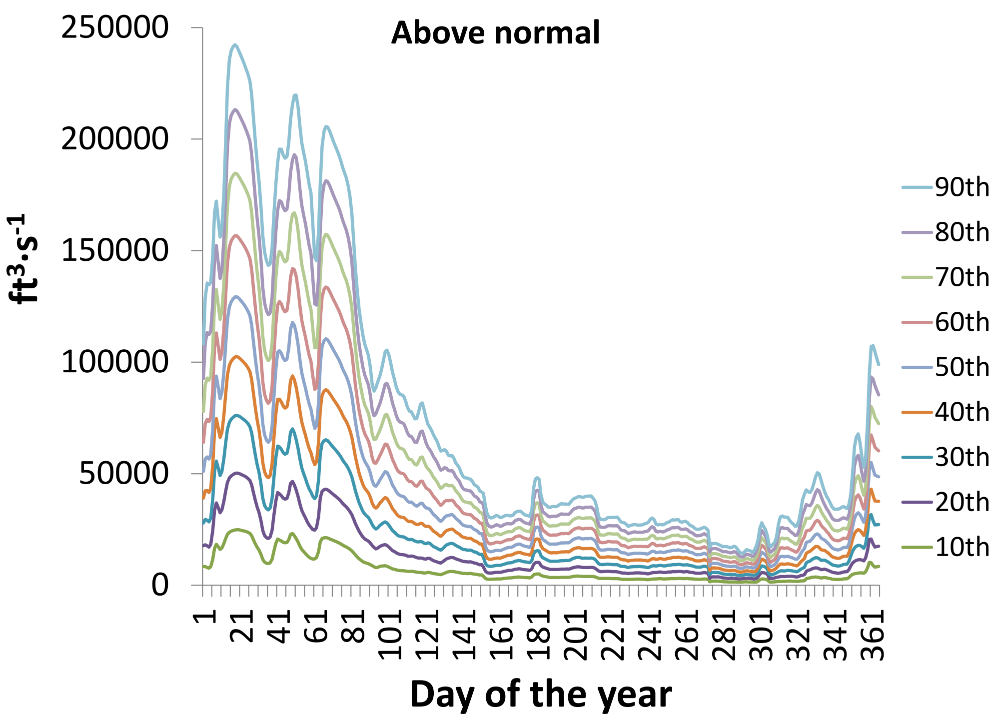



**Figure 5.D-53. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Above Normal Years, Used in the Sensitivity Analysis's Model Demonstration.**

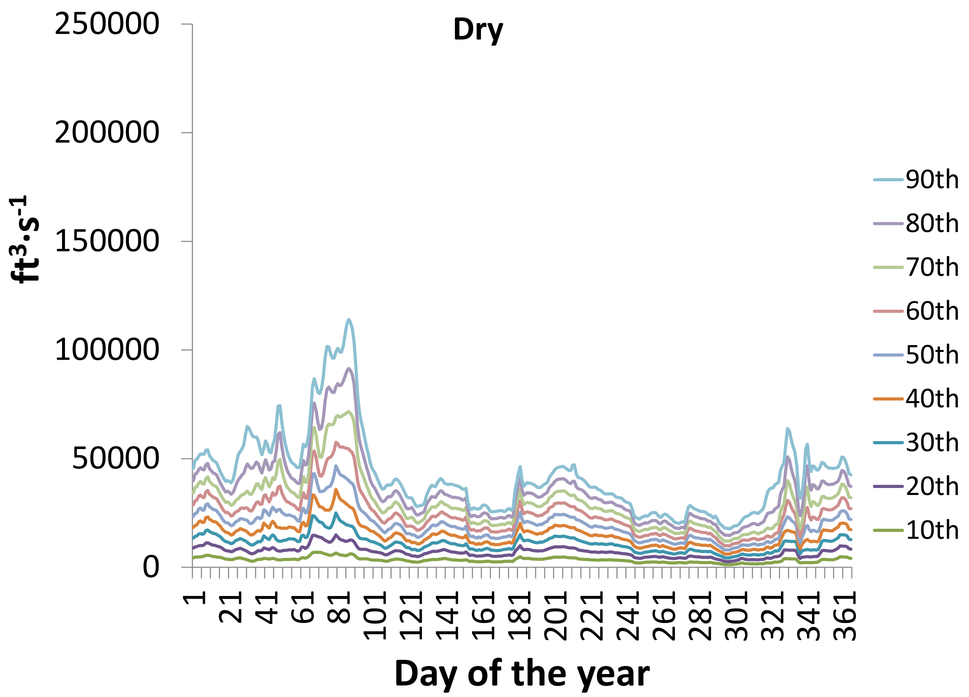



**Figure 5.D-54. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Dry Years, Used in the Sensitivity Analysis's Model Demonstration.**

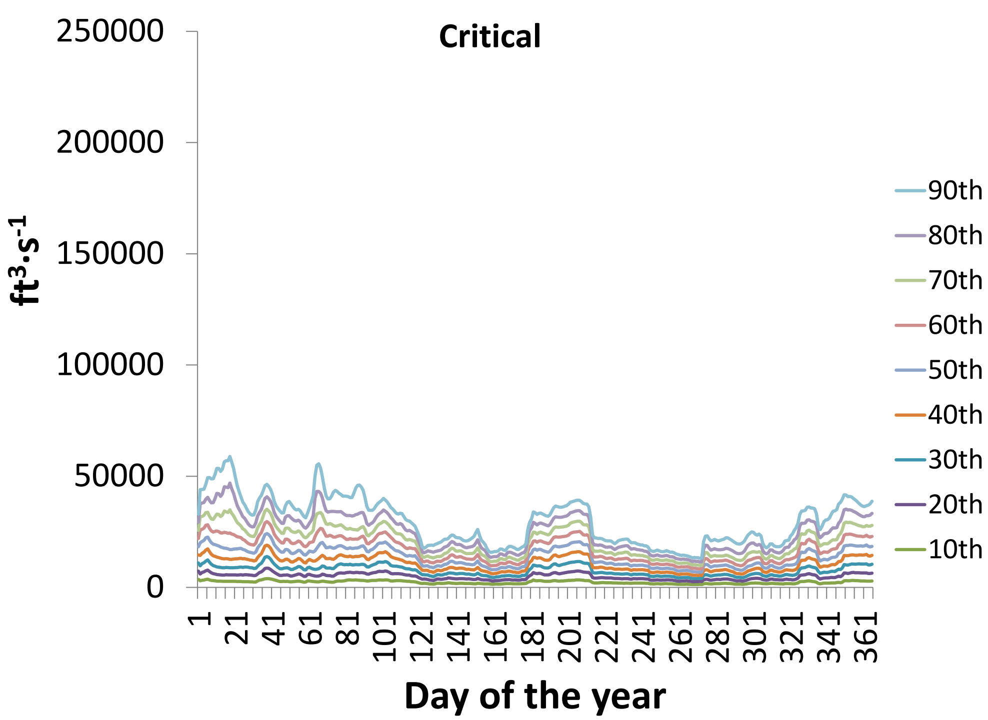



**Figure 5.D-55. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Critical Years, Used in the Sensitivity Analysis's Model Demonstration.**

Variation in exports among water year largely reflected regulatory policy and water demand (Figure 5.D-56, Figure 5.D-57, Figure 5.D-58, Figure 5.D-59). Among all water years, exports were lowest in April and May because of restrictions related to protective actions for migrating juvenile salmon. Exports were highest during the summer-fall irrigation season. The sensitivity analysis was performed on winter run Chinook salmon in the DPM. This race moves through the Delta between November and March when there is considerably more variation in exports among water year-types.

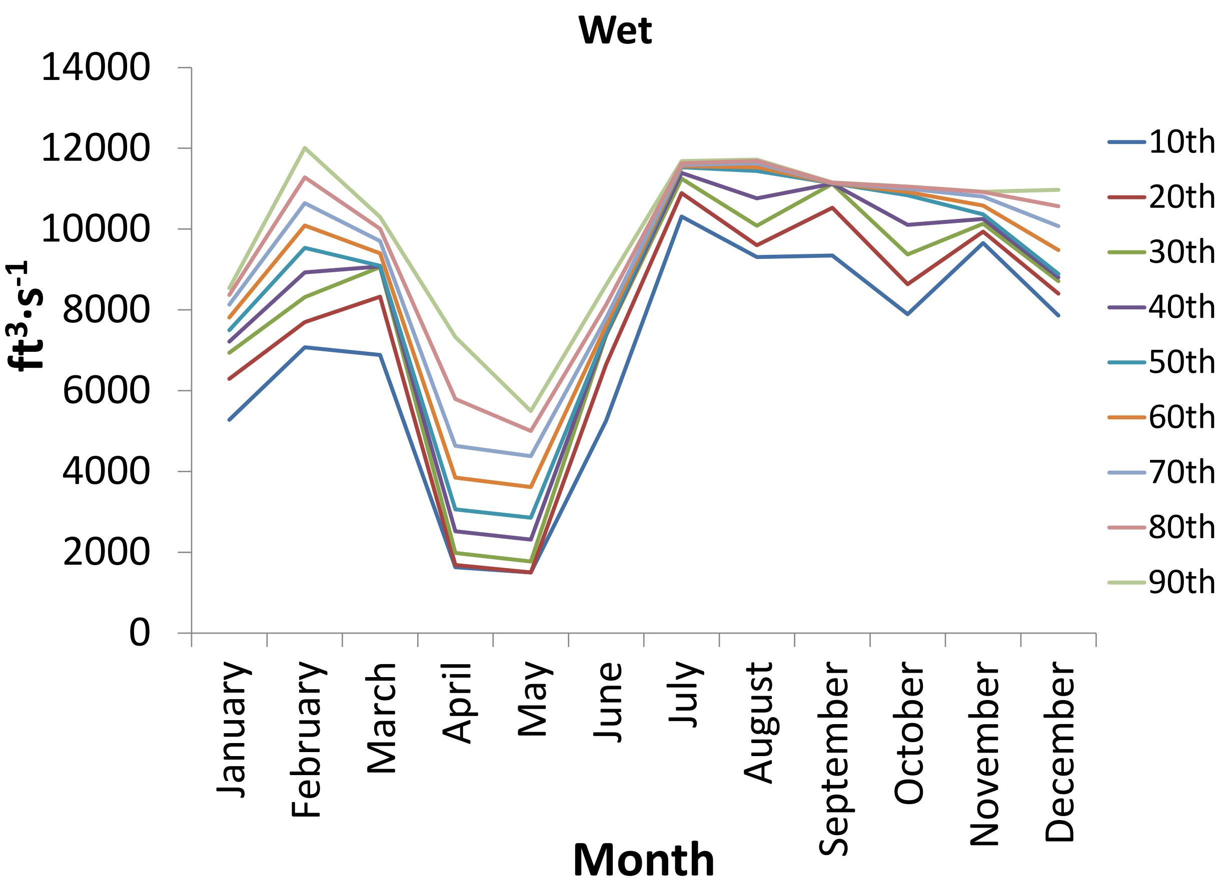



**Figure 5.D-56. Ranges of Daily South Delta Exports in Wet Years, Used in the Sensitivity Analysis's Model Demonstration.**

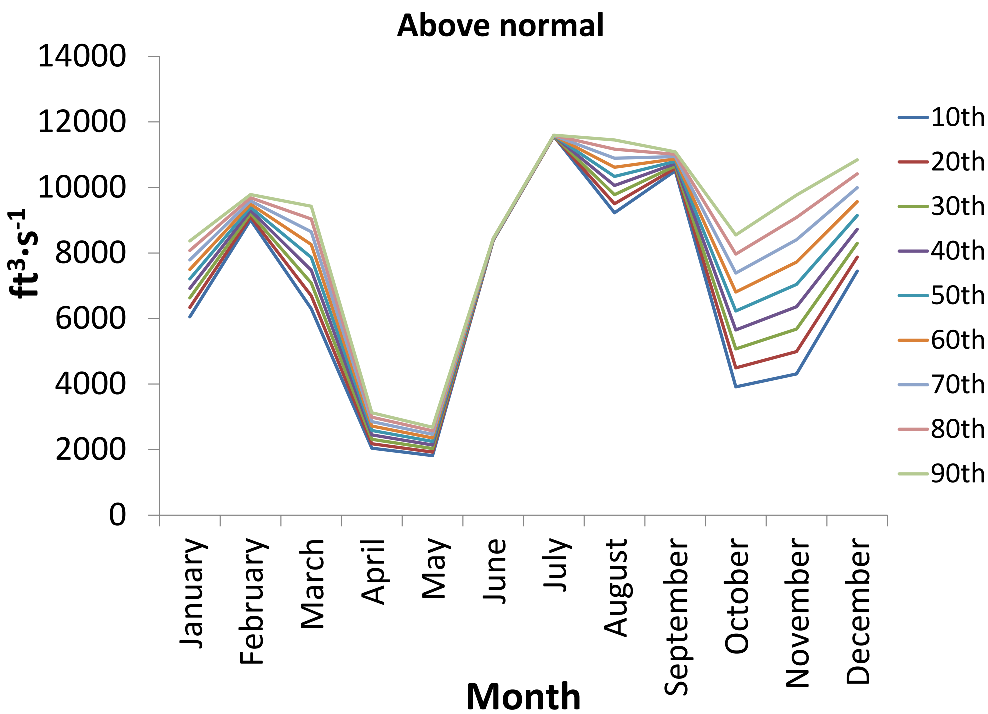



**Figure 5.D-57. Ranges of Daily South Delta Exports in Above Normal Years, Used in the Sensitivity Analysis's Model Demonstration.**

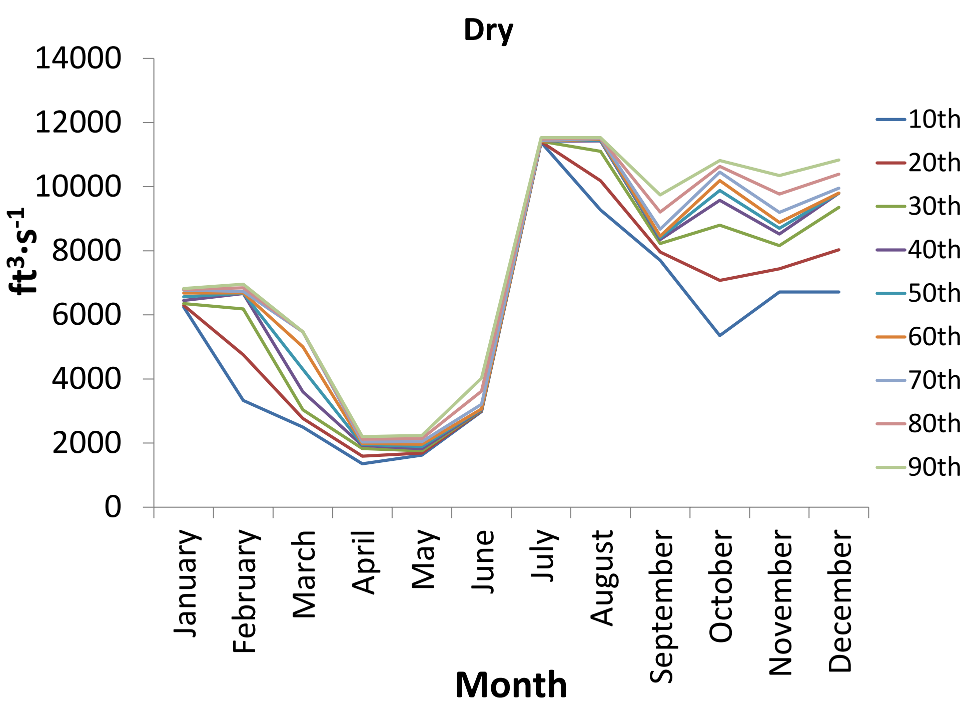



**Figure 5.D-58. Ranges of Daily South Delta Exports in Dry Years, Used in the Sensitivity Analysis's Model Demonstration.**

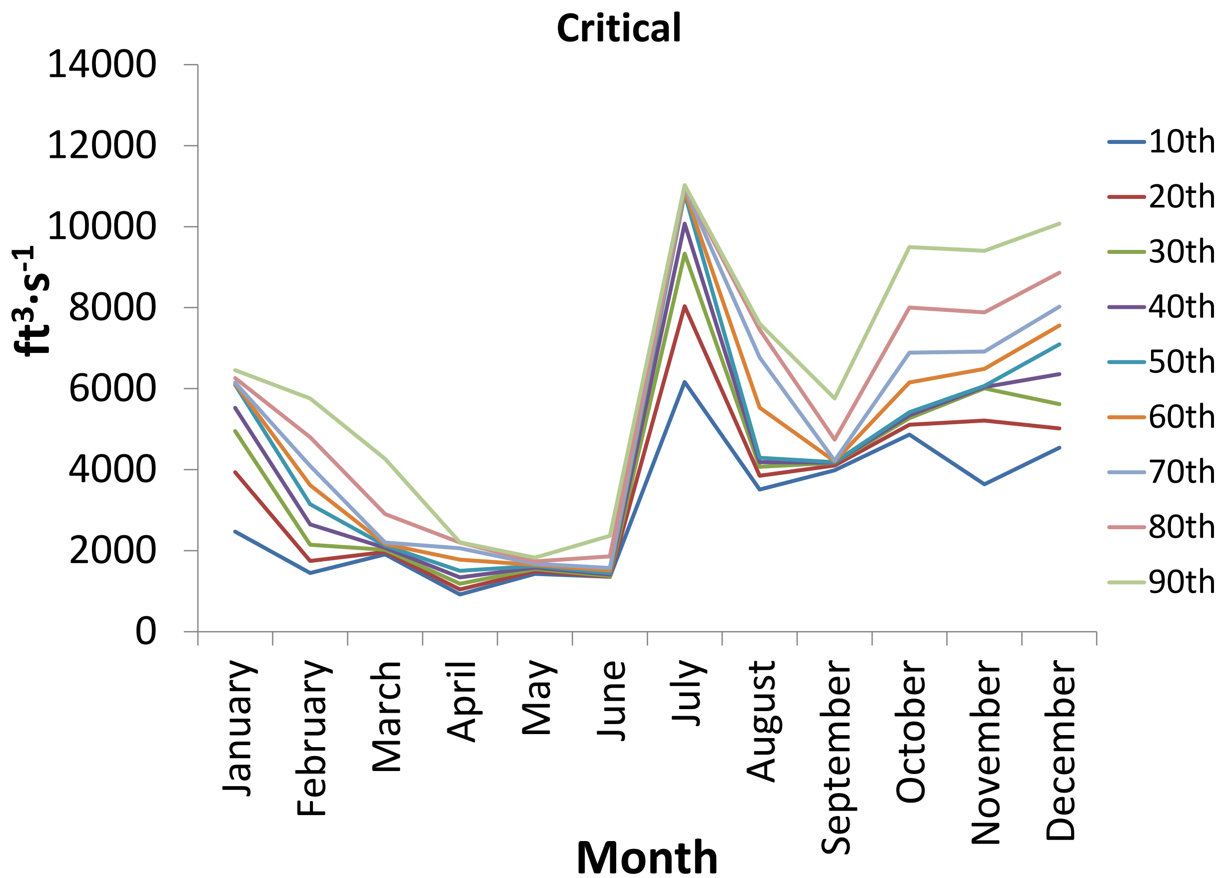



**Figure 5.D-59. Ranges of Daily South Delta Exports in Critical Years, Used in the Sensitivity Analysis's Model Demonstration.**

### *5.D.1.2.3 Analysis Based on Newman (2003)*

#### *5.D.1.2.3.1 Introduction*

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 present 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 spring-run and fall-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 late fall-run Chinook salmon.

## 5.D.3 Life Cycle Models

Two life cycle models were used to assess the potential effects of the PA on winter-run Chinook salmon: IOS and OBAN. The methods and results from these models are presented in this section.

### 5.D.3.1 IOS (Interactive Object-Oriented Simulation)

#### *5.D.3.1.1 Model Structure*

The IOS Model is composed of six model stages defined by a specific spatiotemporal context and are arranged sequentially to account for the entire life cycle of winter-run Chinook salmon, from eggs to returning spawners (Figure 5.D-135). In sequential order, the IOS Model stages are listed below.

1. Spawning, which models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.

2. Early Development, which models the effect of temperature on maturation timing and mortality of eggs at the spawning grounds.

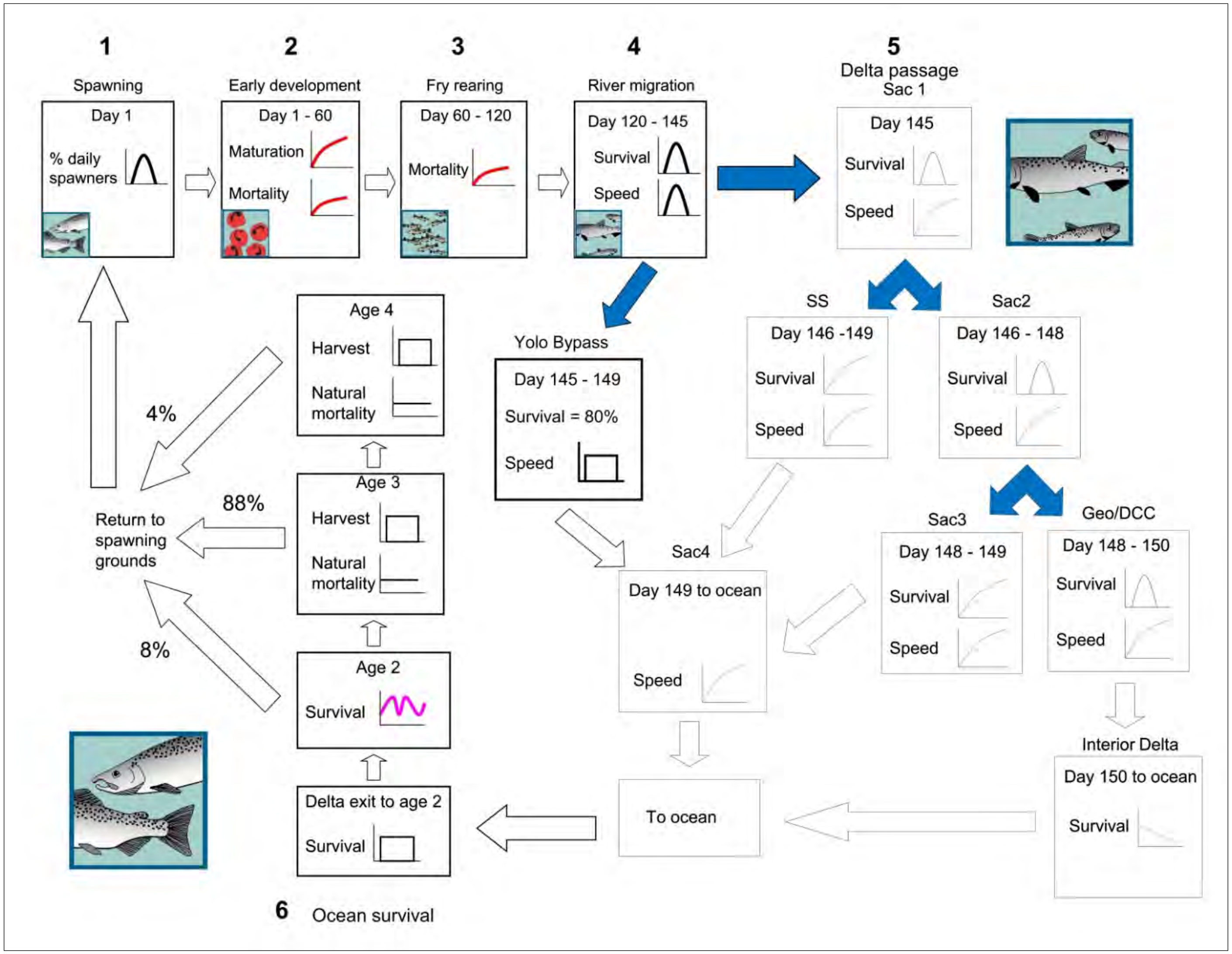
3. Fry Rearing, which models the relationship between temperature and mortality of fry during the river rearing period in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.

4. River Migration, which estimates mortality of migrating smolts in the Sacramento River between the spawning and rearing grounds and the Delta.

5. Delta Passage, which models the effect of flow, route selection, and water exports on the survival of smolts migrating through the Delta to San Francisco Bay.

6. Ocean Survival, which estimates the effect of natural mortality and ocean harvest to predict survival and spawning returns by age.

A detailed description of each model stage follows.




Note: Red = temperature, blue = flow, green = water exports, pink = ocean productivity.

**Figure 5.D-135. Conceptual Diagram of the IOS Model Stages and Environmental Influences on Survival and Development of Winter-Run Chinook Salmon at Each Stage**

##### *5.D.3.1.1.1 Spawning*

For the first four simulation years of the 82-year CalSim simulation period, the model is seeded with 5,000 spawners, of which 3,087.5 are female based on the wild male to female ratio of spawners. In each subsequent simulation year, the number of female spawners is determined by the model's probabilistic simulation of survival to this life stage. To ensure that developing fish experience the correct environmental conditions during each year, spawn timing mimics the observed arrival of salmon on the spawning grounds as determined by 8 years of carcass surveys (2002–2009) conducted by the U.S. Fish and Wildlife Service (USFWS). Eggs deposited on a particular date are treated as cohorts that experience temperature and flow on a daily time step during the early development stage. The daily number of female spawners is calculated by multiplying the daily proportion of the total carcasses observed during the USFWS surveys by the total Jolly-Seber estimate of female spawners (Poytress and Carillo 2010).

(Equation 1) $S_d = C_d S_{JS}$

where, $S_d$ is the daily number of female spawners, $C_d$ is the daily proportion of total carcasses and $S_{JS}$ is the total Jolly-Seber estimate of female spawners.

To account for the time difference between egg deposition and carcass observations, the date of egg deposition is assumed 14 days prior to carcass observations (Niemela pers. comm.).

To obtain estimates of juvenile production, a Ricker stock-recruitment curve (Ricker 1975) was fit between the number of emergent fry produced each year (estimated by rotary screw–trap sampling at Red Bluff Diversion Dam) and the number of female spawners (from USFWS carcass surveys) for years 1996–1999 and 2002–2007:

(Equation 2) $R = \alpha S e^{-\beta S} + \varepsilon$

where $\alpha$ is a parameter that describes recruitment rate, and $\beta$ is a parameter that measures the level of density dependence.

The density-dependent parameter ($\beta$) did not differ significantly from 0 (95% CI = $-6.3\text{x}10^{-6}$ – $5.5\text{x}10^{-6}$), indicating that the relationships between emergent fry and female spawners was linear (density-independent). Therefore, $\beta$ was removed from the equation and a linear version of the stock-recruitment relationship was estimated. The number of female spawners explained 86% of the variation in fry production ($F_{1,9} = 268$, $p<0.001$) in the data, so the value of $\alpha$ was taken from the regression:

(Equation 3) $R = 1043*S$

In the IOS Model, this linear relationship is used to predict values for mean fry production along with the confidence intervals for the predicted values. These values are then used to define a normal probability distribution, which is randomly sampled to determine the annual fry production. Although the Ricker model accounts for mortality during egg incubation, the data used to fit the Ricker model were from a limited time period (1996–1999, 2002–2007) when water temperatures during egg incubation were too cool (<14°C) to cause temperature-related egg mortality (U.S. Fish and Wildlife Service 1999). Thus, additional mortality was imposed at higher temperatures not experienced during the years used to construct the Ricker model.

##### *5.D.3.1.1.2 Early Development*

Data from three laboratory studies were used to estimate the relationship between temperature, egg mortality, and development time (Murray and McPhail 1988; Beacham and Murray 1989; U.S. Fish and Wildlife Service 1999). Using data from these experiments, a relationship was constructed between maturation time and water temperature. First *maturation time* (days) was converted to a *daily maturation rate* (1/day):

(Equation 4) $\text{daily maturation rate} = \text{maturation time}^{-1}$

A significant linear relationship between maturation rate and water temperature was detected using linear regression. Daily water temperature explained 99% of the variation in *daily maturation rate* ($F$ =2188; df =1,15; $p$<0.001):

(Equation 5) $\text{daily maturation rate} = 0.00058*\text{Temp}-0.018$

In the IOS Model, the daily mean maturation rate of the incubating eggs is predicted from daily water temperatures using a linear function; the predicted mean maturation rate, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily maturation rate. A cohort of eggs accumulates a percentage of total maturation each day from the above equation until 100% maturation is reached.

Data from experimental work (U.S. Fish and Wildlife Service 1999) was used to parameterize the relationship between temperature and mortality of developing winter-run Chinook salmon eggs. Predicted proportional mortality over the entire incubation period was converted to a daily mortality rate to apply these temperature effects in the IOS Model. This conversion was used to calculate daily mortality using the methods described by Bartholow and Heasley (2006):

(Equation 6) $\text{mortality} = 1\text{-}(1\text{-total mortality})^{(1/\text{development time})}$

where *total mortality* is the predicted mortality over the entire incubation period observed for a particular water temperature and *development time* was the time to develop from fertilization to emergence.

Limited sample size (n = 3) in the USFWS study (1999) did not allow a statistically valid test for effects of temperature on mortality (e.g., a general additive model) to be performed. However, the following exponential relationship was fitted between observed *daily mortality* and observed water temperatures (U.S. Fish and Wildlife Service 1999) to provide the required values for the IOS Model:

(Equation 7) $\text{daily mortality} = 1.38*10^{-15}e^{(0.503*\text{Temp})}$

Equation 7 yields the following graphic (Figure 5.D-136), which indicates that proportional daily egg mortality increases rapidly with only small changes in water temperature. For example, within the predominant water temperature range found in model scenarios (55°F to 60°F), proportional daily mortality increases over ten-fold (~0.001 at 55°F to ~0.018 at 60°F).

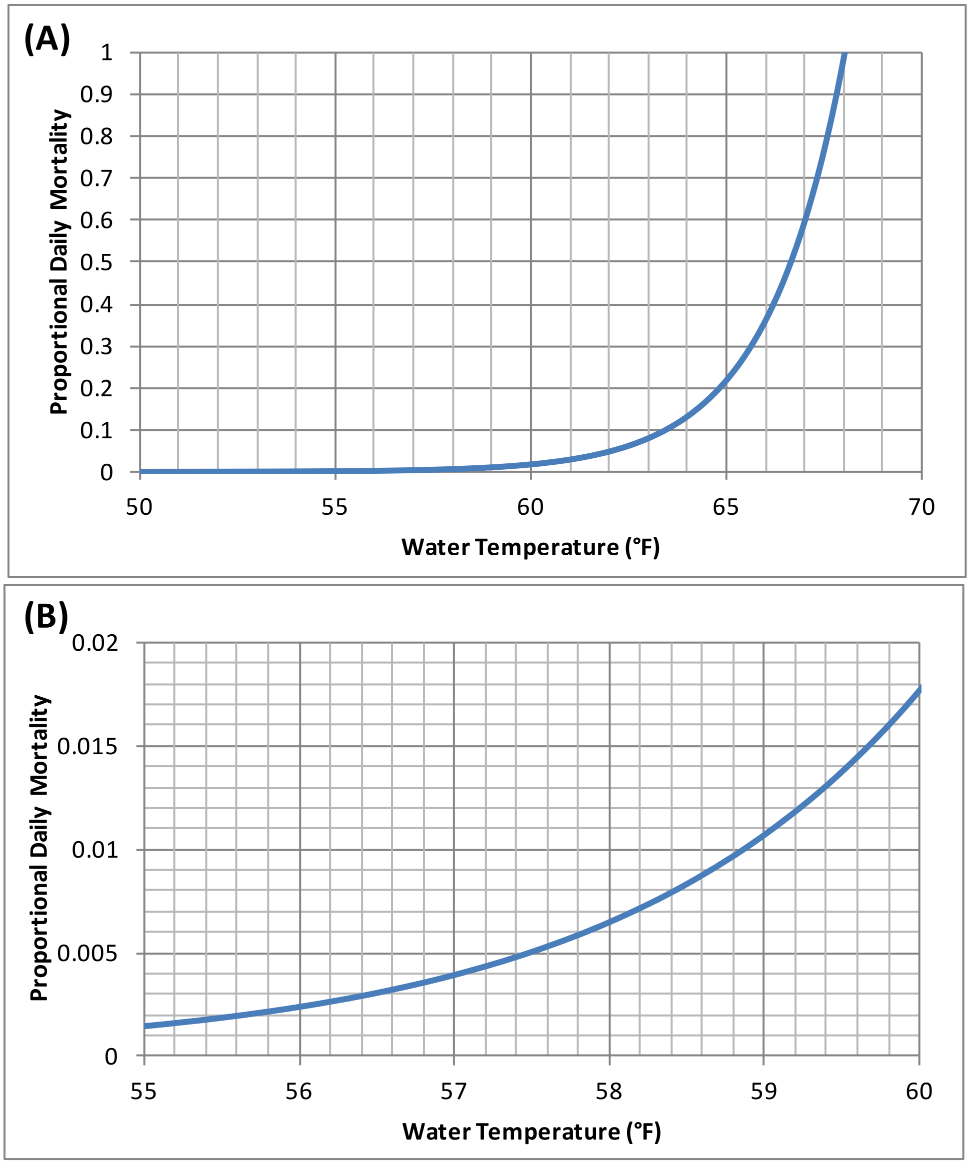



**Figure 5.D-136. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Eggs and Water Temperature (Equation 7) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios**

In the IOS Model, mean daily mortality rates of the incubating eggs are predicted from daily water temperatures measured at Bend Bridge on the Sacramento River using the exponential function above. The predicted mean mortality rate, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily egg mortality rate.

#### *5.D.3.1.1.3 Fry Rearing*

Data from USFWS (1999) was used to model fry mortality during rearing as a function of water temperature. Again, because of a limited sample size from the study by USFWS, statistical analyses to test for the effects of water temperature on rearing mortality could not be run. However, to acquire predicted values for the model, the following exponential relationship was fitted between observed daily mortality and observed water temperatures (U.S. Fish and Wildlife Service 1999):

(Equation 8) daily mortality = 3.92*10-12e (0.349*Temp)

Equation 8 yields the following graphic (Figure 5.D-137), which indicates that proportional daily fry mortality increases rapidly with only small changes in water temperature. For example, within the predominant water temperature range found in model scenarios (55°F to 60°F), proportional daily mortality increases over five-fold (~0.001 at 55°F to ~0.005 at 60°F). This indicates that, although fry mortality is highly sensitive to changes in water temperature, this sensitivity is not as great as that of egg mortality within the predominant range observed in the model scenarios in focus.

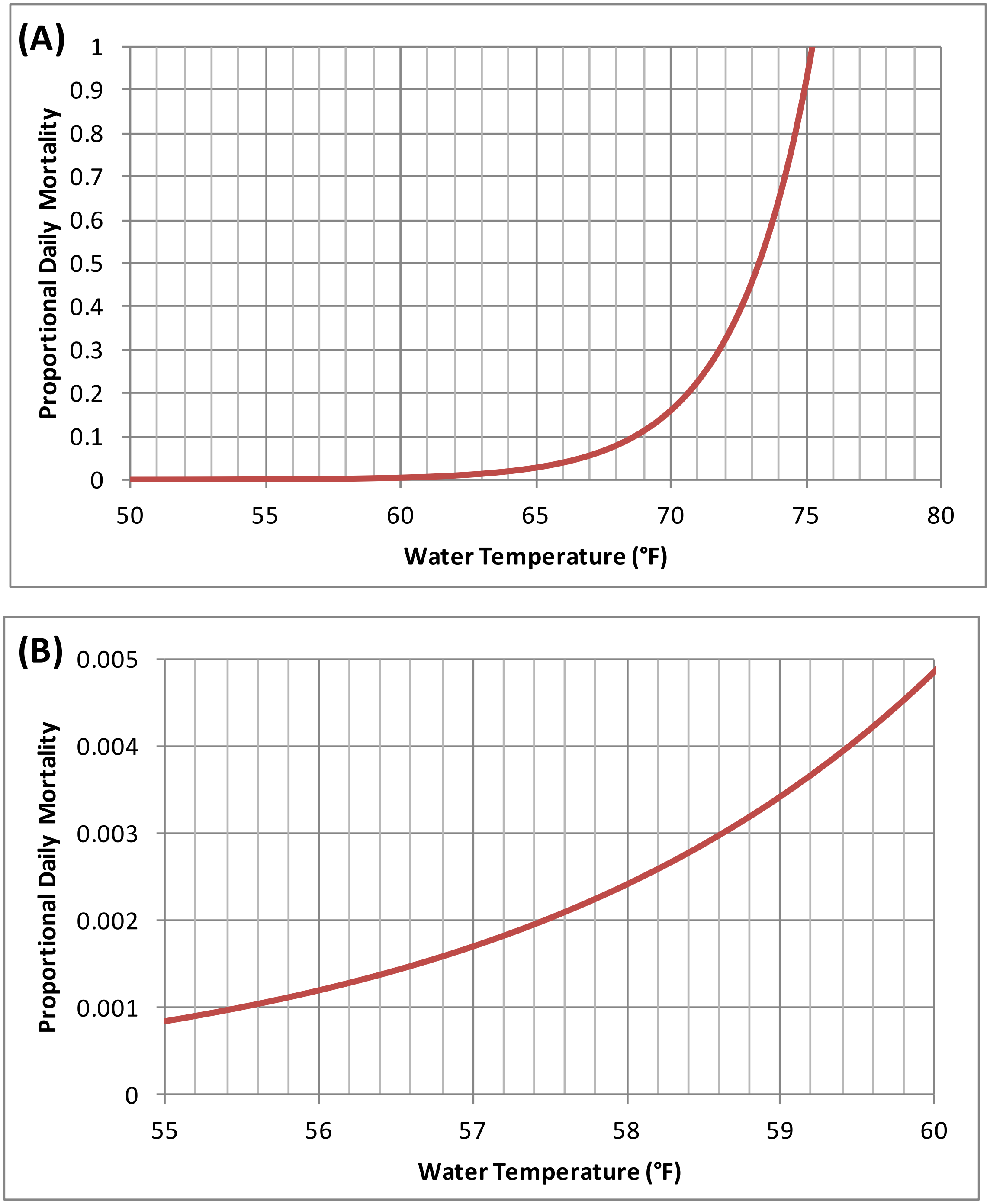



**Figure 5.D-137. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Fry and Water Temperature (Equation 8) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios**

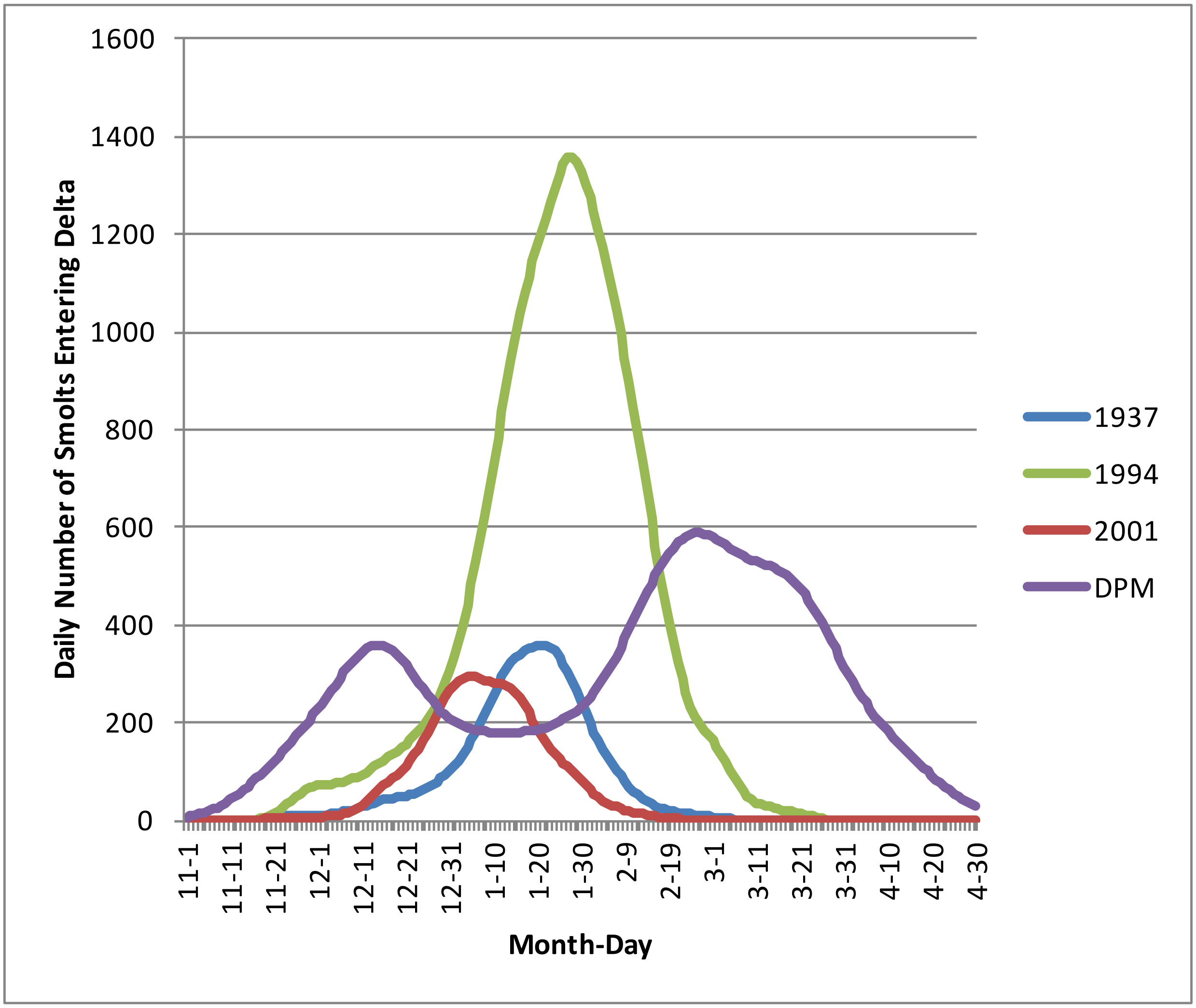
Each day the mean proportional mortality of the rearing fish is predicted from the daily water temperature using the above exponential relationship; the predicted mean mortality, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily mortality of the rearing fish. Temperature mortality is applied to rearing fry for 60 days, which is the approximate time required for fry to transition into smolts (U.S. Fish and Wildlife Service 1999) and enter the *River Migration* stage. All fish migrating through the Delta are assumed smolts.

##### *5.D.3.1.1.4 River Migration*

Survival of smolts from the spawning and rearing grounds to the Delta (city of Freeport on the Sacramento River) is a normally distributed random variable with a mean of 23.5% and a standard error of 1.7%. Mortality in this stage is applied only once in the model and occurs on the same day that a cohort of smolts enters the model stage because there were no data to support a relationship with flow or water temperature. Smolts are delayed from entering the next model stage to account for travel time. Mean travel time (20 days) is used along with the standard error (3.6 days) to define a normal probability distribution, which is randomly sampled to provide estimates of the total travel time of migrating smolts. Survival and travel time means and standard deviations were acquired from a study of late-fall run Chinook salmon smolt migration in the Sacramento River that employed acoustic tags and several monitoring stations (including Freeport) between Coleman National Fish Hatchery (Battle Creek) and the Golden Gate Bridge (Michel 2010).

##### *5.D.3.1.1.5 Delta Passage*

Winter-run Chinook salmon passage through the Delta within IOS is modeled with the DPM, which is described fully in Section 5.D.1.2.2, *Delta Passage Model*. Note that there is one difference between the implementation of the DPM in IOS and the standalone DPM as presented in Section 5.D.1.2.2. The timing of winter-run entry into the Delta is a function of upstream fry/egg rearing and so timing changes annually, in contrast to the fixed nature of Delta entry for the standalone DPM. Also, the IOS entry distribution is a unimodal term that tends to peak between the bimodal peaks of the standalone DPM entry distribution (Figure 5.D-138). As each cohort of smolts exits the final reaches of the Delta (Sac4 and the interior Delta), the cohorts accumulate until all cohorts from that year have exited the Delta. After all cohorts have arrived, they all enter the *Ocean Survival* model as a single cohort and the model begins applying mortality on an annual time step.




DPM: purple line, fixed bimodal distribution.
IOS in 1937: blue line, an average peak of January 21.
IOS in 1994: green line, a late peak of January 28.
IOS in 2001: red line, an early peak of January 4.
IOS data are from scenario ALT9_LLT of the BDCP EIR/EIS.

**Figure 5.D-138. Winter-Run Chinook Salmon Smolt Delta Entry Distributions Assumed under the Delta Passage Model Compared with Entry Distributions for IOS in 1937, 1994, and 2001**

### *5.D.3.1.1.6 Ocean Survival*

As described by Zeug et al. (2012), this model stage uses a set of equations for smolt-to-age-2 mortality, winter mortality, ocean harvest, and spawning returns to predict yearly survival and escapement numbers (i.e., individuals exiting the ocean to spawn). Certain values during the ocean survival life stage were fixed constant among model scenarios. Ocean survival model-stage elements are listed in Table 5.D-187 and discussed below.

**Table 5.D-187. Functions and Environmental Variables Used in the Ocean Survival Stage of the IOS Model**

| Model Element | Environmental Variable | Value |
|---|---|---|
| Smolt-age 2 mortality | None | Uniform random variable between 94% and 98% |
| Age 2 ocean survival | Wells' Index of Ocean productivity | Equation 13 |
| Age 3 ocean survival | None | Equation 14 |
| Age 4 ocean survival | None | Equation 15 |
| Age 3 harvest | None | Fixed at 17.5% |
| Age 4 harvest | None | Fixed at 45% |

Relying on ocean harvest, mortality, and returning spawner data from Grover et al. (2004), a uniformly distributed random variable between 94% and 98% mortality was applied for winter-run Chinook salmon from ocean entry to age 2 and functional relationships were developed to predict ocean survival and returning spawners for age 2 (8%), age 3 (88%), and age 4 (4%), assuming that 100% of individuals that survive to age 4 return for spawning. In the IOS Model, ocean survival to age 2 is given by:

(Equation 13) $A_2 = A_i(1\text{-}M_2)(1\text{-}M_w)(1\text{-}H_2)(1\text{-}S_{r2})*W$

Survival to age 3 is given by:

(Equation 14) $A_3 = A_2(1\text{-}M_w)(1\text{-}H3)(1\text{-}S_{r3})$

And survival to age 4 is given by:

(Equation 15) $A_4 = A_3(1\text{-}M_w)(1\text{-}H_4)$

where $A_i$ is initial abundance at ocean entry (from the DPM stage), $A_{2,3,4}$ are abundances at ages 2–4, $H_{2,3,4}$ are harvest percentages at ages 3–4 represented by uniform distributions bounded by historical harvest levels, $M_2$ is smolt-to-age-2 mortality, $M_w$ is winter mortality for ages 2–4, and $S_{r2,r3}$ are returning spawner percentages at age 2 and age 3.

Harvest mortality is represented by a uniform distribution that is bounded by historical levels of harvest. Age 2 survival is multiplied by a scalar $W$ that corresponds to the value of Wells Index of ocean productivity. This metric was shown to significantly influence over-winter survival of age 2 fish (Wells et al. 2007). The value of Wells Index is a normally distributed random variable that is resampled each year of the simulation. In the analysis, the following values from Grover et al. (2004) were used: $H_2$ = 0%, $H_3$ = 0-39%, $H_4$ = 0-74%, $M_2$ = 94-98%, $M_w$ = 20%, $S_{r2}$ = 8%, and $S_{r3}$ = 96%.

Adult fish designated for return to the spawning grounds are assumed 65% female and are assigned a pre-spawn mortality of 5% to determine the final number of female returning spawners (Snider et al. 2001).

### *5.D.3.1.2 Time Step*

The IOS Model operates on a daily time step, advancing the age of each cohort/life stage and thus tracking their numerical fate throughout the different stages of the life cycle. Some variables (e.g., annual mortality estimates) are randomly sampled from a distribution of values and are applied once per year. In addition, for the ocean phase of the life cycle, the model operates on an annual time step by applying annual survival estimates to each ocean cohort.

### *5.D.3.1.3 Model Inputs*

Delta flows and export flow into SWP and CVP pumping plants were modeled using the DSM2-HYDRO data described for the Delta Passage Model in Section 5.D.1.2.2, *Delta Passage Model*. Flows into the Yolo Bypass over Fremont Weir were based on disaggregated monthly CALSIM II data based on historical patterns of variability. Temperature data for the Sacramento River were obtained from the SRWQM developed by the Bureau of Reclamation (Reclamation) and were used to provide a weighted mean temperature of Keswick (river km 302) and Balls Ferry (river km 276) temperature based on spawning distribution (Figure 5.D-139).

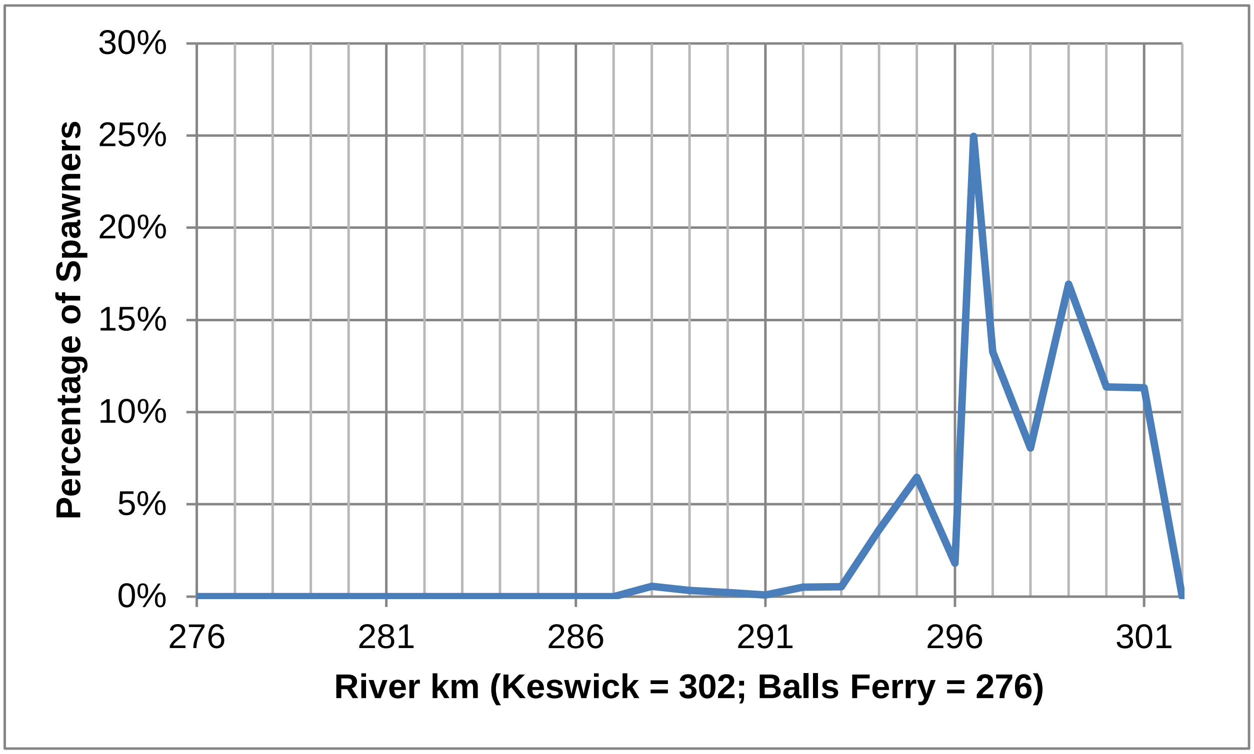



**Figure 5.D-139. Mean Spawning Distribution of Winter-Run Chinook Salmon From 2010-2012 Surveys, Used to Weight SRWQM Keswick and Balls Ferry Water Temperatures Outputs for Input into IOS.**

### *5.D.3.1.4 Model Outputs*

Four model outputs were used to determine differences among model scenarios.

1. Egg survival: The Sacramento River between Keswick Dam and the Red Bluff Diversion Dam provides egg incubation habitat for winter-run Chinook salmon. Water temperature has a large effect on the survival of Chinook salmon during the egg incubation period by controlling mortality as well as development rate. Temperatures in this reach are partially

controlled by releases of cold water from Shasta Reservoir and ambient weather conditions.

2. Fry survival: The Sacramento River between Keswick Dam and Red Bluff Diversion Dam provides rearing habitat for juvenile winter-run Chinook salmon. Water temperature can have a large effect on the survival of Chinook salmon during the fry rearing stage by controlling mortality and development rate. Temperatures in this reach are partially controlled by releases of cold water from Shasta Reservoir and ambient weather conditions.

3. Through-Delta survival: The Delta between the Fremont Weir on the Sacramento River and Chipps Island is a migration route for juvenile winter-run Chinook salmon. Flow magnitude in different reaches of the Delta influences survival and travel time through the Delta and entrainment into alternative migration routes. Fish entering the interior Delta via the Geo/DCC reach are potentially exposed to mortality from water exports in the interior Delta.

4. Escapement: Each year of the IOS Model simulation, escapement is calculated as the combined number of 2-, 3-, and 4-year-old fish that leave the ocean and migrate back into the Sacramento River to spawn between Keswick Dam and the Red Bluff Diversion Dam. These numbers are influenced by the combination of all previous life stages and the functional relationships between environmental variables and survival rates. Only the 1926–2002 water years were considered because the first four years of the CALSIM modeling (1922–1925) were used to seed the model and had fixed numbers of spawners assumed, as described above.

#### *5.D.3.1.5 Randomization to Illustrate Uncertainty*

As described previously for the DPM (Section 5.D.1.2.2, *Delta Passage Model*), various IOS model functions incorporate uncertainty in relationships between fish response and physical parameters, e.g., survival in response to river flow for some reaches within the DPM; re-sampling from these relationships on each modeled day allows this uncertainty to be captured in the model effects. In order to illustrate the uncertainty in modeled annual estimates of IOS outputs (egg survival, fry survival, through-Delta survival, and escapement), 75 iterations of IOS were run, each with different randomizations of the model functions. As noted for the DPM, 75 iterations were sufficient to allow the error in the estimates to stabilize so that no additional iterations were required. The 75 iterations gave 75 estimates of the IOS outputs for each year in the simulation period, from which 95% confidence intervals (the 2.5$^{th}$ and 97.5$^{th}$ percentiles of the 75 iterations) were calculated for each annual estimate. This allowed comparison of the number of years that the confidence intervals overlapped for the NAA and PA scenarios.

#### *5.D.3.1.6 Model Limitations and Assumptions*

The following model limitations and assumptions should be recognized when interpreting results.

1. The model focuses only on flow-related operational effects (river flow, exports, and water temperature) and does not consider other potential PA effects (e.g., near-field

predation at the NDD) or the effects of conservation measures (e.g., nonphysical barriers).

2. Other important ecological relationships likely exist but quantitative relationships are not available for integration into IOS (e.g., the interaction among flow, turbidity, and predation). To the extent that these unrepresented relationships are important and alter IOS outcomes, each alternative considered is assumed to be affected in the same way.

3. For relationships that are represented in IOS, the operational alternatives considered are not assumed to alter those underlying functional relationships.

4. There is a specific range of environmental conditions (temperature, flow, exports, and ocean productivity) under which functional relationships were derived. These functional relationships are assumed to hold true for the environmental conditions in the scenarios considered.

5. Differential growth because of different environmental conditions (e.g., river temperature) and subsequent potential differences in survival and other factors are not directly included in the model. Differences in survival related to growth are indirectly included to an unknown extent in flow-survival, temperature-survival, and ocean productivity-survival relationships.

6. Survival and travel time during Stages 4 (River Migration) and 5 (Delta Passage) are based on studies of yearling late fall–run Chinook salmon (c. 150–170-mm fork length) (Stage 4: Michel 2010; Stage 5: Perry et al. 2010), which are appreciably larger than downstream-migrating winter-run Chinook salmon (c. 70–100-mm fork length during the peak downstream migration) (Williams 2006:101); however, differences between model scenarios do not occur during stage 4 because survival and travel time during River Migration are independent of flow.

7. Juvenile winter-run Chinook salmon migrating through the Delta all are assumed smolts that are not rearing in the Delta.

8. Between Stage 5 (Delta Passage) and Stage 1 (Spawning), the only differences in survival between model scenarios comes from random differences based on probability distributions, although some functions have been fixed at constant values to minimize these random differences. There are no modeled flow effects on adult upstream migration (e.g., attraction flows) because there are no data available for such effects to be modeled.

#### *5.D.3.1.7 Model Sensitivity and Influence of Environmental Variables*

Zeug et al. (2012) examined the sensitivity of the IOS model estimates of escapement to its input parameter values, input parameters being the functional relationships between environmental inputs and biological outputs. Although revisions have been undertaken to IOS since that time, the main points from their analysis are still likely to be valid.

Zeug et al. (2012) found that escapement of different age classes was sensitive to different input parameters (Table 5.D-188). Escapement of age-2 fish (which compose 8% of the total returning fish in a given cohort) was most sensitive to smolt-to-age-2-survival and water year when considering either independent or interactive effects of these parameters, and there was sensitivity to river migration survival when considering interactive effects of this parameter with other parameters. Escapement of age-3 fish (which compose 88% of the total returning fish in a given cohort) was sensitive to several input parameters when considering the independent effects of these parameters but was sensitive to through-Delta survival alone when considering first-order interactions between parameters. Escapement of age-4 fish (which compose 4% of the total returning fish in a given cohort) was sensitive to nearly all input parameters when considering the independent effects of these parameters, but was not sensitive to any of the parameters when considering first-order interactions between parameters (Zeug et al. 2012).

Zeug et al. (2012) also explored how uncertainty in model parameter estimates influences model output by increasing by 10–50% the variation around the mean of selected parameters that could be addressed by management actions (egg survival, fry-to-smolt survival, river migration survival, Delta survival, age-3 harvest, and age-4 harvest). They found that model output was robust to parameter uncertainty and that age-3 and age-4 harvest had the greatest coefficients of variation because of the uniform distribution of these parameters. Zeug et al. (2012) noted that there are limitations in the data used to inform certain parameters in the model that may be ecologically relevant but that are not sensitive in the current IOS configuration: river survival is a good example because it is based on a three-year field study of relatively low-flow conditions that does not cover the range of potential conditions that may be experienced by downstream-migrating juvenile Chinook salmon.

To understand the influence of environmental parameter inputs on escapement estimates from IOS, Zeug et al. (2012) performed three sets of simulations of a baseline condition and either a 10% increase or a 10% decrease in river flow, exports, water temperature (on the Sacramento River at Bend Bridge, as in the original formulation of the model), and ocean productivity (i.e., Wells Index; see above). They found that only 10% changes in temperature produced a statistically significant change in escapement; a 10% increase in temperature produced a far greater reduction in escapement (>95%) than a 10% decrease in temperature gave an increase in escapement (>10%). Zeug et al. (2012) suggested that the lack of significant changes in escapement with 10% changes of flow, exports, and ocean productivity may reflect the fact that these variables' relationships within the model were based on observational studies with large error estimates associated with the responses. In contrast, temperature functions were parameterized with data from controlled experiments with small error estimates. Also, Zeug et al. (2012) noted that water temperatures within the winter-run Chinook salmon spawning and rearing area are close to the upper tolerance limit for the species; therefore, even small changes have the potential to significantly affect the population.

**Table 5.D-188. Sobol' Sensitivity Indices (Standard Deviation in Parentheses) for Each Age Class of Returning Spawners Based on 1,000 Monte Carlo Iterations, Conducted to Test Sensitivity of IOS Input Parameters by Zeug et al. (2012)**

| Input Parameter | Age 2 | | Age 3 | | Age 4 | |
|---|---|---|---|---|---|---|
| | Main Index (Effect Independent of Other Input Parameters) | Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters) | Main Index (Effect Independent of Other Input Parameters) | Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters) | Main Index (Effect Independent of Other Input Parameters) | Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters) |
| Water year | 0.300[a] (0.083) | 0.306[a] (0.079) | 0.181[a] (0.091) | 0.150 (0.091) | 0.073 (0.067) | 0.012 (0.065) |
| Egg survival | 0.030 (0.016) | -0.006 (0.016) | 0.222[a] (0.081) | -0.021 (0.081) | 0.102[a] (0.044) | -0.072 (0.044) |
| Fry-to-smolt survival | 0.039 (0.020) | -0.009 (0.020) | 0.166 (0.090) | 0.091 (0.092) | 0.079a (0.017) | -0.071 (0.017) |
| River migration survival | 0.007 (0.034) | 0.135a (0.034) | 0.164 (0.084) | 0.062 (0.085) | 0.079 (0.018) | -0.07 (0.018) |
| Delta survival | 0.010[a] (0.002) | -0.009 (0.002) | 0.404[a] (0.180) | 0.643[a] (0.177) | 0.313[a] (0.134) | -0.009 (0.132) |
| Smolt to age 2 survival | 0.734[a] (0.118) | 0.454[a] (0.113) | 0.015 (0.016) | -0.006 (0.016) | 0.057a (0.017) | -0.052 (0.017) |
| Ocean productivity | 0.003 (0.009) | 0.009 (0.009) | 0.034[a] (0.015) | -0.034 (0.015) | 0.061[a] (0.030) | -0.048 (0.029) |
| Age 3 harvest | N/A | N/A | 0.029[a] (0.001) | -0.028 (0.001) | 1.48[a] (0.306) | 0.188 (0.293) |
| Age 4 harvest | N/A | N/A | N/A | N/A | 0.055a (0.003) | -0.054 (0.003) |

Source: Zeug et al. 2012.
[a] Index value was statistically significant at α=0.05.

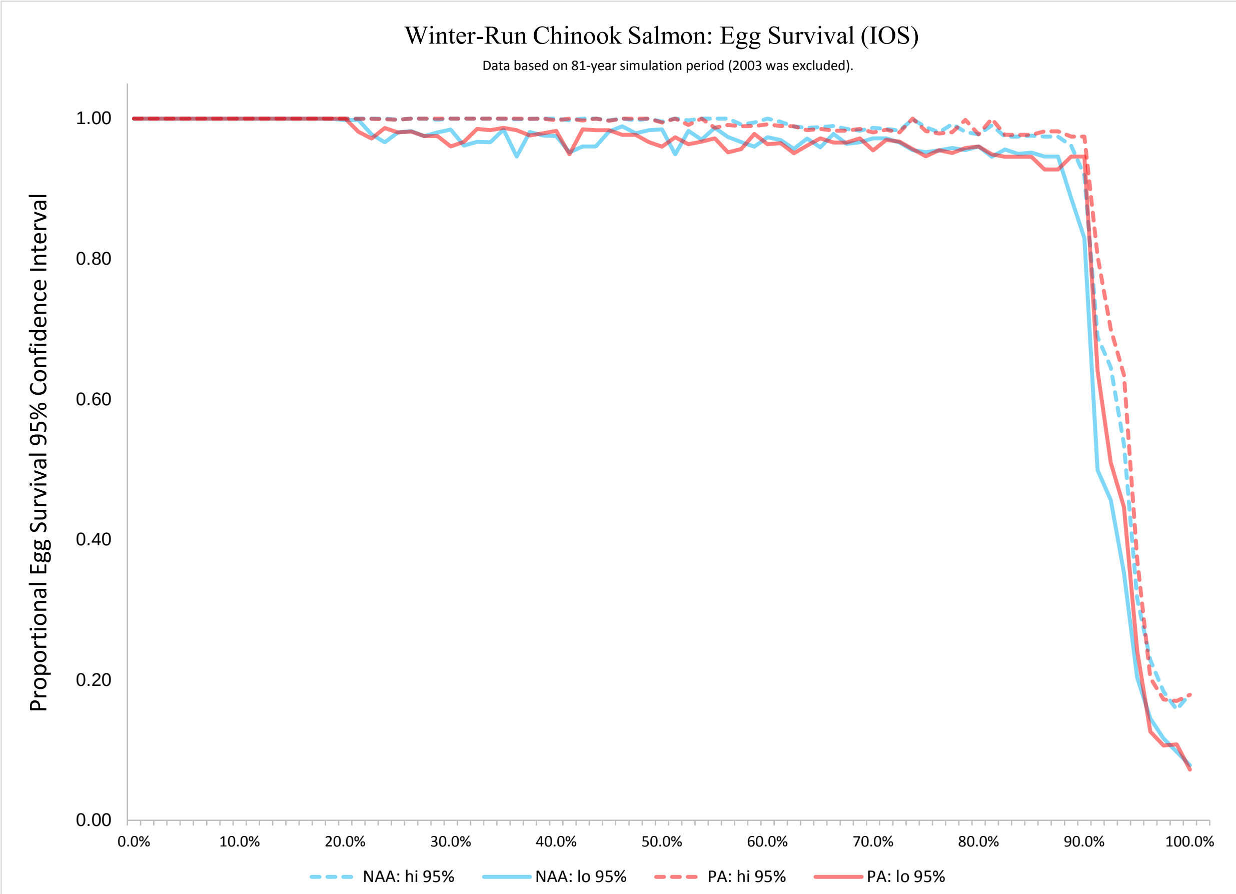
### *5.D.3.1.8 Results*

As with other quantitative analyses conducted for the effects analysis, it is important to bear in mind that IOS provides inference for future conditions on a relative basis. That is, the predictions are not expected to be accurate in an absolute sense, but do provide important information when evaluating scenarios relative to each other.

#### *5.D.3.1.8.1 Egg Survival*

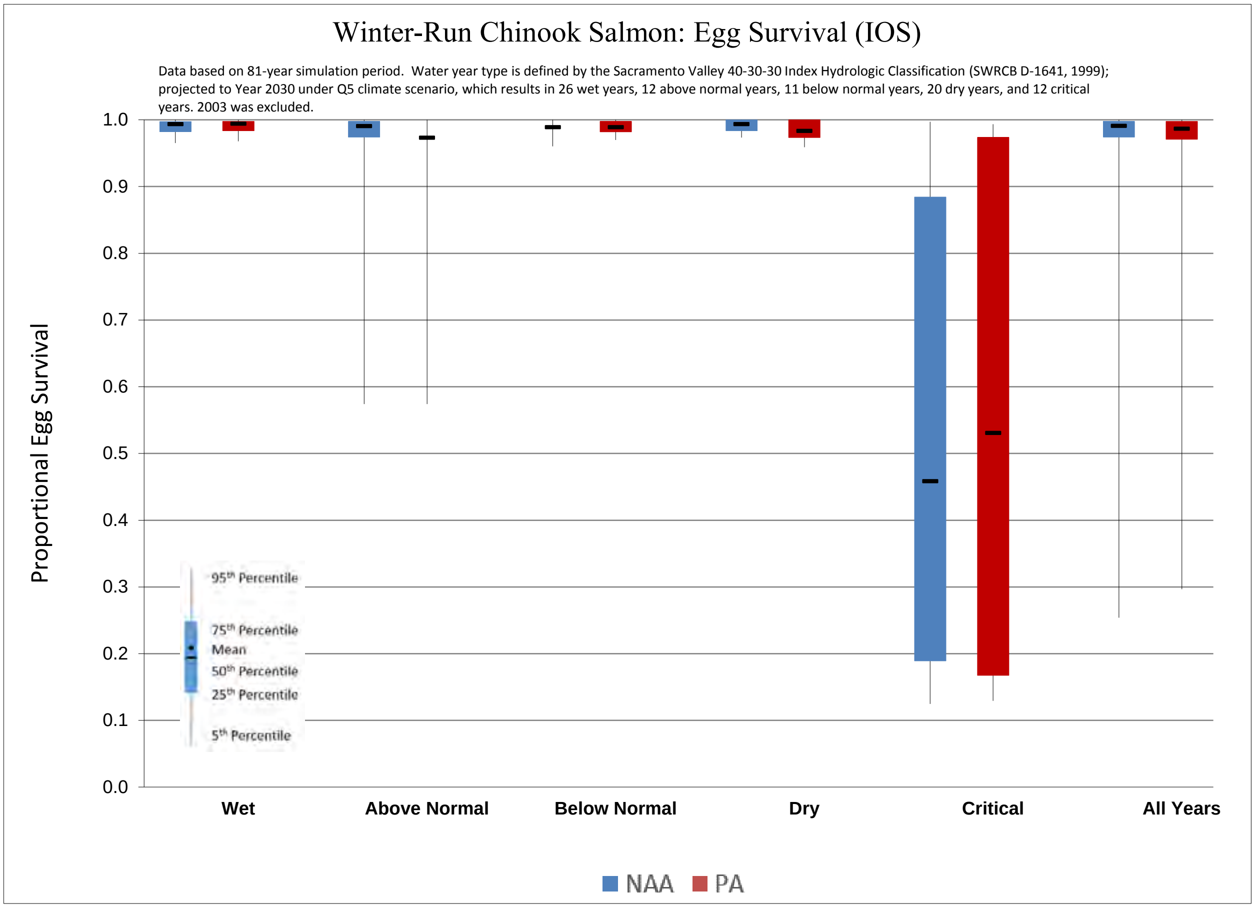
The IOS model predicted very similar egg survival for winter-Run Chinook salmon between the NAA and PA (Figure 5.D-140 and Figure 5.D-141). NAA median egg survival was 0.990 and PA median egg survival was 0.991 (Figure 5.D-140). In 12 of the 81 years simulated, the 95% confidence intervals of the annual estimates did not overlap for NAA and PA; of these, egg survival under PA was greater than NAA in 6 years and less than PA in 6 years (Figure

5.D-142). This illustrates that while there was variability between years, the overall pattern in egg survival was very similar between NAA and PA.




Note: Data are sorted by mean estimate, with only 95% confidence intervals shown.

**Figure 5.D-140. Exceedance Plots of Annual egg survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**




Note: Plot only includes annual mean responses and does not consider model uncertainty.

**Figure 5.D-141. Box Plots of Annual egg survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**

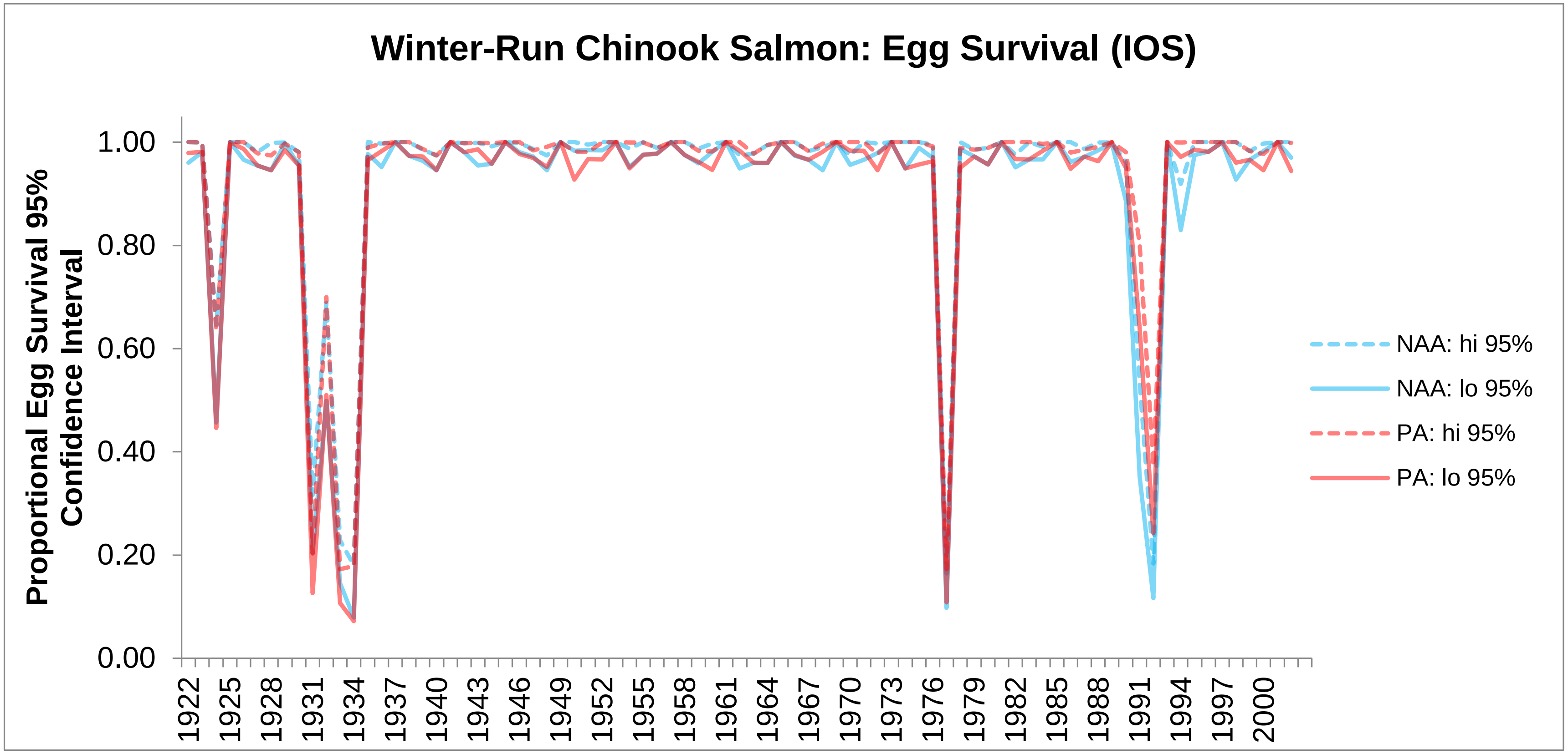
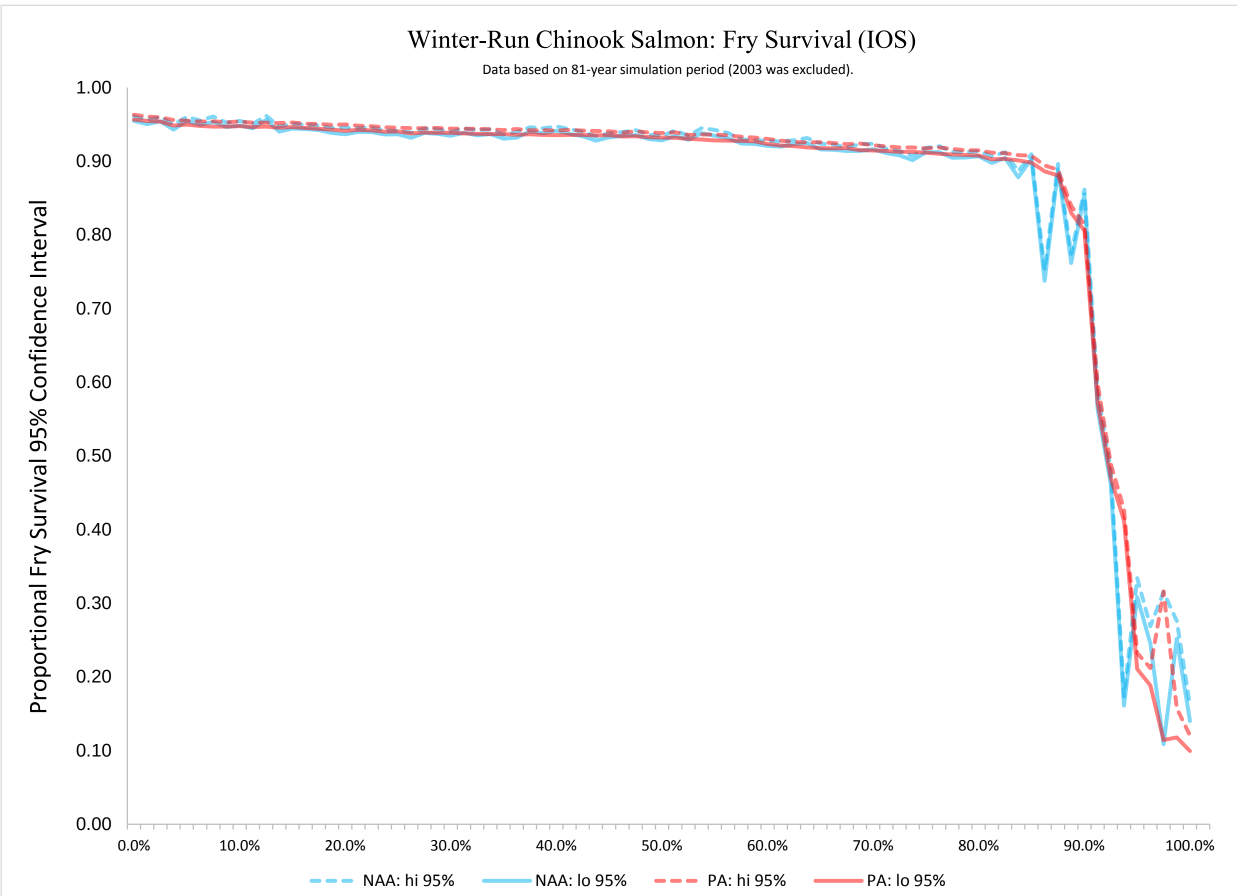



**Figure 5.D-142. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Egg Survival Estimates.**

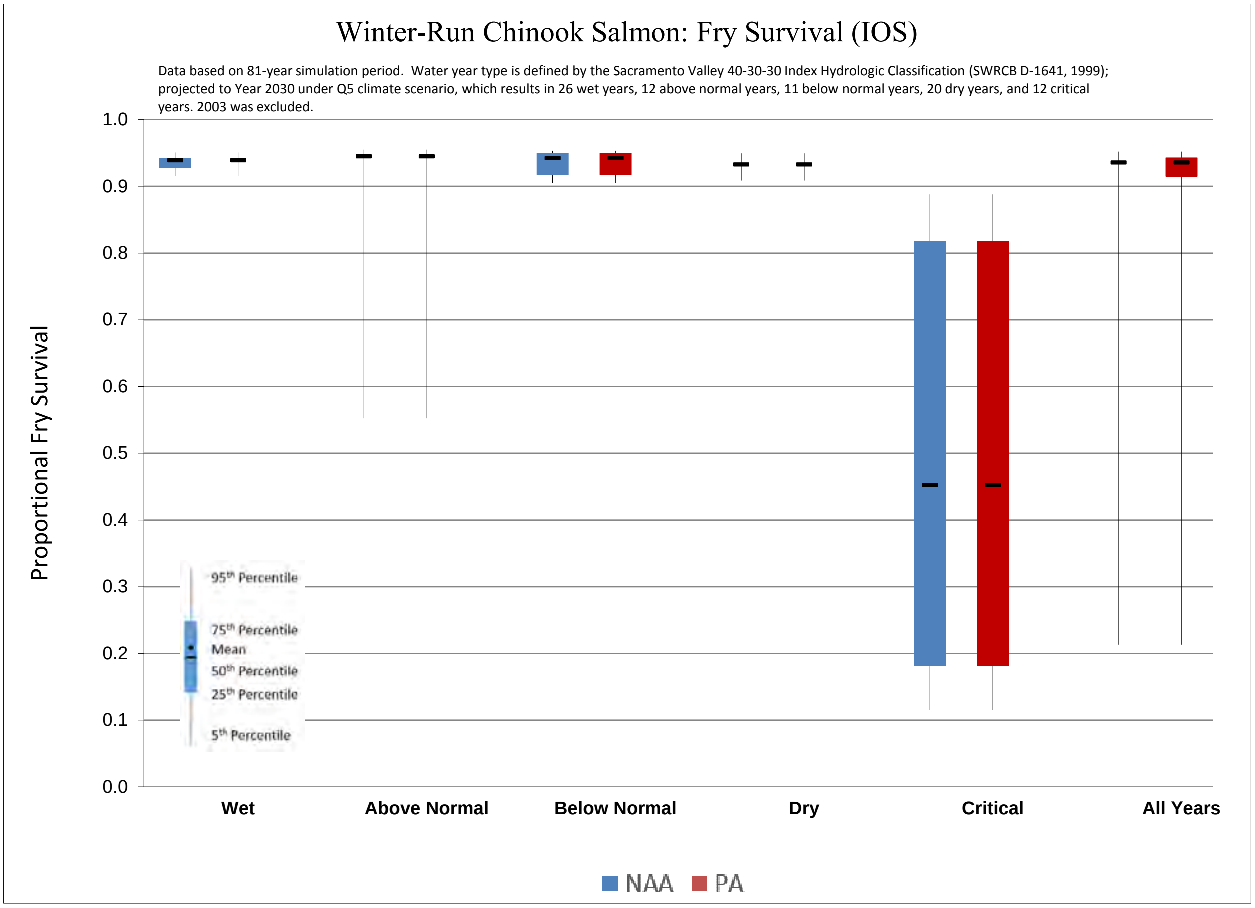
### *5.D.3.1.8.2 Fry Survival*

The IOS model predicted very similar egg survival for winter-Run Chinook salmon between the NAA and PA (Figure 5.D-140 and Figure 5.D-141). NAA median egg survival was 0.935 and PA median egg survival was 0.936. In 15 of the 81 years simulated, the 95% confidence intervals of the annual estimates did not overlap for NAA and PA; of these, fry survival under PA was greater than NAA in 8 years and less than PA in 7 years (Figure 5.D-145). As noted for egg survival, this illustrates that while there was variability between years, the overall pattern in fry survival was very similar between NAA and PA.




Note: Data are sorted by mean estimate, with only 95% confidence intervals shown.

**Figure 5.D-143. Exceedance Plots of Annual fry survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**




Note: Plot only includes annual mean responses and does not consider model uncertainty.

**Figure 5.D-144. Box Plots of Annual fry survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**

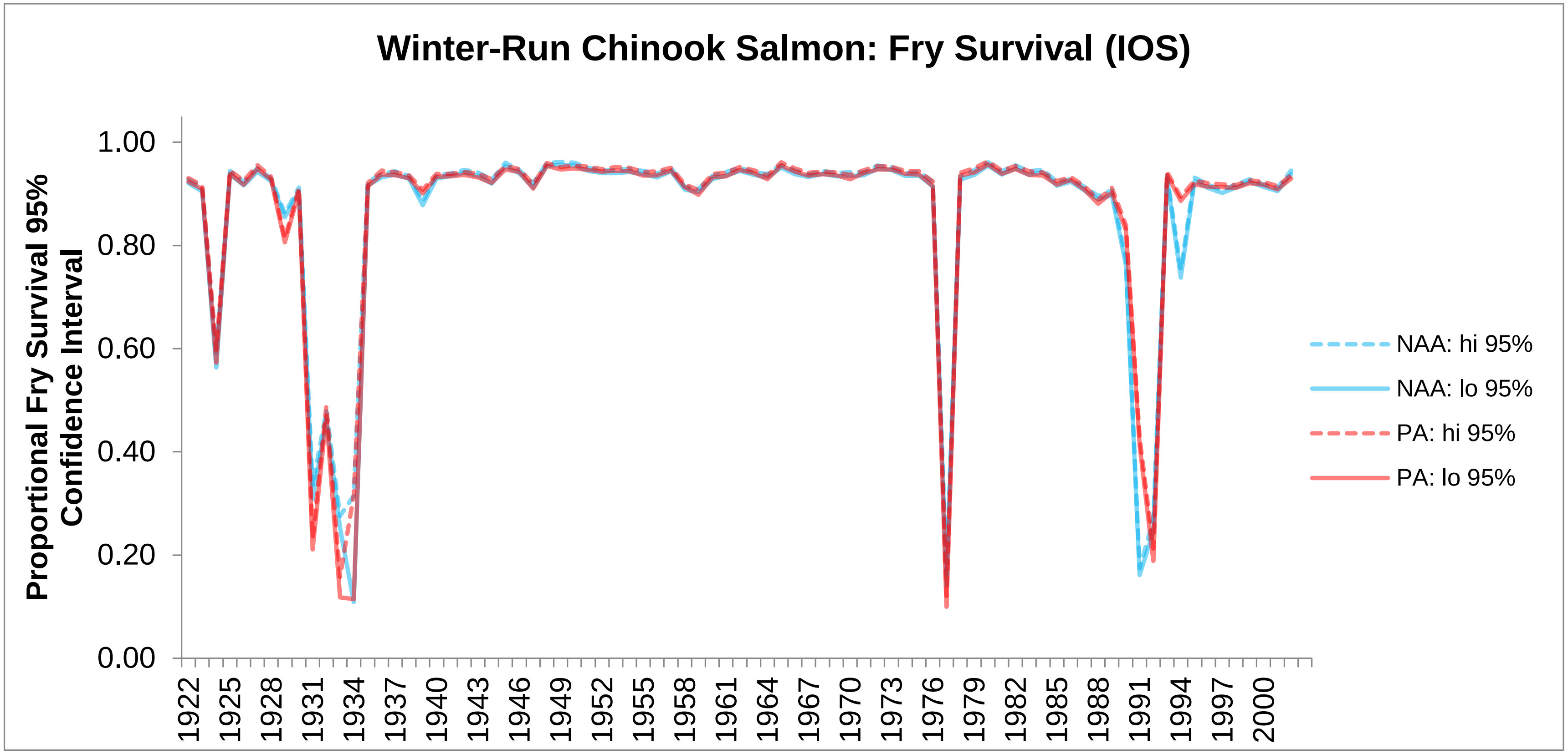
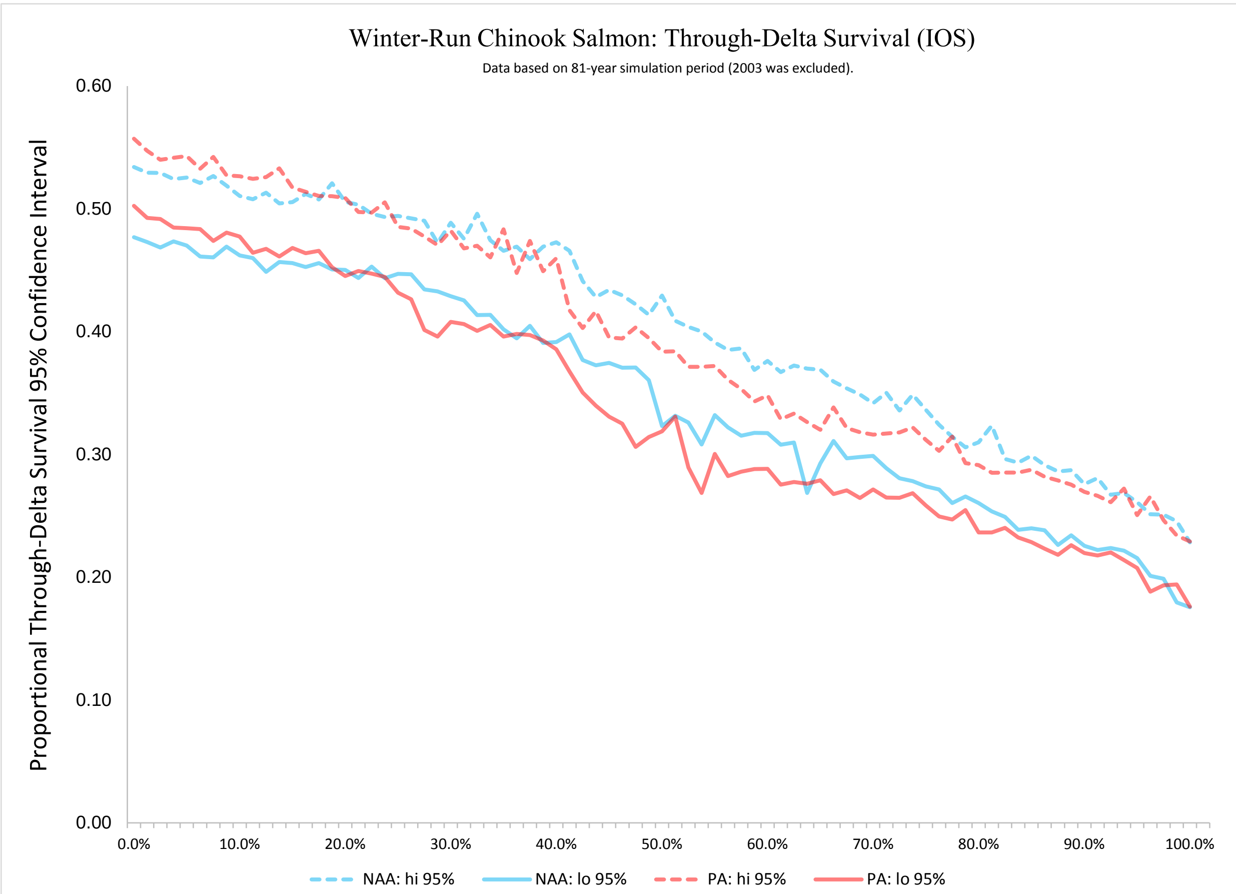



**Figure 5.D-145. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Fry Survival Estimates.**

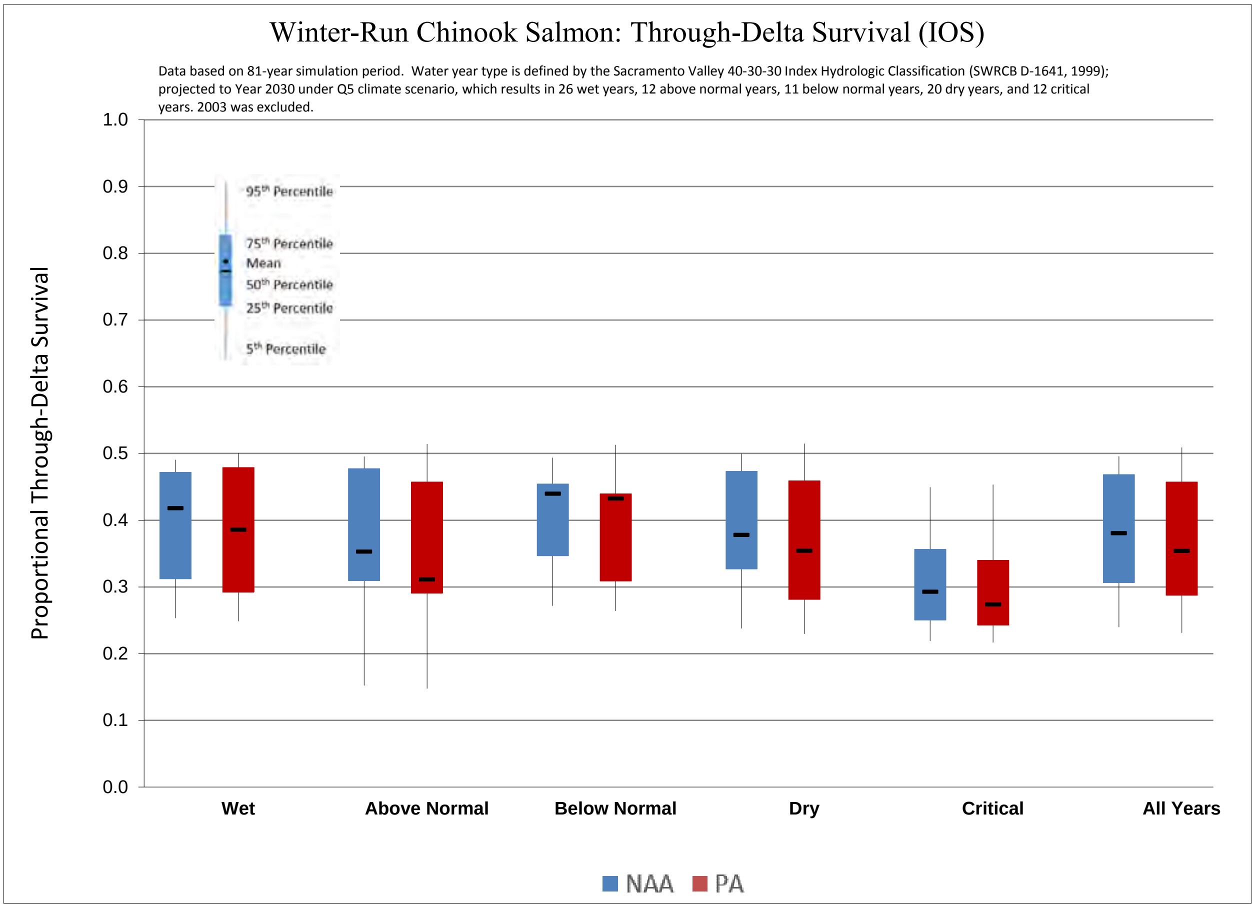
### 5.D.3.1.8.3 *Through-Delta Survival*

Across all water years, the IOS model's median predicted through-Delta survival was 0.380 for the NAA and 0.354 for the PA (Figure 5.D-146 and Figure 5.D-147), a difference of 7%. Across all years, the 25th percentile value of survival for the NAA was 0.306 and 0.287 for the PA while the 75th percentile value was 0.469 for the NAA and 0.457 for the PA. The minimum value for survival for the NAA was 0.200 and 0.200 for the PA and the maximum survival for the NAA was 0.504 and 0.527 for the PA. There was only one year in which the 95% confidence intervals of the annual through-Delta survival estimates did not overlap (2001); during this year, PA (95% CI: 0.265-0.318) was less than NAA (95% CI: 0.398-0.466) (Figure 5.D-148).




Note: Data are sorted by mean estimate, with only 95% confidence intervals shown.

**Figure 5.D-146. Exceedance Plots of Annual Through-Delta Survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**




Note: Plot only includes annual mean responses and does not consider model uncertainty.

**Figure 5.D-147. Box Plots of Annual Through-Delta Survival for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**

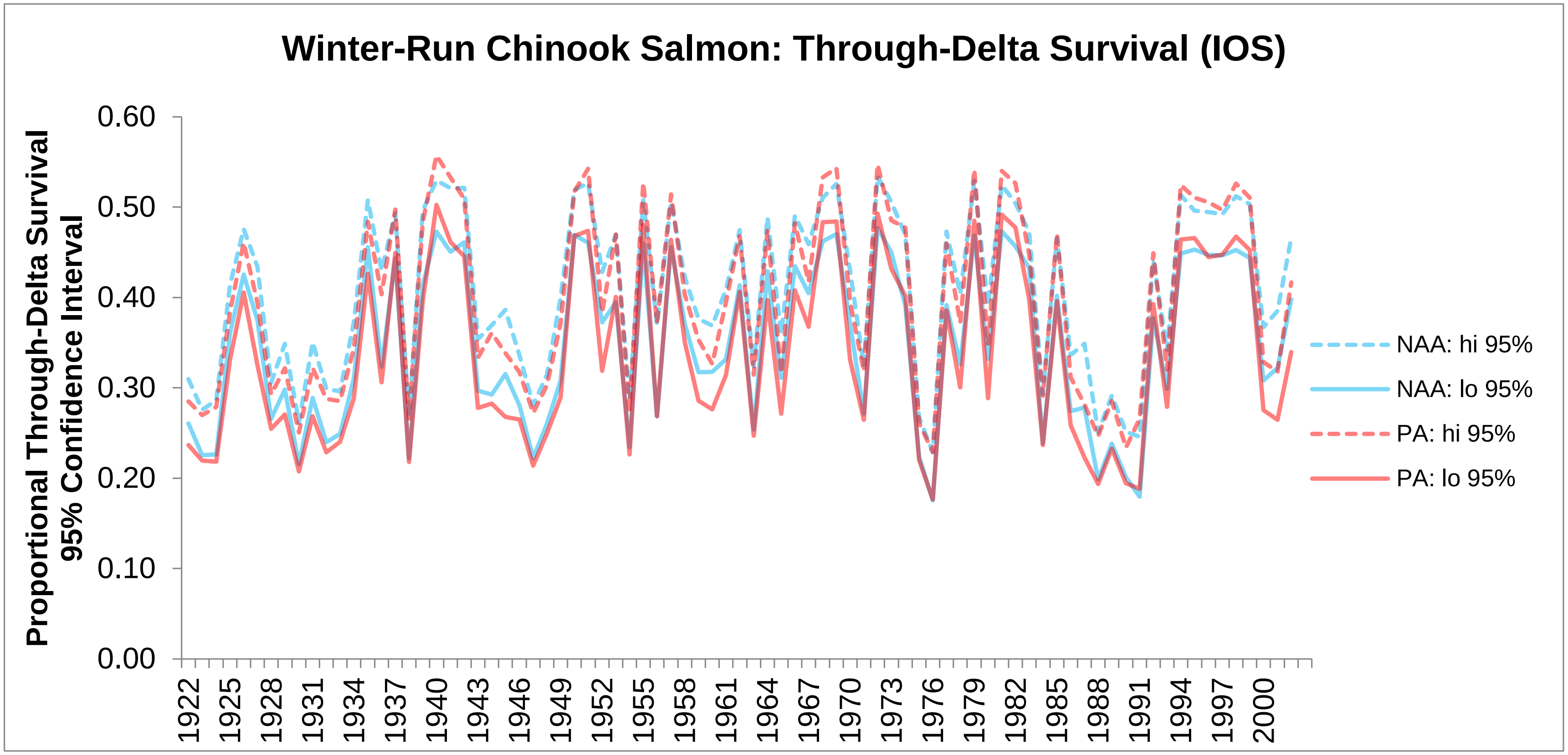


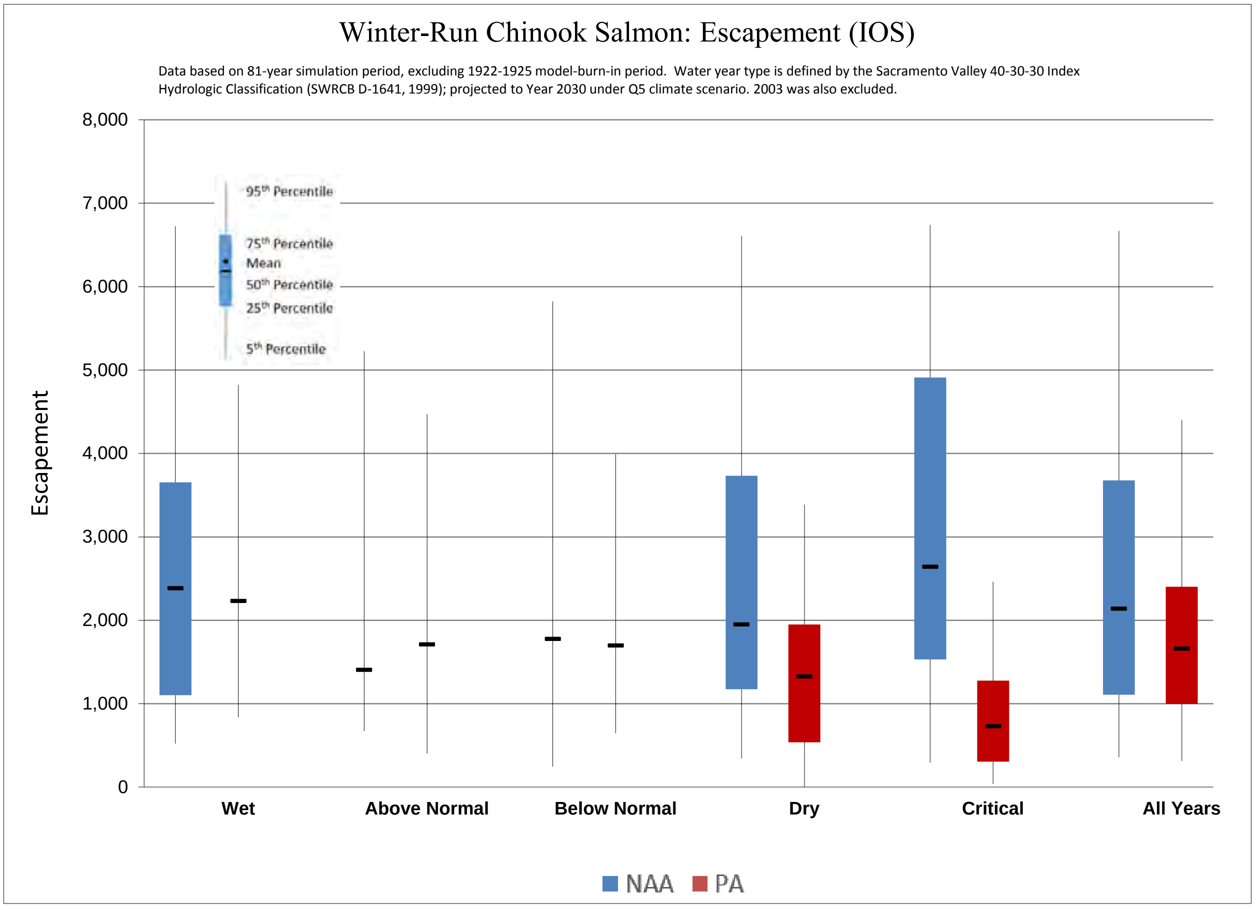

**Figure 5.D-148. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Through-Delta Survival Estimates.**

### *5.D.3.1.8.4 Escapement*

The IOS model predicted NAA median adult escapement of 2,274 and PA median escapement of 1,699, a difference of 25% (Figure 5.D-149 and Figure 5.D-150). The 25th percentile escapement for the NAA was 1,119 and 1,007 for the PA while the 75th percentile value was 3,651 for the NAA and 2,858 for the PA. The minimum value for escapement for the NAA was 45 and 18 for the PA and the maximum escapement for the NAA was 7,868 and 5,501 for the PA. The 95% confidence intervals for escapement under the NAA and PA overlapped in all years (Figure 5.D-151). The time series of escapement under PA and NAA increasingly diverged from each other from the early years of the simulation to the 1970s-1990s, before the differences decreased again and escapement was comparable from the mid-1990s onward. The relatively large differences in escapement in the 1970s-1990s were driven by the cumulative effect of differences in Delta survival over time; however, as the mean estimates grew larger, so did the confidence intervals, which were very wide in these years, e.g., in 1985: 838-28,350 for NAA, and 717-22,814 for PA (Figure 5.D-151).


Note: Data are sorted by mean estimate, with only 95% confidence intervals shown.

**Figure 5.D-149. Exceedance Plots of Annual Escapement for Winter-Run Chinook Salmon across all 81 water years estimated by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**




Note: Plot only includes annual mean responses and does not consider model uncertainty.

**Figure 5.D-150. Box Plots of Annual Escapement for Winter-Run Chinook Salmon by the IOS Model for the comparison between the NAA (NAA) and the PA (PA).**

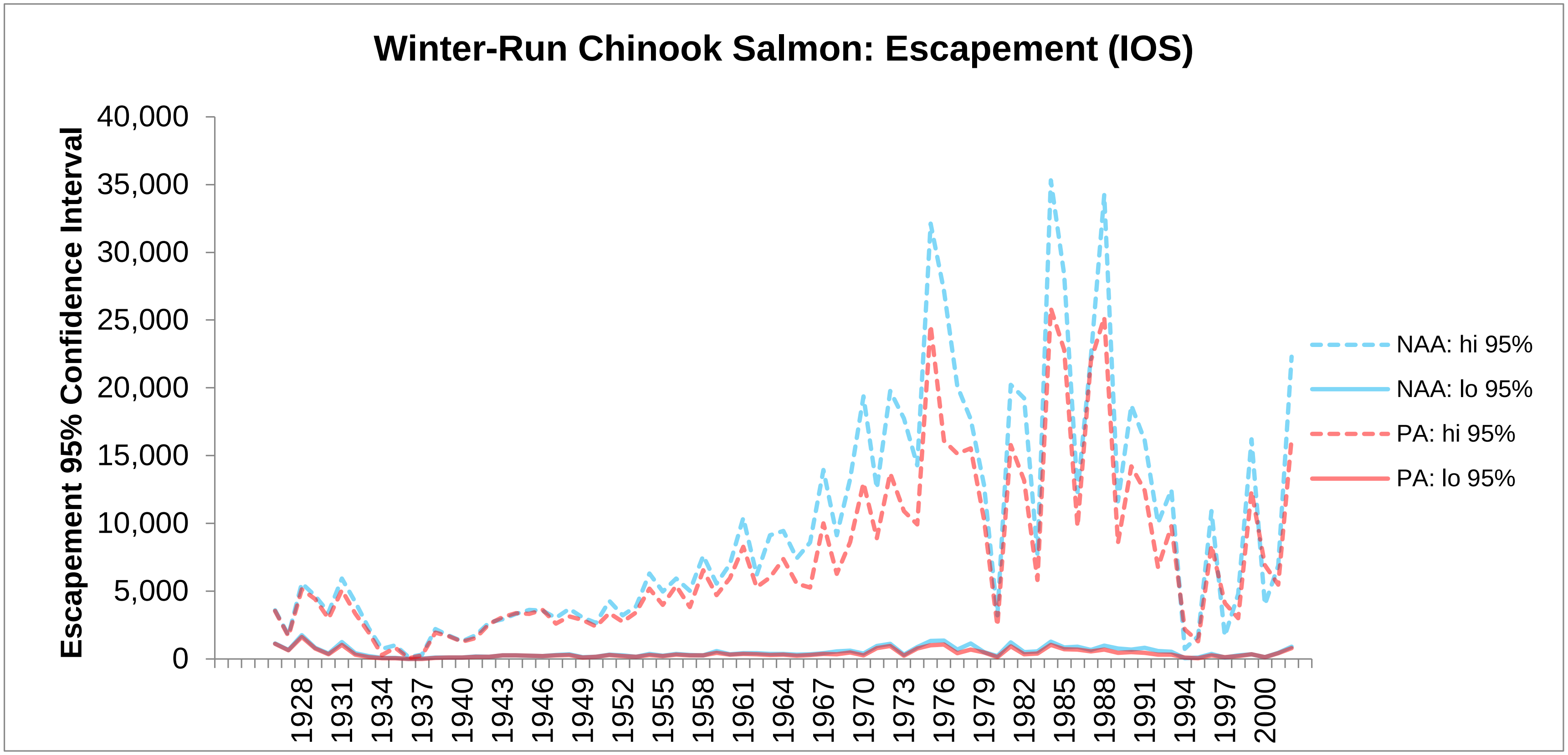



**Figure 5.D-151. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Escapement Estimates.**

##### *5.D.2.1.2.4 SALMOD*

The SALMOD model was used to evaluate flow- and temperature-related mortality of early life stages and overall production of spring- and winter-run Chinook salmon in the Sacramento River. Attachment 5.D-2, *SALMOD* Model, describes the details of the model and the results of the analysis described here.

There are two primary sources of mortality evaluated in SALMOD, water temperature-related and flow-related, both of which could affect multiple life stages. Water temperature-related mortality for the *Spawning, Egg incubation, and Alevins* section of the results included *pre-spawn* (in vivo, or in the mother before spawning) and *egg* (in the gravel) life stages (see Attachment 5.D-2, *SALMOD Model*, for full description). Water temperature-related mortality included in Chapter 5, Section 5.4.2.1.3.1.2, *Fry and Juvenile Rearing*, for winter-run Chinook salmon and Section 5.4.2.1.3.2.2, *Fry and Juvenile Rearing,* for spring-run Chinook salmon includes the fry, pre-smolt, and immature smolt life stages. For each source of mortality by life stage for the NAA and PA, results are presented as exceedance plots and mean annual values, as well as differences between NAA and PA. These results are presented by water year type and for all water year types combined. A 5% difference between NAA and PA in mean value of an output parameter was considered biologically meaningful. Each source of mortality was also combined to assess all flow- or water temperature-related mortality by life stage, as well as combined for all life stages to assess overall mortality under the PA compared to the NAA.

SALMOD calculates juvenile production each year as the cumulative survival of a predetermined set of eggs through the smolt life stage. There are several sources of mortality during these early life stages that varies based on flow and water temperature. SALMOD is not a true life cycle model because it treats production results of each year independently such that outcomes do not accumulate year over year.

For this effects analysis, overall juvenile production was assessed by water year type and for all water years combined and presented as exceedance plots and mean annual values. Production values were given a higher importance in this effects analysis because they integrate all early life stages and provide an overall assessment of effects to production as a whole.

In addition, the potential effect of the PA on the frequency of “worst case” juvenile production years was evaluated. The “worst case” was defined as years with juvenile production values that were <5% and <10% of potential egg values, which are based on the number of spawners defined by the SALMOD user (Table 5.D-53). These percentages were used because they can be considered catastrophic to an individual brood year, as was seen for the 2014 winter-run Chinook salmon brood year, in which there was an estimated 95% mortality (5% survival) associated with water temperature-related effects of the drought in the Sacramento River (Murillo 2015). The 5% survival was also doubled in an additional analysis of 10% survival to provide a more conservative worst-case scenario. For each race, the number of years during which juvenile production was lower than these worst-case scenarios was compared between NAA and PA.

**Table 5.D-53. Juvenile Production Values Used to Define Worst Case Scenarios for SALMOD.**

| Race | Potential Eggs[1] | 5% of Eggs | 10% of Eggs |
|---|---|---|---|
| Winter-run Chinook Salmon | 5,913,000 | 295,650 | 591,300 |
| Spring-run Chinook Salmon | 1,210,000 | 60,500 | 121,000 |

[1] These values are pre-defined in SALMOD

## 5.D.2.2 Spawning Flows Methods

### *5.D.2.2.1 Introduction*

This section describes procedures used in the effects analysis to evaluate flow-related effects resulting from the No Action Alternative (NAA) and Proposed Action (PA) on spawning and adult holding habitat of winter-run and spring-run Chinook salmon, California Central Valley (CCV) steelhead, and green sturgeon in the Sacramento and American Rivers. The specific potential effects evaluated are (1) flow reductions during the months of adult holding, (2) changes in flow affecting conditions during the months of spawning, egg incubation and alevin development, (3) reductions in the availability of suitable physical habitat for spawning, egg incubation, and alevin development, (4) reductions in flow resulting in dewatering of the redds, and (5) high flows resulting in redd scour or entombment.

Modeled flow results for key locations in the Sacramento and American Rivers are reported in Appendix 5A, *CALSIM Methods and Results*. Results in Appendix 5A are presented as (1) mean monthly exceedance plots, (2) box and whiskers plots, with mean, median, quartiles, and 25$^{th}$ and 75$^{th}$ percentile values indicated; and (3) a table of summary statistics and differences between NAA and PA for each statistic.

The availability of spawning habitat was estimated using weighted usable area (WUA) curves obtained from the literature (U.S. Fish and Wildlife Service 2003a, 2003b, 2006). WUA is an index of the surface area of physical habitat available, weighted by the suitability of that habitat. WUA curves are normally developed as part of instream flow incremental methodology (IFIM) studies.

Dewatering of redds occurs when the water level drops below the depth of the redds or drops low enough to produce depth and flow velocity conditions that are inadequate to sustain incubating eggs or alevins in the redds. The percentage of redds lost to dewatering in the Sacramento River was estimated using relationships developed by the USFWS (2006) between spawning habitat weighted usable area and changes in flow. Dewatering field data were not available for the

American River, so percentage reduction in flow was used as a proxy for percentage of redds dewatered.

Loss of redds to scouring or entombment occurs when flows are high enough to mobilize sediments, destroying redds and their incubating eggs and alevins, or entombing the redds when sediments are redeposited. Estimates of redd losses resulting from scouring flows in the Sacramento and American Rivers were based on estimates from various sources of the minimum flows required to mobilize sediments and the frequency of occurrence of those flows.

Details particular to each of the flow analysis methods implemented are provided below.

#### *5.D.2.2.2 Characterization of Flow*

Flow at key locations within the Sacramento and American Rivers, as simulated by CALSIM II modeling, was evaluated for each period that each life stage of winter-run or spring-run Chinook salmon, CCV steelhead, or green sturgeon is normally present. General flow patterns for each such period were identified and are summarized at the beginning of each race/species and life stage section in Chapter 5, Section 5.4.2, *Upstream Hydrologic Changes*. The purpose of this characterization of flow patterns was to identify whether there were any locations, months, or water year types in which differences in flow between the PA and NAA could have potentially meaningful biological effects. The characterizations include an evaluation of exceedance plots of mean monthly flows by month, box and whisker plots, and differences in mean monthly flows by month and water year type, all of which can be found in Appendix 5.A, *CALSIM Modeling and Results*. No strict criteria were used to directly determine a biologically meaningful effect from these physical modeling results. However, if, based on best professional judgment, a specific result was considered to have a potential to produce a biologically meaningful effect, the month, water year type, and location in which the result occurred was flagged as requiring closer examination in the results of the remaining flow evaluation. In addition, specifics of the month, water year type, and location with the potentially meaningful result were closely reviewed to determine the cause of the result.

#### *5.D.2.2.3 Adult Holding Habitat*

Changes in Sacramento and American River flow may affect holding habitat for Chinook salmon, CCV steelhead, and green sturgeon adults, but the actual relationship between flow and the amount and quality of adult holding habitat is uncertain. In general, higher flows provide greater depths in pools and may result in improved water quality. Therefore, reduced flow resulting from the PA is treated as a potential adverse effect and increased flow is treated as a beneficial effect. Mean monthly flow rates were examined for the PA and NAA at the locations where, and during the months when, most salmon, CCV steelhead, or green sturgeon holding occurs. Differences in the mean flows of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on Chinook salmon and CCV steelhead holding habitat and warranting further investigation.

#### *5.D.2.2.4 Weighted Usable Area (WUA) Analysis Methods*

##### *5.D.2.2.4.1 Sacramento River*

The WUA curves used for Chinook salmon and CCV steelhead spawning habitat in the Sacramento River were obtained from two U.S. Fish and Wildlife Service (USFWS) reports (U.S. Fish and Wildlife Service 2003a, 2006). As noted above, WUA is computed as the surface area of physical habitat available weighted by its suitability. Modeling assumptions used to derive WUA curves include that the suitability of physical habitat for salmon and steelhead spawning is largely a function of substrate particle size, water depth, and flow velocity. The race- or species-specific suitability of the habitat with respect to these variables is determined by observing the fish and is used to develop habitat suitability criteria (HSC) for each race or species of fish. Hydraulic modeling is then used to estimate the amount of habitat available for different HSC levels at different river flows, and the results are used to develop spawning habitat WUA curves (Bovee et al. 1998). The WUA curves and tables are used to look up the amount of WUA available at different flows.

USFWS 2003a provides WUA curves and tables for spawning winter-run, fall-run, and late fall–run Chinook salmon and CCV steelhead for three segments of the Sacramento River encompassing the reach from Keswick Dam to Battle Creek (Figure 5.D-86). The WUA tables were updated in USFWS 2006. No WUA curves were developed for spring-run Chinook salmon, but, as discussed later, the fall-run curves were used to quantify spring-run spawning habitat. Figure 5.D-87 through Figure 5.D-89 show the flow versus spawning WUA results for winter- run and fall-run Chinook salmon and CCV steelhead in the three river segments (Segment 6 = Keswick to Anderson-Cottonwood Irrigation District [ACID] Dam, Segment 5 = ACID Dam to Cow Creek, and Segment 4 = Cow Creek to Battle Creek) as provided in USFWS 2006 (Figure 5.D-86). Note that for Segment 6, separate WUA curves were developed for periods when the ACID Dam boards were installed and for when the boards were out because installation of the boards affected water levels and velocities for some of the sampling transects used to develop the curves.

Because a number of tributaries enter the Sacramento River between Keswick Dam and Battle Creek, flows are generally different among the segments. For the USFWS studies, flows were measured directly at the sampling transects and were estimated as the sum of Keswick flow releases and tributary gage readings upstream of the transects. To estimate WUA for the effects analysis, the segment flows were estimated with CALSIM II, using the midpoint location of each segment. For Segment 6, the WUA curves for the months when the ACID Dam boards are installed (April through October) were used with the flows for those months and the WUA curves for the months when the ACID Dam boards are out were used with the flows for the rest of the year.

Although fall-run spawning WUA curves were used as surrogates for spring-run spawning, CALSIM II flows for the months of spring-run spawning, not those of fall-run spawning, were used to compute the spring-run WUA results.

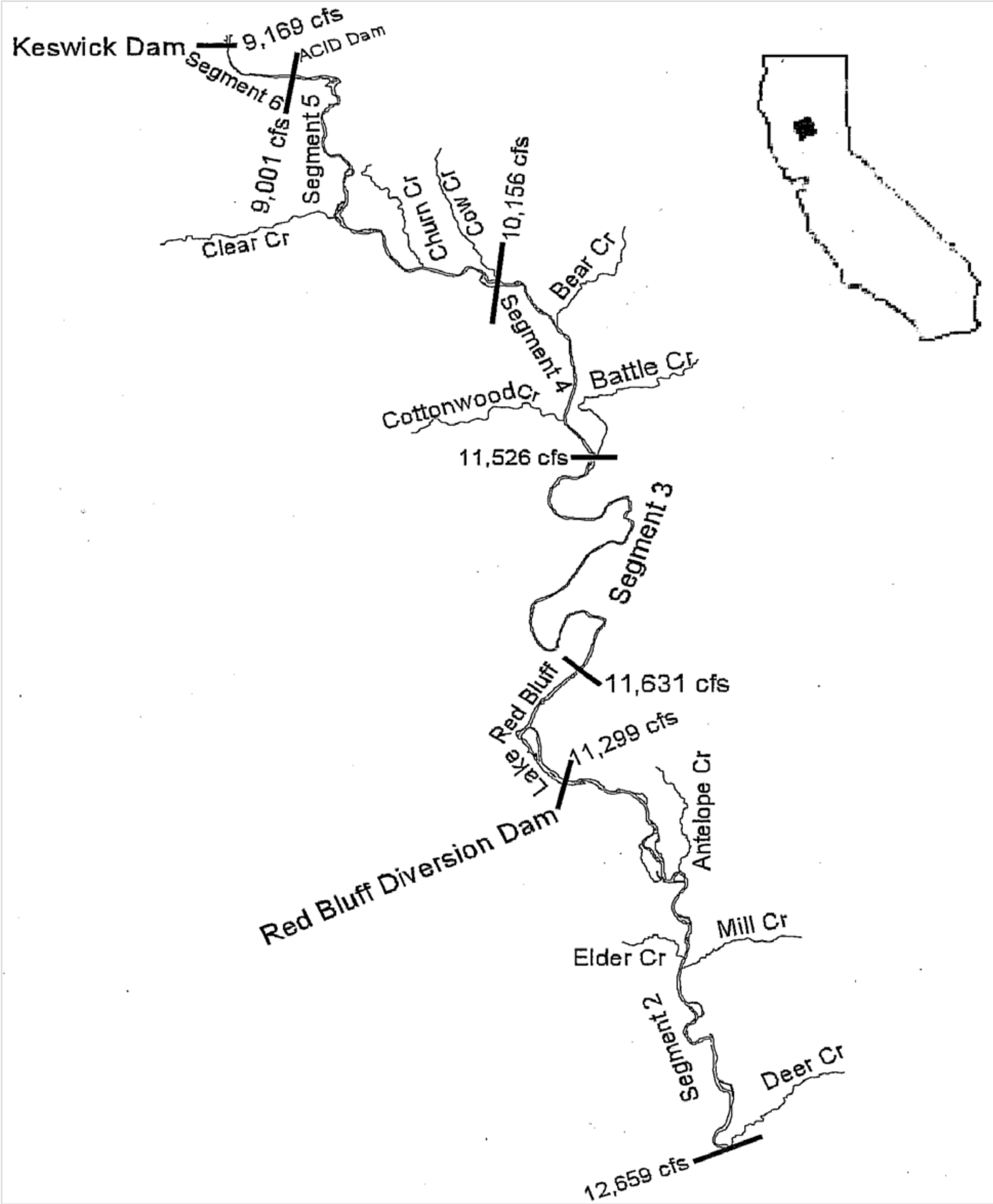



**Figure 5.D-86. Segments 2–6 of the Sacramento River Used in USFWS Studies to Determine Spawning Weighted Usable Area (WUA) (flows in the figure are the average flows at the upstream boundary of each segment for October 1974 to September 1993). Source: USFWS 2003a.**

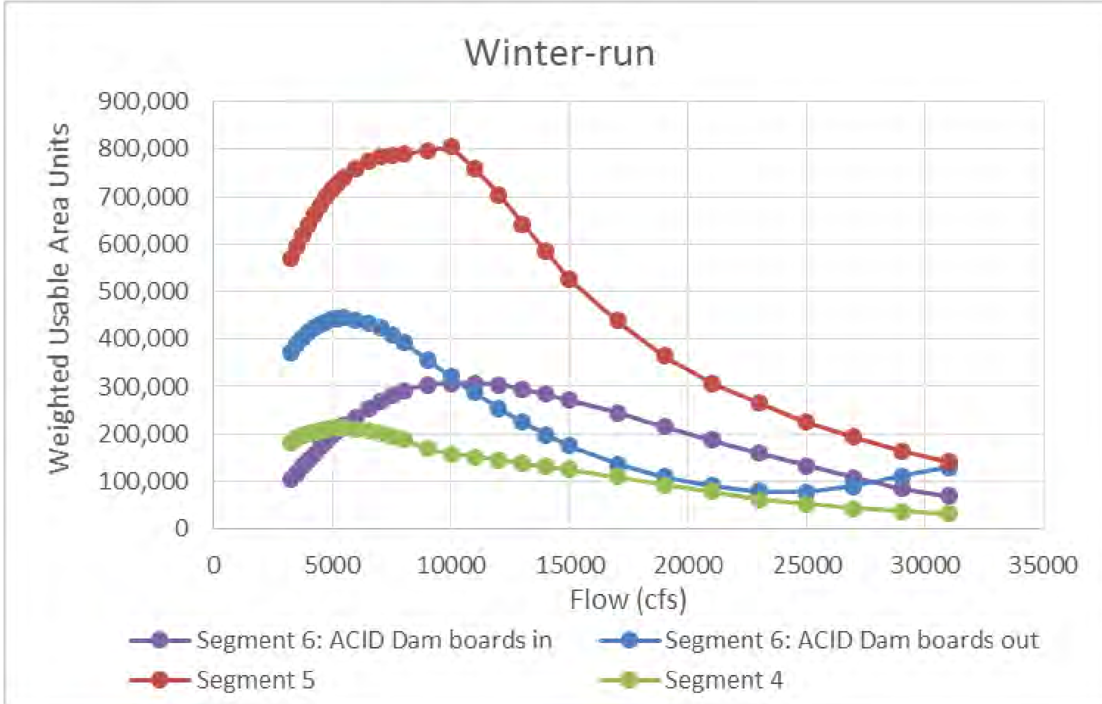



**Figure 5.D-87. Spawning WUA curves for Winter-Run Chinook Salmon in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District**

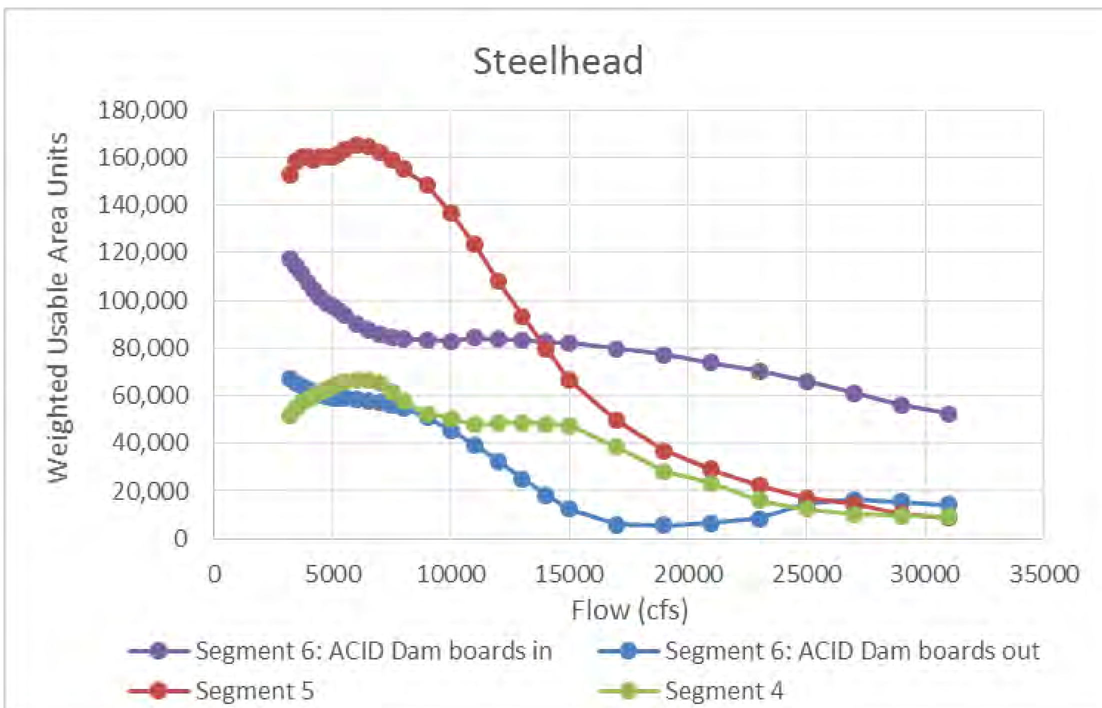



**Figure 5.D-88. Spawning WUA curves for California Central Valley Steelhead in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District**

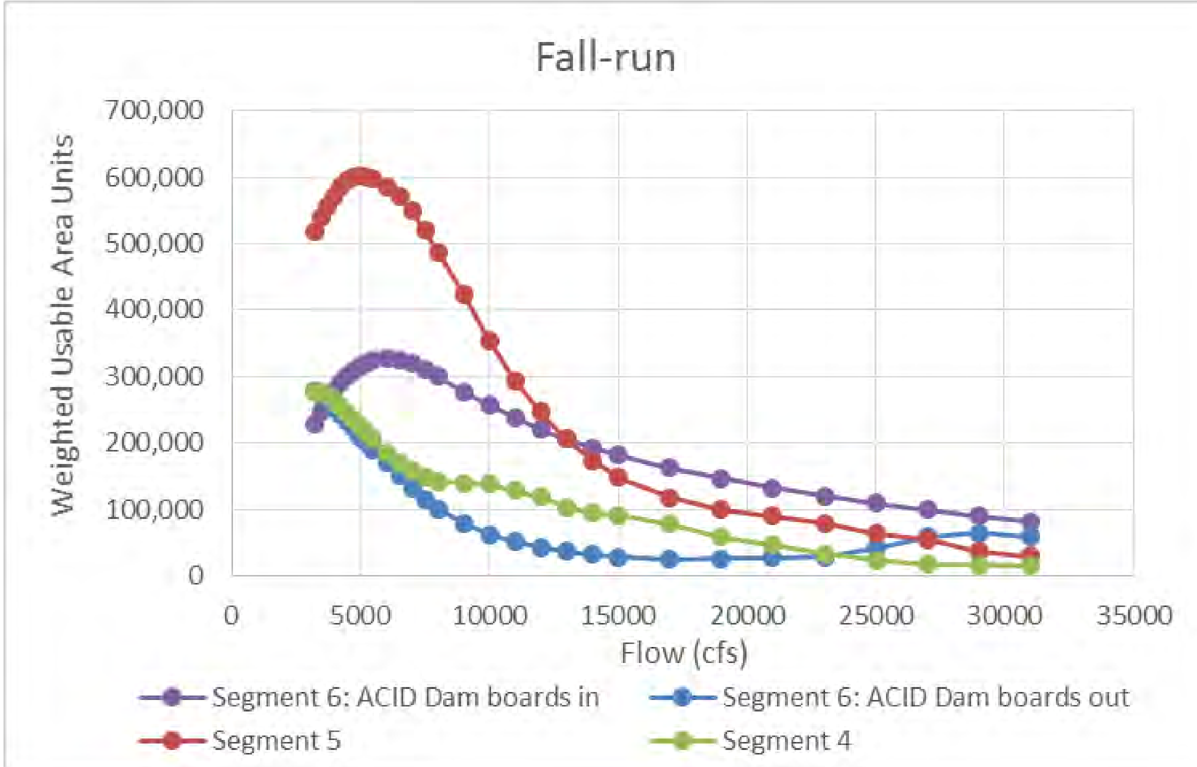



**Figure 5.D-89. Spawning WUA Curves for Fall-Run Chinook Salmon in the Sacramento River, Segments 4 to 6. The fall-run curves were used to quantify spring-run Chinook salmon WUA, as discussed in the text. ACID = Anderson-Cottonwood Irrigation District**

Because there are no spring-run Chinook salmon WUA curves in the USFWS documentation, previous practice, as described below, has been to use fall-run Chinook salmon WUA curves to model spring-run habitat. Two models that currently produce spawning WUA outputs for spring-run Chinook salmon, SALMOD and SacEFT, derive the spring-run WUA results using the fall-run Chinook salmon spawning WUA curves as surrogates (Bartholow 2004; ESSA 2011). Mark Gard, who led the USFWS studies that produced the Sacramento River WUA curves, has endorsed this practice (Gard pers. comm.). However, this practice introduces uncertainty to the spring-run Chinook salmon results.

A potential limitation of the WUA curves presented above, as of all IFIM studies, is that they assume the channel characteristics of the river during the time of field data collection by USFWS (1995–1999), such as proportions of mesohabitat types, have remained in dynamic equilibrium to the present time and will continue to do so through the end of the PA (at least 15 years into the future). If the channel characteristics substantially change, the shape of the curve may no longer be applicable.

A further limitation of the WUA curves for CCV steelhead is that the HSC used in developing the curves had been previously obtained from studies of steelhead in the American River (USFWS 2003b). HSC data were not collected by USFWS for steelhead in the Sacramento River because very few steelhead redds were observed and because the steelhead redds could not be distinguished from those of resident rainbow trout. The validity of this substitution could not be tested and is uncertain (USFWS 2003a).

Differences in spawning WUA under the PA and NAA for a given species or race were examined using exceedance plots of monthly mean WUA for the spawning period (Chapter 5, Section 5.4.2, *Upstream Hydrologic Changes*, Table 5.D-63, Table 5.D-65, Table 5.D-67, Table 5.D-68, and A-1) in each of the river segments for each water year type and all water year types combined. Further, differences in spawning WUA in each segment under the PAA and NAA were examined using the grand mean spawning WUA for each month of the spawning period under each water year type and all water year types combined. Differences in mean spawning WUA of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on Chinook salmon and CCV steelhead spawning habitat and warranting further investigation.

The USFWS WUA studies did not include sturgeon, and no other study providing WUA curves for green or white sturgeon in the Sacramento River has been located. Therefore, effects of the PA on spawning habitat for green sturgeon in the Sacramento River were evaluated by comparing flows under the PA and the NAA in the Sacramento River at the principal locations that green sturgeon spawn (Keswick Dam to Red Bluff) and during the months of their spawning and egg incubation period (March through July). Changes in flow can affect the instream area available for spawning and egg incubation, the quality of the spawning and egg incubation habitat, and the downstream dispersal of larvae to rearing habitat in the bay and Delta. There is some evidence that green sturgeon year class strength is positively correlated with Delta outflow, perhaps, in part, as a result of improved downstream dispersal that benefits from increased flow. In general, therefore, reduced flow resulting from the PA is treated in the effects analysis as a potential adverse effect and increased flow is treated as a beneficial effect, although the certainty of this relationship is unknown.

#### *5.D.2.2.4.2 American River*

The WUA curves used for CCV steelhead spawning habitat in the American River were obtained from USFWS 2003b, which provides spawning WUA curves for steelhead and fall-run Chinook salmon in five segments of the American River. The five segments lie within the approximately 6-mile river reach from Nimbus Dam downstream to Rossmoor Bar, where most salmon and steelhead spawning occurs. Figure 5.D-90 shows the flow versus spawning WUA results for CCV steelhead in the five river segments.

The five river segments were not contiguous and, as indicated by the results of 5 prior years of redd studies, over half of the redds of both species occurred outside of the surveyed segments. However, because the WUA curves provide relative, not absolute, estimates of habitat availability, the segments can be treated as representative samples of the entire 6-mile reach and exhaustive sampling is not necessary.

Because the five surveyed segments were all within 6 miles downstream of Nimbus Dam and there are no significant tributaries in this reach of the river, the five steelhead WUA curves were combined by summing the WUAs for each flow level. In the effects analysis, CALSIM II flows at Nimbus Dam were used to compute steelhead WUAs from the combined WUA curve.

Differences in steelhead spawning WUA under the PA and NAA were examined using exceedance plots of monthly mean WUA during the steelhead spawning period for each water year type and all water year types combined. Also, differences in the mean spawning WUA under the PA and NAA were examined for the months of the spawning period under each water year type and all water year types combined. Differences in mean spawning WUA of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on CCV steelhead spawning habitat and warranting further investigation.

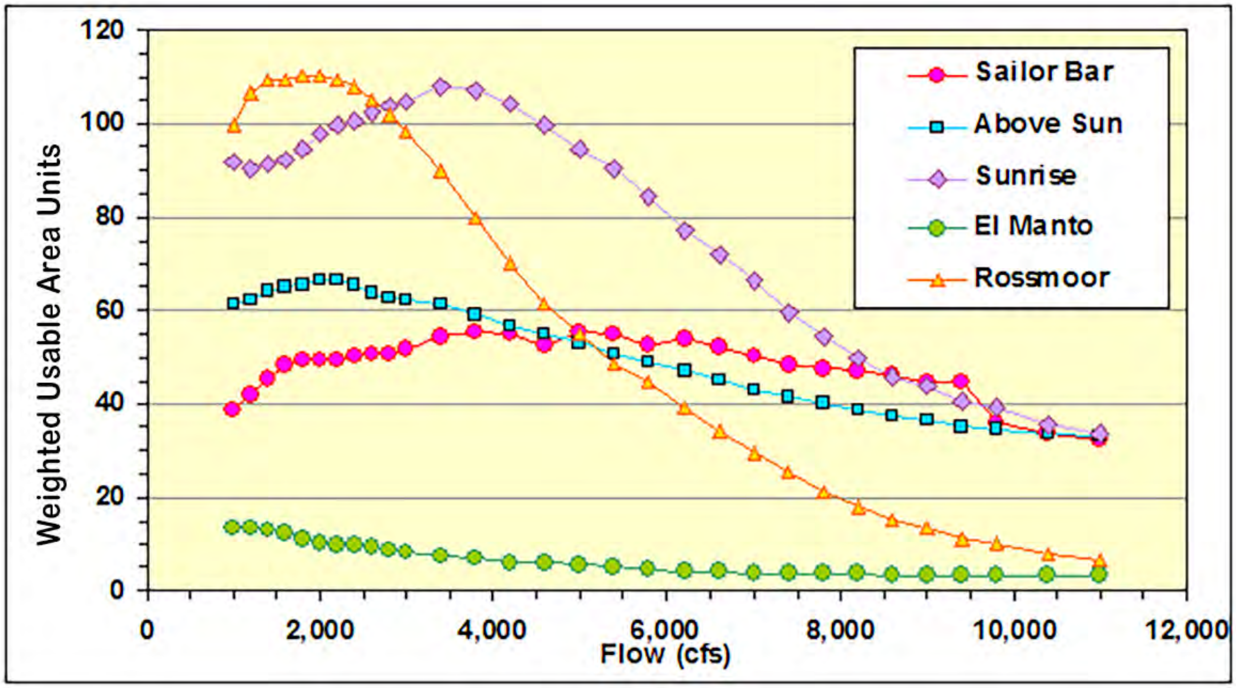



**Figure 5.D-90. Spawning WUA Curves for Steelhead in the American River.**

### *5.D.2.2.5 Redd Dewatering*

The redd dewatering analyses for both the Sacramento and American Rivers are based on the maximum reduction in flow from the initial flow, or *spawning flow*, that occurs over the duration of an egg cohort. The duration of a cohort in a redd includes egg incubation and alevin development to emergence from the gravel. The analysis assumes that a new egg cohort begins each month of the spawning period. Based on technical assistance from NMFS, cohort duration was estimated as three months for both winter-run and spring-run Chinook salmon races and CCV steelhead. Therefore, the difference between the spawning flow and the minimum flow of the three months subsequent to spawning was used for the redd dewatering analyses. This minimum flow of the egg cohort period is referred to herein as the *dewatering flow*. If flows during the three subsequent months were all greater than the spawning flow, dewatering was assumed not to occur. It should be noted that the use of monthly time-step flow estimates likely underestimates redd dewatering rates. This potential bias is expected to affect both project scenarios equally.

##### *5.D.2.2.5.1 Sacramento River*

The percentage of redds lost to dewatering in the Sacramento River was estimated using tables in USFWS (2006) that relate spawning and dewatering flows to percent reductions in species-specific spawning habitat WUA. These tables are reproduced in Table 5.D-55 through Table 5.D-60.

USFWS (2006) developed dewatering tables for the same species as those for which USFWS (2003a) produced spawning habitat WUA curves—winter-run, fall-run, late fall-run Chinook salmon and CCV steelhead—but not for spring-run Chinook salmon. Therefore, as was done for the WUA curves, the fall-run salmon tables were used to estimate spring-run redd dewatering. The validity of substituting the fall-run tables for spring-run is discussed in Section 5.D.2.2.4, *Weighted Usable Area (WUA) Analysis Methods*.

The redd dewatering analysis for winter-run and spring-run Chinook salmon and CCV steelhead was conducted using the months of the spawning periods (Table 5.D-54). These spawning periods are shorter than the full spawning and incubation periods given in Section 5.4.2, *Upstream Hydrologic Changes,* Table 5.D-63, Table 5.D-65, Table 5.D-67, Table 5.D-68, and A-1 because they include only the months when spawning is expected to occur, but not the months after spawning has ceased but the eggs and larvae continue to incubate. As described above, redd dewatering was estimated from the difference between the CALSIM II flow for the month of spawning and the lowest flow of the three months following. For spring-run, although the fall-run redd dewatering tables were used for the analysis, flows from the spring-run spawning period (August through October) were used to look up the percent of spring-run redds dewatered.

**Table 5.D-54. Spawning Periods for Dewatering Analyses (include months of spawning only)**

| Race/Species | Spawning Period |
|---|---|
| Winter-run Chinook salmon | Apr–Aug |
| Spring-run Chinook salmon | Aug–Oct |
| California Central Valley Steelhead | Sacramento: Nov–Feb |
| | American: Dec–Feb |

The spawning and dewatering flows for each location and month of spawning under the PA and NAA, as estimated by CALSIM II, were used to look up the percent of redds dewatered for each of the salmon races and CCV steelhead. Absolute differences between the PA and NAA percentages of greater than 5% were flagged as potentially having a biologically meaningful effect on the race or species and warranting further investigation.

**Table 5.D-55. Percent Redd Dewatered Look-up Table for Winter-Run Chinook Salmon with ACID Dam Boards Out (the percent of redds dewatered are looked up at the intersection of the "Spawning Flow" columns and "Dewatering Flow" rows).**

| | Spawning Flow | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | 3,500 | 3,750 | 4,000 | 4,250 | 4,500 | 4,750 | 5,000 | 5,250 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 |
| 3,250 | 0.8 | 1.5 | 2.2 | 3 | 3.9 | 4.9 | 5.8 | 7 | 8.2 | 11 | 13.8 | 16.7 | 19.7 | 22.6 | 28.8 | 34.8 | 39.4 |
| 3,500 | | 0.6 | 1 | 1.4 | 2 | 2.7 | 3.4 | 4.2 | 5.1 | 7.2 | 9.5 | 12.1 | 14.7 | 17.4 | 23.4 | 29.5 | 34.3 |
| 3,750 | | | 0.2 | 0.5 | 0.8 | 1.2 | 1.6 | 2.1 | 2.8 | 4.3 | 6.1 | 8.3 | 10.6 | 13.1 | 18.9 | 25.1 | 30 |
| 4,000 | | | | 0.2 | 0.4 | 0.7 | 1 | 1.4 | 2 | 3.2 | 4.7 | 7.6 | 8.9 | 11.3 | 16.9 | 23.1 | 27.9 |
| 4,250 | | | | | 0.1 | 0.3 | 0.5 | 0.8 | 1.2 | 2.2 | 3.4 | 5.9 | 7 | 9.1 | 14.3 | 20.3 | 25 |
| 4,500 | | | | | | 0.2 | 0.3 | 0.6 | 0.8 | 1.7 | 2.6 | 3.9 | 5.5 | 7.6 | 12.2 | 17.8 | 22.3 |
| 4,750 | | | | | | | 0.1 | 0.3 | 0.5 | 1.2 | 1.9 | 2.9 | 4.3 | 5.8 | 10.2 | 15.5 | 19.8 |
| 5,000 | | | | | | | | 0.2 | 0.4 | 0.9 | 1.5 | 2.4 | 3.5 | 4.8 | 8.7 | 13.8 | 17.9 |
| 5,250 | | | | | | | | | 0.2 | 0.6 | 1.1 | 1.8 | 2.7 | 3.8 | 7 | 11.8 | 15.7 |
| 5,500 | | | | | | | | | | 0.3 | 0.8 | 1.4 | 2.1 | 3 | 5.8 | 10.3 | 14.1 |
| 6,000 | | | | | | | | | | | 0.2 | 0.6 | 1.1 | 1.7 | 3.7 | 7.7 | 10.9 |
| 6,500 | | | | | | | | | | | | 0.1 | 0.4 | 0.8 | 2.2 | 5.5 | 8.4 |
| 7,000 | | | | | | | | | | | | | 0.2 | 0.4 | 1.2 | 3.5 | 5.6 |
| 7,500 | | | | | | | | | | | | | | 0.2 | 0.7 | 2.6 | 4.3 |
| 8,000 | | | | | | | | | | | | | | | 0.3 | 1.9 | 3.2 |
| 9,000 | | | | | | | | | | | | | | | | 1.2 | 1.8 |
| 10,000 | | | | | | | | | | | | | | | | | 0.4 |
| 11,000 | | | | | | | | | | | | | | | | | |
| 12,000 | | | | | | | | | | | | | | | | | |
| 13,000 | | | | | | | | | | | | | | | | | |
| 14,000 | | | | | | | | | | | | | | | | | |
| 15,000 | | | | | | | | | | | | | | | | | |
| 17,000 | | | | | | | | | | | | | | | | | |
| 19,000 | | | | | | | | | | | | | | | | | |
| 21,000 | | | | | | | | | | | | | | | | | |
| 23,000 | | | | | | | | | | | | | | | | | |
| 25,000 | | | | | | | | | | | | | | | | | |
| 27,000 | | | | | | | | | | | | | | | | | |
| 29,000 | | | | | | | | | | | | | | | | | |

**Table 5.D-55 (cont.)**

| | | Spawning Flow | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12,000 | 13,000 | 14,000 | 15,000 | 17,000 | 19,000 | 21,000 | 23,000 | 25,000 | 27,000 | 29,000 | 31,000 |
| Dewatering Flow | 3,250 | 43.2 | 46.2 | 49.1 | 51.4 | 55 | 57.6 | 59.9 | 62.6 | 64.7 | 68.9 | 73.3 | 77.3 |
| | 3,500 | 38.3 | 41.5 | 44.6 | 47.1 | 51 | 53.6 | 56.1 | 58.8 | 61.1 | 65.4 | 70.2 | 74.5 |
| | 3,750 | 34.1 | 37.5 | 40.6 | 43.2 | 47.2 | 50 | 52.5 | 55.4 | 57.7 | 62.3 | 67.4 | 72 |
| | 4,000 | 32.1 | 35.5 | 38.6 | 41.2 | 45.4 | 48.2 | 50.7 | 53.6 | 56.1 | 60.8 | 66.1 | 70.8 |
| | 4,250 | 29.1 | 32.5 | 35.5 | 38.2 | 42.4 | 45.3 | 47.8 | 50.8 | 53.4 | 58.3 | 63.8 | 68.8 |
| | 4,500 | 26.3 | 29.6 | 32.6 | 35.3 | 39.6 | 42.5 | 45.1 | 48.2 | 51 | 56 | 61.7 | 66.9 |
| | 4,750 | 23.7 | 26.9 | 29.9 | 32.7 | 37 | 40 | 42.7 | 45.9 | 48.8 | 54 | 59.9 | 65.4 |
| | 5,000 | 21.6 | 24.7 | 27.7 | 30.4 | 34.8 | 37.9 | 40.6 | 43.8 | 44.1 | 52.3 | 58.4 | 64.1 |
| | 5,250 | 19.4 | 22.4 | 25.4 | 28.2 | 32.7 | 35.8 | 38.6 | 41.9 | 45.2 | 50.7 | 57 | 62.8 |
| | 5,500 | 17.6 | 20.6 | 23.5 | 26.2 | 30.7 | 33.9 | 36.8 | 40.1 | 43.5 | 49 | 55.5 | 61.5 |
| | 6,000 | 14 | 16.7 | 19.4 | 22 | 26.4 | 29.6 | 32.6 | 35.9 | 39.6 | 45.4 | 52.2 | 58.5 |
| | 6,500 | 11.2 | 13.6 | 16.2 | 18.8 | 23.1 | 26.2 | 29.3 | 32.7 | 36.5 | 42.6 | 49.7 | 56.4 |
| | 7,000 | 7.9 | 10.1 | 12.4 | 14.8 | 19 | 22.3 | 25.6 | 29.2 | 33.3 | 39.7 | 47.2 | 54.1 |
| | 7,500 | 6.3 | 8.1 | 10.2 | 12.4 | 16.3 | 19.7 | 23 | 26.7 | 31 | 37.6 | 45.3 | 52.5 |
| | 8,000 | 4.9 | 6.6 | 8.6 | 10.5 | 14.3 | 17.7 | 21.1 | 25 | 29.3 | 36.1 | 44.1 | 51.4 |
| | 9,000 | 3 | 4.4 | 6 | 7.8 | 11.4 | 14.7 | 18.3 | 22.1 | 26.6 | 33.6 | 41.9 | 49.5 |
| | 10,000 | 1.3 | 2.3 | 3.7 | 5.3 | 8.6 | 11.8 | 15.4 | 19.3 | 23.8 | 30.6 | 39.7 | 47.5 |
| | 11,000 | 0.6 | 1.2 | 2.2 | 3.5 | 6.4 | 9.5 | 13.2 | 17.1 | 21.7 | 28.5 | 37.6 | 45.6 |
| | 12,000 | | 0.2 | 0.9 | 1.8 | 4.1 | 7 | 10.5 | 14.7 | 19.3 | 26.3 | 35.7 | 43.8 |
| | 13,000 | | | 0.4 | 1 | 2.8 | 5.3 | 8.7 | 13 | 17.5 | 24.5 | 34 | 42.3 |
| | 14,000 | | | | 0.4 | 1.6 | 4.2 | 7.5 | 11.8 | 16.2 | 23 | 32.6 | 41 |
| | 15,000 | | | | | 0.9 | 2.8 | 5.9 | 10.6 | 14.9 | 21.8 | 31.5 | 40.1 |
| | 17,000 | | | | | | 1.3 | 3.9 | 7.8 | 11.8 | 18.3 | 28.1 | 36.9 |
| | 19,000 | | | | | | | 1.4 | 4 | 7.1 | 13 | 22.5 | 31.7 |
| | 21,000 | | | | | | | | 1.3 | 3.6 | 9.2 | 18.7 | 28 |
| | 23,000 | | | | | | | | | 1.4 | 6.2 | 15.4 | 24.6 |
| | 25,000 | | | | | | | | | | 0 | 8.3 | 15.2 |
| | 27,000 | | | | | | | | | | | 1.6 | 3.6 |
| | 29,000 | | | | | | | | | | | | 0.6 |

**Table 5.D-56. Percent Redd Dewatered Look-up Table for Winter-Run Chinook Salmon with ACID Dam Boards In (the percent of reds dewatered are looked up at the intersection of the "Spawning Flow" columns and "Dewatering Flow" rows).**

| | Spawning Flow | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | 3,500 | 3,750 | 4,000 | 4,250 | 4,500 | 4,750 | 5,000 | 5,250 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 |
| 3,250 | 1.2 | 2.2 | 3.1 | 4.1 | 5.2 | 6.4 | 7.5 | 8.8 | 10.2 | 13 | 16 | 18.9 | 21.9 | 24.7 | 30.5 | 35.9 | 40.1 |
| 3,500 | | 0.9 | 1.4 | 2 | 2.7 | 3.6 | 4.4 | 5.3 | 6.3 | 8.5 | 11 | 13.6 | 16.2 | 18.9 | 24.7 | 30.4 | 34.8 |
| 3,750 | | | 0.4 | 0.8 | 0.2 | 1.7 | 2.2 | 2.8 | 3.5 | 5.1 | 7 | 9.3 | 11.7 | 14.2 | 19.9 | 25.9 | 30.5 |
| 4,000 | | | | 0.4 | 0.7 | 1.1 | 1.4 | 1.9 | 2.5 | 3.8 | 5.4 | 7.5 | 9.8 | 12.2 | 17.7 | 23.7 | 28.3 |
| 4,250 | | | | | 0.3 | 0.5 | 0.8 | 1.1 | 1.5 | 2.6 | 3.9 | 5.6 | 7.6 | 9.7 | 15 | 20.7 | 25.2 |
| 4,500 | | | | | | 0.3 | 0.5 | 0.8 | 1.1 | 1.9 | 2.9 | 4.3 | 5.9 | 7.9 | 12.6 | 18.1 | 22.4 |
| 4,750 | | | | | | | 0.2 | 0.4 | 0.7 | 1.3 | 2.1 | 3.1 | 4.5 | 6.1 | 10.5 | 15.7 | 20 |
| 5,000 | | | | | | | | 0.3 | 0.5 | 1 | 1.6 | 2.5 | 3.7 | 5 | 9 | 14 | 18.1 |
| 5,250 | | | | | | | | | 0.3 | 0.7 | 1.2 | 1.9 | 2.9 | 3.9 | 7.3 | 11.9 | 15.9 |
| 5,500 | | | | | | | | | | 0.4 | 0.9 | 1.5 | 2.3 | 3.2 | 6.1 | 10.5 | 14.3 |
| 6,000 | | | | | | | | | | | 0.3 | 0.7 | 1.3 | 1.9 | 4 | 8 | 11.3 |
| 6,500 | | | | | | | | | | | | 0.2 | 0.5 | 1 | 2.4 | 5.8 | 8.8 |
| 7,000 | | | | | | | | | | | | | 0.3 | 0.5 | 1.4 | 3.8 | 6.1 |
| 7,500 | | | | | | | | | | | | | | 0.3 | 0.9 | 2.9 | 4.8 |
| 8,000 | | | | | | | | | | | | | | | 0.4 | 2.1 | 3.7 |
| 9,000 | | | | | | | | | | | | | | | | 1.3 | 2.4 |
| 10,000 | | | | | | | | | | | | | | | | | 0.9 |
| 11,000 | | | | | | | | | | | | | | | | | |
| 12,000 | | | | | | | | | | | | | | | | | |
| 13,000 | | | | | | | | | | | | | | | | | |
| 14,000 | | | | | | | | | | | | | | | | | |
| 15,000 | | | | | | | | | | | | | | | | | |
| 17,000 | | | | | | | | | | | | | | | | | |
| 19,000 | | | | | | | | | | | | | | | | | |
| 21,000 | | | | | | | | | | | | | | | | | |
| 23,000 | | | | | | | | | | | | | | | | | |
| 25,000 | | | | | | | | | | | | | | | | | |
| 27,000 | | | | | | | | | | | | | | | | | |
| 29,000 | | | | | | | | | | | | | | | | | |

**Table 5.D-56 (cont.)**

| | Spawning Flow | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | 12,000 | 13,000 | 14,000 | 15,000 | 17,000 | 19,000 | 21,000 | 23,000 | 25,000 | 27,000 | 29,000 | 31,000 |
| 3,250 | 43.4 | 46 | 48.4 | 50.3 | 53.5 | 56 | 58.9 | 62.4 | 65.4 | 69.5 | 73.7 | 77.2 |
| 3,500 | 38.5 | 41.1 | 43.9 | 46.1 | 49.6 | 52.3 | 55.3 | 58.8 | 61.9 | 65.9 | 69.9 | 73.5 |
| 3,750 | 34.4 | 37.3 | 40 | 42.4 | 46.1 | 49 | 52.1 | 55.7 | 58.8 | 62.8 | 66.7 | 70.2 |
| 4,000 | 32.2 | 35.3 | 38 | 40.4 | 44.2 | 47.2 | 50.3 | 53.9 | 57 | 61.1 | 65 | 68.5 |
| 4,250 | 29.2 | 32.2 | 34.9 | 37.4 | 41.4 | 44.4 | 47.5 | 51.2 | 54.4 | 58.5 | 62.3 | 65.7 |
| 4,500 | 26.3 | 29.3 | 32 | 34.6 | 38.6 | 41.7 | 45 | 48.7 | 52 | 56 | 59.8 | 63.2 |
| 4,750 | 23.7 | 26.7 | 29.5 | 32.1 | 36.3 | 39.5 | 42.8 | 46.6 | 49.9 | 53.9 | 57.6 | 61.1 |
| 5,000 | 21.7 | 24.6 | 27.4 | 29.9 | 34.2 | 37.4 | 40.8 | 44.6 | 48 | 51.9 | 55.7 | 59.1 |
| 5,250 | 19.5 | 22.5 | 25.2 | 27.9 | 32.2 | 35.6 | 39 | 42.8 | 46.4 | 50.3 | 54.1 | 57.5 |
| 5,500 | 17.9 | 20.7 | 23.5 | 26.1 | 30.5 | 33.9 | 37.4 | 41.2 | 44.8 | 48.7 | 52.4 | 55.8 |
| 6,000 | 14.5 | 17.1 | 19.8 | 22.3 | 26.8 | 30.2 | 33.7 | 37.5 | 41.3 | 45.1 | 48.8 | 52.2 |
| 6,500 | 11.8 | 14.3 | 16.8 | 19.3 | 23.7 | 27.2 | 30.7 | 34.7 | 38.4 | 42.3 | 45.9 | 49.3 |
| 7,000 | 8.7 | 10.9 | 13.3 | 15.7 | 20.1 | 23.7 | 27.5 | 31.5 | 35.4 | 39.4 | 42.9 | 46.2 |
| 7,500 | 7 | 9 | 11.2 | 13.5 | 17.7 | 21.4 | 25.2 | 29.3 | 33.2 | 37.2 | 40.7 | 44 |
| 8,000 | 5.7 | 7.6 | 9.7 | 11.8 | 15.9 | 19.6 | 23.5 | 27.7 | 31.6 | 35.7 | 39.1 | 42.4 |
| 9,000 | 4 | 5.6 | 7.4 | 9.4 | 13.3 | 16.9 | 20.8 | 24.9 | 28.7 | 32.8 | 36.3 | 39.6 |
| 10,000 | 2.2 | 3.6 | 5.2 | 7 | 10.5 | 14 | 17.7 | 18.6 | 25.4 | 28.9 | 32.6 | 35.8 |
| 11,000 | 1.1 | 2 | 3.1 | 4.6 | 7.6 | 10.5 | 13.8 | 17.4 | 20.6 | 23.5 | 26.7 | 29.4 |
| 12,000 | | 0.5 | 1.2 | 2.2 | 4.2 | 6.4 | 9.1 | 12.1 | 14.6 | 16.8 | 19.1 | 21.1 |
| 13,000 | | | 0.5 | 1.1 | 2.6 | 4.4 | 6.7 | 9.2 | 11.7 | 13.5 | 15.3 | 17 |
| 14,000 | | | | 0.5 | 1.7 | 3.5 | 5.5 | 8.2 | 10.1 | 11.7 | 13.4 | 14.9 |
| 15,000 | | | | | 0.7 | 2.1 | 3.9 | 6.8 | 8.6 | 10.1 | 11.6 | 13 |
| 17,000 | | | | | | 0.9 | 2.5 | 4.9 | 6.5 | 7.7 | 9.1 | 10.4 |
| 19,000 | | | | | | | 1 | 2.5 | 3.6 | 4.4 | 5.5 | 6.6 |
| 21,000 | | | | | | | | 0.9 | 1.6 | 2.1 | 3 | 4 |
| 23,000 | | | | | | | | | 0.4 | 0.6 | 1.1 | 1.9 |
| 25,000 | | | | | | | | | | 0.3 | 0.9 | 1.6 |
| 27,000 | | | | | | | | | | | 0.3 | 0.7 |
| 29,000 | | | | | | | | | | | | 0.3 |

**Table 5.D-57. Percent Redd Dewatered Look-up Table for Fall-Run Chinook Salmon (Used for the Spring-Run Chinook Salmon Analysis) with ACID Dam Boards Out (the percent of redds dewatered are looked up at the intersection of the "Spawning Flow" columns and "Dewatering Flow" rows).**

| | | Spawning Flow | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | | 3,500 | 3,750 | 4,000 | 4,250 | 4,500 | 4,750 | 5,000 | 5,250 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 |
| | 3,250 | 1 | 2 | 3.4 | 4.8 | 6.6 | 8.4 | 10.6 | 12.9 | 15.3 | 20.6 | 26.2 | 31.7 | 37 | 41.5 | 50.2 | 56.3 | 60.4 |
| | 3,500 | | 1 | 2.1 | 3.2 | 4.6 | 6.2 | 8.1 | 10.1 | 12.2 | 17 | 22.2 | 27.4 | 29.2 | 37 | 45.9 | 52.8 | 57.3 |
| | 3,750 | | | 0.9 | 1.6 | 2.6 | 3.9 | 5.5 | 7.3 | 9.2 | 13.6 | 18.4 | 23.1 | 28 | 32.4 | 41.5 | 48.7 | 53.6 |
| | 4,000 | | | | 0.9 | 1.7 | 2.8 | 4.1 | 5.7 | 7.3 | 11.4 | 15.8 | 20.3 | 24.8 | 29 | 38 | 45.7 | 50.7 |
| | 4,250 | | | | | 0.8 | 1.6 | 2.7 | 4 | 5.4 | 8.9 | 13 | 17.2 | 21.6 | 25.8 | 34.9 | 42.8 | 48 |
| | 4,500 | | | | | | 0.8 | 1.7 | 2.8 | 4 | 6.9 | 10.4 | 14.2 | 18.2 | 22.1 | 30.9 | 38.8 | 44.2 |
| | 4,750 | | | | | | | 0.8 | 1.6 | 2.5 | 4.8 | 7.6 | 10.8 | 14.2 | 17.6 | 25.8 | 33.2 | 38.8 |
| | 5,000 | | | | | | | | 0.7 | 1.3 | 3.2 | 5.6 | 8.6 | 11.6 | 14.7 | 22.6 | 30.2 | 36 |
| | 5,250 | | | | | | | | | 0.7 | 2.1 | 4.2 | 6.8 | 9.4 | 12.3 | 19.8 | 27.2 | 33.1 |
| | 5,500 | | | | | | | | | | 1.4 | 3.2 | 5.4 | 7.7 | 10.3 | 17.6 | 24.9 | 31 |
| | 6,000 | | | | | | | | | | | 1.2 | 2.8 | 4.6 | 6.4 | 12.9 | 19.7 | 25.8 |
| | 6,500 | | | | | | | | | | | | 1.3 | 2.6 | 4.2 | 9.8 | 15.6 | 21.1 |
| | 7,000 | | | | | | | | | | | | | 0.9 | 2 | 6.6 | 11.8 | 17.3 |
| | 7,500 | | | | | | | | | | | | | | 0.8 | 4.4 | 9.1 | 14.1 |
| | 8,000 | | | | | | | | | | | | | | | 2.6 | 6.6 | 11.5 |
| | 9,000 | | | | | | | | | | | | | | | | 2.2 | 5.5 |
| | 10,000 | | | | | | | | | | | | | | | | | 0.9 |
| | 11,000 | | | | | | | | | | | | | | | | | |
| | 12,000 | | | | | | | | | | | | | | | | | |
| | 13,000 | | | | | | | | | | | | | | | | | |
| | 14,000 | | | | | | | | | | | | | | | | | |
| | 15,000 | | | | | | | | | | | | | | | | | |
| | 17,000 | | | | | | | | | | | | | | | | | |
| | 19,000 | | | | | | | | | | | | | | | | | |
| | 21,000 | | | | | | | | | | | | | | | | | |
| | 23,000 | | | | | | | | | | | | | | | | | |
| | 25,000 | | | | | | | | | | | | | | | | | |
| | 27,000 | | | | | | | | | | | | | | | | | |
| | 29,000 | | | | | | | | | | | | | | | | | |

**Table 5.D-57 (cont.)**

| | | Spawning Flow | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12,000 | 13,000 | 14,000 | 15,000 | 17,000 | 19,000 | 21,000 | 23,000 | 25,000 | 27,000 | 29,000 | 31,000 |
| Dewatering Flow | 3,250 | 62.9 | 63.7 | 65.3 | 66.4 | 66.8 | 65.7 | 67.8 | 71.3 | 74.5 | 80.4 | 87.3 | 92 |
| | 3,500 | 60.1 | 61.1 | 63 | 64.2 | 64.9 | 63.8 | 66 | 69.5 | 73 | 79.1 | 86.2 | 91 |
| | 3,750 | 56.9 | 58.3 | 60.3 | 61.8 | 62.7 | 61.7 | 64 | 67.7 | 71.4 | 77.7 | 84.9 | 89.6 |
| | 4,000 | 54.3 | 55.9 | 58.2 | 59.9 | 61.2 | 60.2 | 62.7 | 66.5 | 70.4 | 77.1 | 84.1 | 88.8 |
| | 4,250 | 51.8 | 53.6 | 56 | 58.1 | 59.6 | 58.8 | 61.3 | 65 | 68.5 | 75.7 | 83.1 | 87.8 |
| | 4,500 | 48.3 | 50.2 | 52.8 | 55.1 | 57.1 | 56.4 | 59 | 62.7 | 66.2 | 73.3 | 81.8 | 86.5 |
| | 4,750 | 43.3 | 45.6 | 48.6 | 51.4 | 54 | 53.7 | 56.6 | 60.4 | 64.5 | 71.7 | 80.3 | 85 |
| | 5,000 | 40.6 | 43 | 46.1 | 49.1 | 52.2 | 52.2 | 55.2 | 59.1 | 63.3 | 70.6 | 79.4 | 84.1 |
| | 5,250 | 37.7 | 40.2 | 43.5 | 46.5 | 50 | 50.2 | 53.5 | 57.4 | 60.7 | 68 | 78.2 | 83 |
| | 5,500 | 35.8 | 38.4 | 41.7 | 44.8 | 48.3 | 48.8 | 52.3 | 56.1 | 60.1 | 67.5 | 77.3 | 82 |
| | 6,000 | 30.9 | 33.8 | 37.3 | 40.6 | 45 | 45.8 | 49.5 | 53.2 | 57.2 | 65 | 75.4 | 80 |
| | 6,500 | 26.5 | 29.2 | 32.7 | 36.1 | 41 | 42.4 | 46.5 | 50.4 | 54.8 | 63 | 73.3 | 77.7 |
| | 7,000 | 22.8 | 25.8 | 29.3 | 32.9 | 38.3 | 40 | 44.4 | 48.3 | 52.9 | 61.3 | 71.8 | 76.1 |
| | 7,500 | 20 | 23.2 | 26.9 | 30.7 | 36.4 | 38.2 | 42.8 | 46.8 | 51.9 | 60.5 | 70.9 | 75.3 |
| | 8,000 | 17.2 | 20.9 | 24.9 | 28.9 | 34.9 | 36.6 | 41.3 | 45.4 | 50.5 | 59.3 | 70.2 | 74.7 |
| | 9,000 | 10.6 | 14.4 | 18.4 | 22.5 | 29.2 | 31.9 | 37.4 | 41.8 | 47.7 | 57 | 68.2 | 72.6 |
| | 10,000 | 4.5 | 7.7 | 12 | 16.4 | 23.5 | 26.9 | 33 | 38.5 | 44.5 | 54.1 | 65.9 | 70.5 |
| | 11,000 | 2.7 | 5.3 | 9 | 13.6 | 21.4 | 24.8 | 30.2 | 35.3 | 41.8 | 51.6 | 63.7 | 68.4 |
| | 12,000 | | 1.6 | 4.7 | 9 | 16.8 | 20.6 | 27 | 32.9 | 39.8 | 50 | 62.3 | 67.2 |
| | 13,000 | | | 1.6 | 4.8 | 12.2 | 16.9 | 24.4 | 31.3 | 38.1 | 48.4 | 60.8 | 65.9 |
| | 14,000 | | | | 2.6 | 9.5 | 14.8 | 22.1 | 28.9 | 36.2 | 46.8 | 59.5 | 64.7 |
| | 15,000 | | | | | 5.3 | 11.1 | 18.5 | 26.2 | 33.5 | 44.6 | 57.6 | 63.1 |
| | 17,000 | | | | | | 4.1 | 11.3 | 18.5 | 26.1 | 37.8 | 51.5 | 57.9 |
| | 19,000 | | | | | | | 4.6 | 10.8 | 18.8 | 30.4 | 44.2 | 51.1 |
| | 21,000 | | | | | | | | 4.2 | 11.7 | 23.9 | 38.4 | 46.3 |
| | 23,000 | | | | | | | | | 6.7 | 17.8 | 31.2 | 38.9 |
| | 25,000 | | | | | | | | | | 2.3 | 6.4 | 10.7 |
| | 27,000 | | | | | | | | | | | 1.8 | 5.3 |
| | 29,000 | | | | | | | | | | | | 2.2 |

**Table 5.D-58. Percent Redd Dewatered Look-up Table for Fall-Run Chinook Salmon (Used for the Spring-Run Chinook Salmon Analysis) with ACID Dam Boards In (the percent of redds dewatered are looked up at the intersection of the "Spawning Flow" columns and "Dewatering Flow" rows).**

| | Spawning Flow | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | 3,500 | 3,750 | 4,000 | 4,250 | 4,500 | 4,750 | 5,000 | 5,250 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 |
| 3,250 | 1.0 | 2.0 | 3.3 | 4.7 | 6.2 | 7.8 | 9.7 | 11.7 | 13.6 | 17.8 | 22.2 | 26.3 | 30.2 | 33.4 | 39.5 | 43.5 | 46.0 |
| 3,500 | | 1.0 | 2.0 | 3.1 | 4.4 | 5.7 | 7.4 | 9.2 | 10.9 | 14.8 | 18.8 | 22.8 | 23.9 | 29.8 | 36.2 | 40.8 | 43.6 |
| 3,750 | | | 0.9 | 1.6 | 2.5 | 3.6 | 5.1 | 6.7 | 8.3 | 11.9 | 15.6 | 19.3 | 23.0 | 26.2 | 32.8 | 37.7 | 40.9 |
| 4,000 | | | | 0.9 | 1.7 | 2.6 | 3.8 | 5.3 | 6.6 | 10.0 | 13.5 | 16.9 | 20.4 | 23.5 | 30.1 | 35.4 | 38.7 |
| 4,250 | | | | | 0.8 | 1.5 | 2.5 | 3.7 | 5.0 | 7.8 | 11.1 | 14.4 | 17.8 | 20.9 | 27.5 | 33.1 | 36.6 |
| 4,500 | | | | | | 0.8 | 1.6 | 2.6 | 3.7 | 6.0 | 8.9 | 11.9 | 15.0 | 17.8 | 24.4 | 29.9 | 33.6 |
| 4,750 | | | | | | | 0.8 | 1.6 | 2.4 | 4.3 | 6.6 | 9.1 | 11.8 | 14.3 | 20.3 | 25.7 | 29.5 |
| 5,000 | | | | | | | | 0.7 | 1.3 | 2.9 | 4.9 | 7.2 | 9.6 | 11.9 | 17.7 | 23.1 | 26.9 |
| 5,250 | | | | | | | | | 0.6 | 1.9 | 3.5 | 5.6 | 7.7 | 9.7 | 15.3 | 20.4 | 24.1 |
| 5,500 | | | | | | | | | | 1.2 | 2.7 | 4.4 | 6.2 | 8.1 | 13.5 | 18.5 | 22.3 |
| 6,000 | | | | | | | | | | | 1.0 | 2.3 | 3.7 | 5.1 | 9.8 | 14.5 | 18.3 |
| 6,500 | | | | | | | | | | | | 1.1 | 2.1 | 3.3 | 7.4 | 11.5 | 15.0 |
| 7,000 | | | | | | | | | | | | | 0.7 | 1.6 | 5.0 | 8.6 | 12.1 |
| 7,500 | | | | | | | | | | | | | | 0.6 | 3.4 | 6.7 | 9.9 |
| 8,000 | | | | | | | | | | | | | | | 2.0 | 4.9 | 8.1 |
| 9,000 | | | | | | | | | | | | | | | | 1.6 | 3.8 |
| 10,000 | | | | | | | | | | | | | | | | | 1.2 |
| 11,000 | | | | | | | | | | | | | | | | | |
| 12,000 | | | | | | | | | | | | | | | | | |
| 13,000 | | | | | | | | | | | | | | | | | |
| 14,000 | | | | | | | | | | | | | | | | | |
| 15,000 | | | | | | | | | | | | | | | | | |
| 17,000 | | | | | | | | | | | | | | | | | |
| 19,000 | | | | | | | | | | | | | | | | | |
| 21,000 | | | | | | | | | | | | | | | | | |
| 23,000 | | | | | | | | | | | | | | | | | |
| 25,000 | | | | | | | | | | | | | | | | | |
| 27,000 | | | | | | | | | | | | | | | | | |
| 29,000 | | | | | | | | | | | | | | | | | |

**Table 5.D-58 (cont.)**

| | | Spawning Flow | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12,000 | 13,000 | 14,000 | 15,000 | 17,000 | 19,000 | 21,000 | 23,000 | 25,000 | 27,000 | 29,000 | 31,000 |
| Dewatering Flow | 3,250 | 47.6 | 48.0 | 49.3 | 50.5 | 52.0 | 52.5 | 55.1 | 57.6 | 57.4 | 59.0 | 61.1 | 63.3 |
| | 3,500 | 45.5 | 46.0 | 47.4 | 48.8 | 50.4 | 50.8 | 53.4 | 55.9 | 55.7 | 57.2 | 59.3 | 61.6 |
| | 3,750 | 43.1 | 43.9 | 45.5 | 47.0 | 48.7 | 49.1 | 51.8 | 54.3 | 54.1 | 55.6 | 57.6 | 59.8 |
| | 4,000 | 41.2 | 42.2 | 43.8 | 45.5 | 47.5 | 47.9 | 50.5 | 53.1 | 52.9 | 54.5 | 56.3 | 58.5 |
| | 4,250 | 39.2 | 4.0 | 42.1 | 43.9 | 46.0 | 46.4 | 49.0 | 51.3 | 50.8 | 52.5 | 54.4 | 56.5 |
| | 4,500 | 36.4 | 37.6 | 39.4 | 41.4 | 43.6 | 43.9 | 46.4 | 48.7 | 47.8 | 49.1 | 51.6 | 53.7 |
| | 4,750 | 32.6 | 34.0 | 36.1 | 38.3 | 40.8 | 41.1 | 43.6 | 45.7 | 44.9 | 46.0 | 48.3 | 50.3 |
| | 5,000 | 30.0 | 31.2 | 33.2 | 35.3 | 37.6 | 37.6 | 39.8 | 41.7 | 40.5 | 41.3 | 43.2 | 45.1 |
| | 5,250 | 27.1 | 28.2 | 29.9 | 31.8 | 33.9 | 33.5 | 35.4 | 36.8 | 34.6 | 35.0 | 37.4 | 39.0 |
| | 5,500 | 25.3 | 26.4 | 28.0 | 29.7 | 31.5 | 31.0 | 32.7 | 33.8 | 31.7 | 31.9 | 33.6 | 35.1 |
| | 6,000 | 21.5 | 22.7 | 24.4 | 26.2 | 28.2 | 27.5 | 29.0 | 29.8 | 27.1 | 27.1 | 28.7 | 29.8 |
| | 6,500 | 18.3 | 19.5 | 21.1 | 23.0 | 25.2 | 24.7 | 26.4 | 27.1 | 24.4 | 24.2 | 25.3 | 26.3 |
| | 7,000 | 15.6 | 17.0 | 18.7 | 20.7 | 23.2 | 22.8 | 24.5 | 25.1 | 22.4 | 22.1 | 23.2 | 24.0 |
| | 7,500 | 13.7 | 15.3 | 17.1 | 19.3 | 21.9 | 21.5 | 23.3 | 23.9 | 21.3 | 21.0 | 21.9 | 22.7 |
| | 8,000 | 11.8 | 13.7 | 15.7 | 17.9 | 20.7 | 20.2 | 21.9 | 22.4 | 19.8 | 19.4 | 20.5 | 21.4 |
| | 9,000 | 7.2 | 9.2 | 11.3 | 13.6 | 16.8 | 16.8 | 18.9 | 19.6 | 17.2 | 16.8 | 17.9 | 18.5 |
| | 10,000 | 3.0 | 4.9 | 7.2 | 9.8 | 13.3 | 13.8 | 16.2 | 17.4 | 14.9 | 14.5 | 15.9 | 16.7 |
| | 11,000 | 1.9 | 3.4 | 5.4 | 8.2 | 12.1 | 12.2 | 14.5 | 15.6 | 13.3 | 12.8 | 14.1 | 15.0 |
| | 12,000 | | 1.0 | 2.8 | 5.4 | 9.4 | 10.0 | 12.5 | 14.0 | 11.9 | 11.5 | 12.9 | 13.9 |
| | 13,000 | | | 1.0 | 3.0 | 6.9 | 8.1 | 11.1 | 13.1 | 11.0 | 10.7 | 12.1 | 13.1 |
| | 14,000 | | | | 1.8 | 5.4 | 7.0 | 9.8 | 11.8 | 10.0 | 9.9 | 11.4 | 12.4 |
| | 15,000 | | | | | 2.8 | 4.8 | 7.7 | 10.2 | 8.6 | 8.7 | 10.4 | 11.5 |
| | 17,000 | | | | | | 1.8 | 5.0 | 7.5 | 6.5 | 6.8 | 8.5 | 10.0 |
| | 19,000 | | | | | | | 2.3 | 4.8 | 4.6 | 5.0 | 6.9 | 8.4 |
| | 21,000 | | | | | | | | 1.9 | 2.0 | 2.6 | 4.7 | 6.6 |
| | 23,000 | | | | | | | | | 0.7 | 1.6 | 3.6 | 5.7 |
| | 25,000 | | | | | | | | | | 1.2 | 3.0 | 5.0 |
| | 27,000 | | | | | | | | | | | 1.2 | 3.3 |
| | 29,000 | | | | | | | | | | | | 1.5 |

**Table 5.D-59. Percent Redd Dewatered Look-up Table for California Central Valley Steelhead with ACID Dam Boards In (the percent of redds dewatered are looked up at the intersection of the "Spawning Flow" columns and "Dewatering Flow" rows).**

| | Spawning Flow | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | 3,500 | 3,750 | 4,000 | 4,250 | 4,500 | 4,750 | 5,000 | 5,250 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 |
| 3,250 | 1.1 | 2.3 | 3.3 | 4.7 | 6.5 | 8.7 | 11 | 13.6 | 16 | 20.3 | 23.9 | 26.9 | 29.3 | 31.8 | 37.6 | 42.3 | 46.7 |
| 3,500 | | 1.4 | 2.2 | 3.2 | 4.6 | 6.4 | 8.4 | 10.8 | 13 | 17.1 | 20.6 | 23.7 | 26.1 | 28.6 | 34.5 | 39.2 | 43.5 |
| 3,750 | | | 0.6 | 1.3 | 2.6 | 4.1 | 5.9 | 8.1 | 10 | 13.6 | 17 | 20 | 22.5 | 25.1 | 31.2 | 35.9 | 40.3 |
| 4,000 | | | | 0.9 | 2.1 | 3.3 | 4.7 | 6.7 | 8.3 | 11.6 | 14.6 | 17.4 | 19.7 | 22.2 | 28.3 | 33.3 | 37.8 |
| 4,250 | | | | | 1.3 | 2.6 | 4 | 5.8 | 7.2 | 10.3 | 13.2 | 15.9 | 18.1 | 20.5 | 26.5 | 31.3 | 35.7 |
| 4,500 | | | | | | 1.4 | 2.7 | 4.2 | 5.5 | 8.2 | 10.8 | 13.3 | 15.4 | 17.6 | 23.6 | 28.4 | 32.7 |
| 4,750 | | | | | | | 1.5 | 2.9 | 3.8 | 6.2 | 8.5 | 11 | 12.9 | 15.1 | 20.9 | 25.7 | 30 |
| 5,000 | | | | | | | | 1.7 | 2.4 | 4.4 | 6.5 | 8.8 | 10.6 | 12.6 | 18.3 | 23.1 | 27.5 |
| 5,250 | | | | | | | | | 1.1 | 2.6 | 4.6 | 6.5 | 8 | 9.6 | 15 | 19.7 | 24 |
| 5,500 | | | | | | | | | | 1.5 | 3.2 | 4.8 | 6.2 | 7.7 | 12.8 | 17.5 | 21.6 |
| 6,000 | | | | | | | | | | | 1.3 | 2.7 | 3.8 | 5.1 | 9.9 | 14.3 | 18.3 |
| 6,500 | | | | | | | | | | | | 2.7 | 1.4 | 2.5 | 6.9 | 10.8 | 14.8 |
| 7,000 | | | | | | | | | | | | | 0.5 | 1.3 | 4.9 | 8.4 | 12.2 |
| 7,500 | | | | | | | | | | | | | | 0.7 | 4 | 7.3 | 10.8 |
| 8,000 | | | | | | | | | | | | | | | 3 | 5.9 | 9.2 |
| 9,000 | | | | | | | | | | | | | | | | 2.2 | 4.4 |
| 10,000 | | | | | | | | | | | | | | | | | 1.6 |
| 11,000 | | | | | | | | | | | | | | | | | |
| 12,000 | | | | | | | | | | | | | | | | | |
| 13,000 | | | | | | | | | | | | | | | | | |
| 14,000 | | | | | | | | | | | | | | | | | |
| 15,000 | | | | | | | | | | | | | | | | | |
| 17,000 | | | | | | | | | | | | | | | | | |
| 19,000 | | | | | | | | | | | | | | | | | |
| 21,000 | | | | | | | | | | | | | | | | | |
| 23,000 | | | | | | | | | | | | | | | | | |
| 25,000 | | | | | | | | | | | | | | | | | |
| 27,000 | | | | | | | | | | | | | | | | | |
| 29,000 | | | | | | | | | | | | | | | | | |

**Table 5.D-59 (cont.)**

| | | Spawning Flow | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12,000 | 13,000 | 14,000 | 15,000 | 17,000 | 19,000 | 21,000 | 23,000 | 25,000 | 27,000 | 29,000 | 31,000 |
| Dewatering Flow | 3,250 | 50.5 | 53.5 | 55.6 | 56.3 | 54.1 | 49.5 | 46.8 | 42.3 | 39.1 | 38.3 | 37.7 | 39.2 |
| | 3,500 | 47.4 | 50.6 | 52.9 | 54.1 | 52.3 | 48.1 | 45.6 | 41.3 | 38.2 | 37.6 | 37 | 38.5 |
| | 3,750 | 44.2 | 47.4 | 49.9 | 51.4 | 50.6 | 46.3 | 44.4 | 40.4 | 37.6 | 37 | 36.5 | 38.1 |
| | 4,000 | 41.7 | 45.1 | 47.7 | 49.4 | 48.3 | 44.8 | 43.2 | 39.4 | 37 | 36.5 | 36.2 | 37.8 |
| | 4,250 | 36.5 | 42.8 | 45.5 | 47.3 | 46.6 | 43.2 | 41.7 | 38.2 | 36 | 35.6 | 35.4 | 37.1 |
| | 4,500 | 36.6 | 39.8 | 42.6 | 44.6 | 44.5 | 41.5 | 40.1 | 36.5 | 34.2 | 34 | 34 | 35.8 |
| | 4,750 | 33.7 | 37 | 39.7 | 41.8 | 42.1 | 39.4 | 38.2 | 34.8 | 32.9 | 32.8 | 33 | 34.8 |
| | 5,000 | 31.2 | 34.4 | 37.2 | 39.4 | 39.8 | 37.2 | 36.2 | 32.8 | 31.1 | 31.1 | 31.1 | 32.8 |
| | 5,250 | 27.9 | 31.1 | 33.8 | 36.2 | 36.9 | 34.8 | 33.8 | 30.3 | 28.2 | 28.4 | 28.9 | 30.4 |
| | 5,500 | 25.3 | 28.4 | 31.1 | 33.5 | 34.5 | 32.8 | 32.3 | 28.9 | 26.8 | 27 | 27.3 | 28.8 |
| | 6,000 | 21.9 | 25.1 | 27.8 | 30.2 | 31.3 | 29.7 | 29.4 | 26.3 | 24.3 | 24.5 | 24.8 | 26 |
| | 6,500 | 18.7 | 22.1 | 27.8 | 27.1 | 28.1 | 26.2 | 25.9 | 22.9 | 21.2 | 21.5 | 21.7 | 22.8 |
| | 7,000 | 16.2 | 19.6 | 22.5 | 24.9 | 26.4 | 24.7 | 24.5 | 21.7 | 19.9 | 20.2 | 20.4 | 21.4 |
| | 7,500 | 14.8 | 18.3 | 21.2 | 23.7 | 25.2 | 23.5 | 23.5 | 20.7 | 19.1 | 19.3 | 19.4 | 20.4 |
| | 8,000 | 13.1 | 16.6 | 19.5 | 21.9 | 23.7 | 22.2 | 22.5 | 19.7 | 18 | 18.1 | 18.5 | 19.5 |
| | 9,000 | 7.6 | 10.8 | 13.6 | 16.6 | 19.4 | 18.7 | 19.3 | 16.8 | 15.2 | 15.4 | 15.9 | 17 |
| | 10,000 | 3.6 | 6.6 | 9.2 | 12.1 | 15.1 | 15.3 | 16.4 | 14.5 | 12.9 | 13.4 | 14.3 | 15.5 |
| | 11,000 | 2.3 | 5 | 7.5 | 10.1 | 13.1 | 13.1 | 14.5 | 12.8 | 11.5 | 11.9 | 12.8 | 14.1 |
| | 12,000 | | 2.2 | 4.3 | 6.7 | 10.1 | 10.9 | 12.9 | 11.4 | 10.4 | 10.9 | 11.9 | 13.2 |
| | 13,000 | | | 3.7 | 3.6 | 6.8 | 8.3 | 10.7 | 10.5 | 9.6 | 10.3 | 11.3 | 12.7 |
| | 14,000 | | | | 2.1 | 5.1 | 6.6 | 9.1 | 9 | 8.3 | 9.2 | 10.3 | 11.9 |
| | 15,000 | | | | | 2.6 | 4.2 | 7.2 | 7.9 | 7.4 | 8.3 | 9.4 | 10.9 |
| | 17,000 | | | | | | 1.9 | 5.1 | 5.8 | 5.6 | 6.8 | 8.3 | 10 |
| | 19,000 | | | | | | | 3 | 3.7 | 3.8 | 5.1 | 6.7 | 8.4 |
| | 21,000 | | | | | | | | 1.4 | 1.8 | 2.9 | 4.4 | 6.3 |
| | 23,000 | | | | | | | | | 0.9 | 2.2 | 3.8 | 5.7 |
| | 25,000 | | | | | | | | | | 1.7 | 3.4 | 5.4 |
| | 27,000 | | | | | | | | | | | 1.8 | 3.8 |
| | 29,000 | | | | | | | | | | | | 2.2 |

**Table 5.D-60. Percent Redd Dewatered Look-up Table for California Central Valley Steelhead with ACID Dam Boards In (the percent of redds dewatered are looked up at the intersection of the "Spawning Flow" columns and "Dewatering Flow" rows).**

| | Spawning Flow | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | 3,500 | 3,750 | 4,000 | 4,250 | 4,500 | 4,750 | 5,000 | 5,250 | 5,500 | 6,000 | 6,500 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 |
| 3,250 | 1.1 | 2.3 | 3.3 | 4.7 | 6.5 | 8.7 | 11 | 13.6 | 16 | 20.3 | 23.9 | 26.9 | 29.3 | 31.8 | 37.6 | 42.3 | 46.7 |
| 3,500 | | 1.4 | 2.2 | 3.2 | 4.6 | 6.4 | 8.4 | 10.8 | 13 | 17.1 | 20.6 | 23.7 | 26.1 | 28.6 | 34.5 | 39.2 | 43.5 |
| 3,750 | | | 0.6 | 1.3 | 2.6 | 4.1 | 5.9 | 8.1 | 10 | 13.6 | 17 | 20 | 22.5 | 25.1 | 31.2 | 35.9 | 40.3 |
| 4,000 | | | | 0.9 | 2.1 | 3.3 | 4.7 | 6.7 | 8.3 | 11.6 | 14.6 | 17.4 | 19.7 | 22.2 | 28.3 | 33.3 | 37.8 |
| 4,250 | | | | | 1.3 | 2.6 | 4 | 5.8 | 7.2 | 10.3 | 13.2 | 15.9 | 18.1 | 20.5 | 26.5 | 31.3 | 35.7 |
| 4,500 | | | | | | 1.4 | 2.7 | 4.2 | 5.5 | 8.2 | 10.8 | 13.3 | 15.4 | 17.6 | 23.6 | 28.4 | 32.7 |
| 4,750 | | | | | | | 1.5 | 2.9 | 3.8 | 6.2 | 8.5 | 11 | 12.9 | 15.1 | 20.9 | 25.7 | 30 |
| 5,000 | | | | | | | | 1.7 | 2.4 | 4.4 | 6.5 | 8.8 | 10.6 | 12.6 | 18.3 | 23.1 | 27.5 |
| 5,250 | | | | | | | | | 1.1 | 2.6 | 4.6 | 6.5 | 8 | 9.6 | 15 | 19.7 | 24 |
| 5,500 | | | | | | | | | | 1.5 | 3.2 | 4.8 | 6.2 | 7.7 | 12.8 | 17.5 | 21.6 |
| 6,000 | | | | | | | | | | | 1.3 | 2.7 | 3.8 | 5.1 | 9.9 | 14.3 | 18.3 |
| 6,500 | | | | | | | | | | | | 2.7 | 1.4 | 2.5 | 6.9 | 10.8 | 14.8 |
| 7,000 | | | | | | | | | | | | | 0.5 | 1.3 | 4.9 | 8.4 | 12.2 |
| 7,500 | | | | | | | | | | | | | | 0.7 | 4 | 7.3 | 10.8 |
| 8,000 | | | | | | | | | | | | | | | 3 | 5.9 | 9.2 |
| 9,000 | | | | | | | | | | | | | | | | 2.2 | 4.4 |
| 10,000 | | | | | | | | | | | | | | | | | 1.6 |
| 11,000 | | | | | | | | | | | | | | | | | |
| 12,000 | | | | | | | | | | | | | | | | | |
| 13,000 | | | | | | | | | | | | | | | | | |
| 14,000 | | | | | | | | | | | | | | | | | |
| 15,000 | | | | | | | | | | | | | | | | | |
| 17,000 | | | | | | | | | | | | | | | | | |
| 19,000 | | | | | | | | | | | | | | | | | |
| 21,000 | | | | | | | | | | | | | | | | | |
| 23,000 | | | | | | | | | | | | | | | | | |
| 25,000 | | | | | | | | | | | | | | | | | |
| 27,000 | | | | | | | | | | | | | | | | | |
| 29,000 | | | | | | | | | | | | | | | | | |

**Table 5.D-60 (cont.)**

| | | Spawning Flow | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering Flow | | 12,000 | 13,000 | 14,000 | 15,000 | 17,000 | 19,000 | 21,000 | 23,000 | 25,000 | 27,000 | 29,000 | 31,000 |
| | 3,250 | 50.5 | 53.5 | 55.6 | 56.3 | 54.1 | 49.5 | 46.8 | 42.3 | 39.1 | 38.3 | 37.7 | 39.2 |
| | 3,500 | 47.4 | 50.6 | 52.9 | 54.1 | 52.3 | 48.1 | 45.6 | 41.3 | 38.2 | 37.6 | 37 | 38.5 |
| | 3,750 | 44.2 | 47.4 | 49.9 | 51.4 | 50.6 | 46.3 | 44.4 | 40.4 | 37.6 | 37 | 36.5 | 38.1 |
| | 4,000 | 41.7 | 45.1 | 47.7 | 49.4 | 48.3 | 44.8 | 43.2 | 39.4 | 37 | 36.5 | 36.2 | 37.8 |
| | 4,250 | 36.5 | 42.8 | 45.5 | 47.3 | 46.6 | 43.2 | 41.7 | 38.2 | 36 | 35.6 | 35.4 | 37.1 |
| | 4,500 | 36.6 | 39.8 | 42.6 | 44.6 | 44.5 | 41.5 | 40.1 | 36.5 | 34.2 | 34 | 34 | 35.8 |
| | 4,750 | 33.7 | 37 | 39.7 | 41.8 | 42.1 | 39.4 | 38.2 | 34.8 | 32.9 | 32.8 | 33 | 34.8 |
| | 5,000 | 31.2 | 34.4 | 37.2 | 39.4 | 39.8 | 37.2 | 36.2 | 32.8 | 31.1 | 31.1 | 31.1 | 32.8 |
| | 5,250 | 27.9 | 31.1 | 33.8 | 36.2 | 36.9 | 34.8 | 33.8 | 30.3 | 28.2 | 28.4 | 28.9 | 30.4 |
| | 5,500 | 25.3 | 28.4 | 31.1 | 33.5 | 34.5 | 32.8 | 32.3 | 28.9 | 26.8 | 27 | 27.3 | 28.8 |
| | 6,000 | 21.9 | 25.1 | 27.8 | 30.2 | 31.3 | 29.7 | 29.4 | 26.3 | 24.3 | 24.5 | 24.8 | 26 |
| | 6,500 | 18.7 | 22.1 | 27.8 | 27.1 | 28.1 | 26.2 | 25.9 | 22.9 | 21.2 | 21.5 | 21.7 | 22.8 |
| | 7,000 | 16.2 | 19.6 | 22.5 | 24.9 | 26.4 | 24.7 | 24.5 | 21.7 | 19.9 | 20.2 | 20.4 | 21.4 |
| | 7,500 | 14.8 | 18.3 | 21.2 | 23.7 | 25.2 | 23.5 | 23.5 | 20.7 | 19.1 | 19.3 | 19.4 | 20.4 |
| | 8,000 | 13.1 | 16.6 | 19.5 | 21.9 | 23.7 | 22.2 | 22.5 | 19.7 | 18 | 18.1 | 18.5 | 19.5 |
| | 9,000 | 7.6 | 10.8 | 13.6 | 16.6 | 19.4 | 18.7 | 19.3 | 16.8 | 15.2 | 15.4 | 15.9 | 17 |
| | 10,000 | 3.6 | 6.6 | 9.2 | 12.1 | 15.1 | 15.3 | 16.4 | 14.5 | 12.9 | 13.4 | 14.3 | 15.5 |
| | 11,000 | 2.3 | 5 | 7.5 | 10.1 | 13.1 | 13.1 | 14.5 | 12.8 | 11.5 | 11.9 | 12.8 | 14.1 |
| | 12,000 | | 2.2 | 4.3 | 6.7 | 10.1 | 10.9 | 12.9 | 11.4 | 10.4 | 10.9 | 11.9 | 13.2 |
| | 13,000 | | | 3.7 | 3.6 | 6.8 | 8.3 | 10.7 | 10.5 | 9.6 | 10.3 | 11.3 | 12.7 |
| | 14,000 | | | | 2.1 | 5.1 | 6.6 | 9.1 | 9 | 8.3 | 9.2 | 10.3 | 11.9 |
| | 15,000 | | | | | 2.6 | 4.2 | 7.2 | 7.9 | 7.4 | 8.3 | 9.4 | 10.9 |
| | 17,000 | | | | | | 1.9 | 5.1 | 5.8 | 5.6 | 6.8 | 8.3 | 10 |
| | 19,000 | | | | | | | 3 | 3.7 | 3.8 | 5.1 | 6.7 | 8.4 |
| | 21,000 | | | | | | | | 1.4 | 1.8 | 2.9 | 4.4 | 6.3 |
| | 23,000 | | | | | | | | | 0.9 | 2.2 | 3.8 | 5.7 |
| | 25,000 | | | | | | | | | | 1.7 | 3.4 | 5.4 |
| | 27,000 | | | | | | | | | | | 1.8 | 3.8 |
| | 29,000 | | | | | | | | | | | | 2.2 |

#### *5.D.2.2.5.2 American River*

No redd dewatering field data similar to USFWS (2006) were available for CCV steelhead in the American River; therefore, the flow reduction from the spawning to the dewatering flow was used directly. The spawning and dewatering flows for each location and month of CCV steelhead spawning under the PA and the NAA, as estimated by CALSIM II, were used to compute the reduction, expressed as a percentage of the spawning flow, under the two scenarios. Absolute differences in percentages of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on CCV steelhead and warranting further investigation.

### *5.D.2.2.6 Redd Scour*

The probability of flows occurring that would be high enough to mobilize sediments and scour or entomb Chinook salmon and CCV steelhead redds was estimated for the PA and the NAA using monthly modeled flows from CALSIM. The amount of flow needed to mobilize sediments in the Sacramento and American Rivers has been little studied (Kondolf 2000; Ayers 2001), but the information available suggests that a minimum of roughly 40,000 cubic feet per second (cfs) of flow is required in both rivers for significant bed movement (scour flow threshold) (Table 5.D-61). It should be noted that 40,000 cfs is likely to be a conservative estimate for redd scour because, due to the areas of a streambed that salmonids typically select for redd construction, the flows needed to scour redds may be significantly greater than those that initiate bed mobility (May et al. 2009).

**Table 5.D-61. Estimated Bed Mobility Flows for Potentially Affected Rivers.**

| River | Approximate flow ranges to initiate mobility (cfs) | References |
|---|---|---|
| Sacramento River | 24,000–50,000 | Kondolf 2000; Cain and Monohan 2008 |
| American River | 26,500–50,000 | Ayres Associates 2001; Fairman 2007 |

Redd scour could occur at a very small temporal scale (minutes to hours), whereas CALSIM provides mean monthly flow estimates, and daily flows used to model daily water temperatures in HEC-5Q were uniform within a month and, therefore, not useful for this analysis. In an attempt to overcome this discrepancy in temporal scales, historical monthly and daily flow data during December through April (when scour is most likely to occur) were plotted to determine whether the probability of occurrence of daily flows above the scour flow threshold could be predicted with monthly flow data (Figure 5.D-91, Figure 5.D-92, Figure 5.D-93). The purpose was to find the minimum monthly flow value at which the maximum daily flow in that month would always be greater than the 40,000-cfs scour flow threshold. These minimum monthly flows were found to be 27,300 cfs at Keswick Dam, 21,800 cfs at Bend Bridge, and 19,350 cfs at Hazel Avenue. Therefore, the redd scour/entombment risks for the PA and the NAA were evaluated by comparing frequencies of CALSIM II flows greater than these minimum monthly flows during the spawning and incubation periods of the winter-run and spring-run Chinook salmon and CCV steelhead. CALSIM II flows for Keswick Dam were used to estimate the Keswick Dam flows, CALSIM II flows for Red Bluff were used to estimate the Bend Bridge flows, and CALSIM II flows for Nimbus Dam were used to estimate the Hazel Avenue flows. The Red Bluff location is about 14 miles downstream of Bend Bridge and the Nimbus Dam location is immediately upstream of the Hazel Avenue gage location.

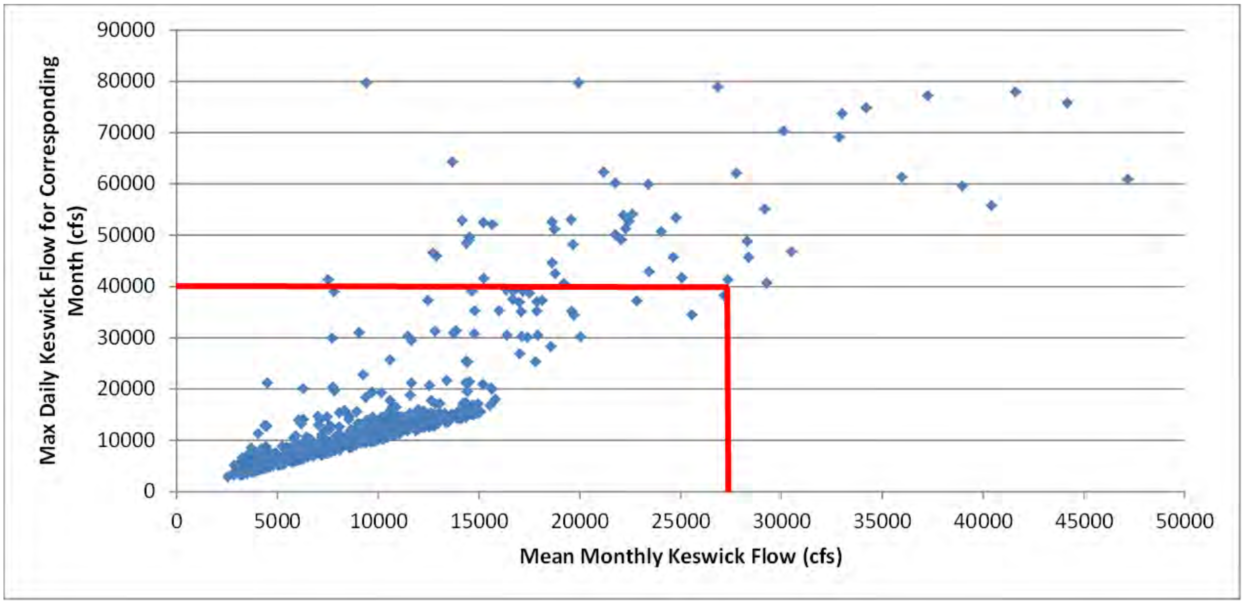



**Figure 5.D-91. Relationship between Mean Monthly Flows and Maximum Daily Flows during December through April, Sacramento River at Keswick 1938–2015. Minimum monthly flow is identified in red.**

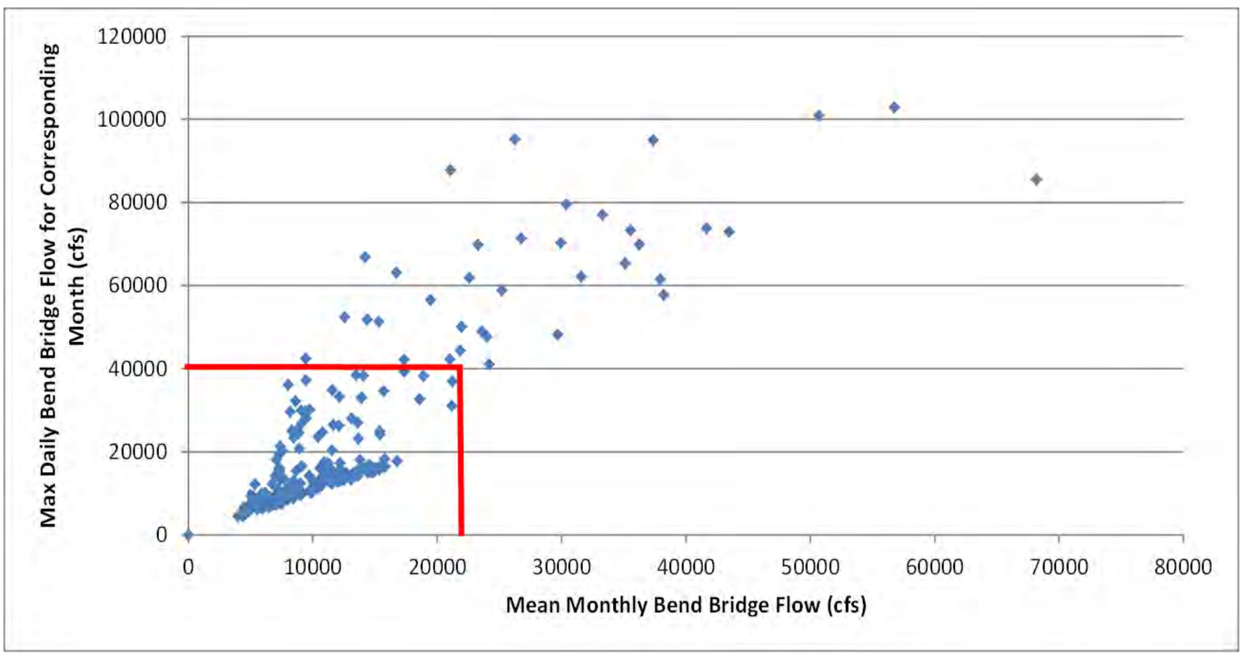



**Figure 5.D-92. Relationship between Mean Monthly Flows and Maximum Daily Flows during December through April, Sacramento River at Bend Bridge, 1993–2015. Minimum monthly flow is identified in red.**

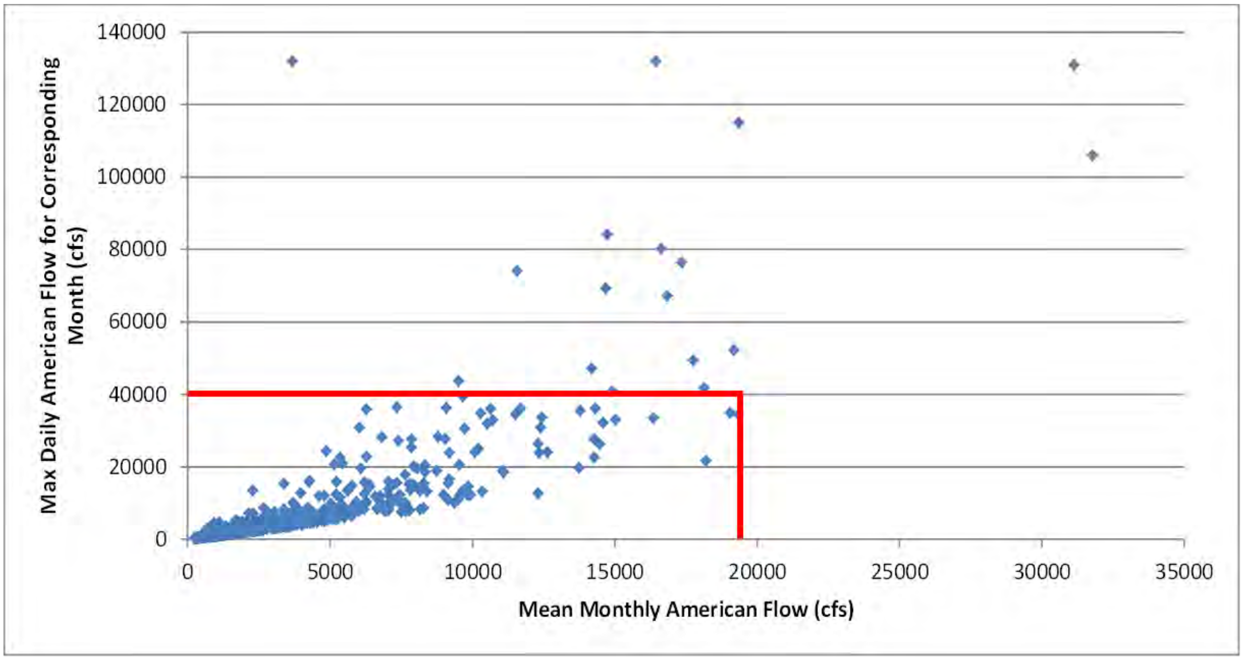



**Figure 5.D-93. Relationship between Mean Monthly Flows and Maximum Daily Flows during December through April, American River Downstream of Hazel Avenue, 1950–2015. Minimum monthly flow is identified in red.**

#### *5.D.2.2.7 SALMOD*

As described in Section 5.D.2.1.2.4, *SALMOD*, the SALMOD model was used to evaluate flow- and temperature-related mortality of early life stages and overall production of winter- and spring-run Chinook salmon in the Sacramento River. Attachment 5.D.2, *SALMOD Model*, describes the details of the model.

There are two primary sources of mortality evaluated in SALMOD, water temperature-related and flow-related, both of which could affect multiple life stages. Flow-related mortality for the *Spawning, Egg incubation, and Alevins* section of the results includes *incubation* mortality (which refers to redd dewatering and scour) and *superimposition* (of redds) mortality (see Attachment 5.D.2, *SALMOD Model*, for full description). Redd superimposition for each race of salmon is predicted without consideration of redd densities of the other races. Flow-related mortality results of the NAA and PA are presented as exceedance plots and mean annual values, as well as differences between NAA and PA. The mean values are presented by water year type and for all water year types combined. A 5% difference between NAA and PA in mean number of a life stage lost was considered biologically meaningful.

### 5.D.2.3 Rearing Flows Methods

#### *5.D.2.3.1 Introduction*

This section describes procedures used in the effects analysis to evaluate potential flow-related effects - resulting from the No Action Alternative (NAA) and Proposed Action (PA) on rearing habitat of winter-run and spring-run Chinook salmon, California Central Valley (CCV) steelhead, and Southern Distinct Population Segment (DPS) green sturgeon in the Sacramento and American Rivers. The specific potential effects evaluated are (1) changes in flow conditions during the months of fry and juvenile rearing and (2) the availability of suitable physical habitat for fry and juvenile rearing.

Modeled flow results for key locations in the Sacramento and American Rivers are reported in Appendix 5A, *CALSIM Methods and Results*. Results in Appendix 5A are presented as (1) mean monthly exceedance plots; (2) box and whiskers plots, with mean, median, quartiles, and 25$^{th}$ and 75$^{th}$ percentile values indicated; and (3) a table of summary statistics and differences between the NAA and PA for each statistic.

The availability of rearing habitat was estimated using weighted usable area (WUA) curves obtained from the literature (U.S. Fish and Wildlife Service 2005b). WUA is an index of the surface area of physical habitat available, weighted by the suitability of that habitat. WUA curves are normally developed as part of instream flow incremental methodology (IFIM) studies.

A potential effect that is not evaluated in the effects analysis is juvenile stranding. Juvenile stranding generally results from reductions in flow that occur over short periods of time, and the CALSIM modeling used to evaluate flow in this effects analysis has a monthly time step, which is too long for any meaningful analysis of juvenile stranding. Juvenile salmon typically rest in shallow slow-moving water between feeding forays into swifter water. This tendency makes them particularly susceptible to stranding during rapid reductions in flow that dewater and isolate the shallow river margin areas (Jarrett and Killam 2015). Juveniles are most vulnerable to stranding during periods of high and fluctuating flow, when they typically move into side channel habitats that may be extensively inundated. Stranding can lead to direct mortality when these areas drain or dry up, or to indirect mortality from predators or rising water temperatures and deteriorating water quality. High, rapidly changing flows may result from flow release pulses to meet Delta water quality standards and from flood control releases, as well as from tributary freshets following rain events (Jarrett and Killam 2015, USBR 2008). Stranding may also occur during periods of controlled flow reductions, such as when irrigation demand declines in the fall (NMFS 2009) or following gate removal at the ACID dam in November and the RBDD dam in September (NMFS 2009).

The effect of juvenile stranding on production of Chinook salmon and steelhead populations is not well understood, but stranding is frequently identified as a potentially important mortality factor for the populations in the Sacramento River and its tributaries (Snider et al. 2001, USFWS 2001, Water Forum 2005, Reclmation 2008, NMFS 2009, Cramer Fish Sciences 2014, Jarret and Killam 2014, 2015). To determine the impact of juvenile stranding on salmonid populations, the number of juveniles lost to stranding is compared the number of juveniles produced. Numbers of stranded juveniles observed in CDFW juvenile stranding surveys are typically very low relative to estimates of total juvenile production. For instance, in the most recent CDFW stranding surveys, 76 surveys conducted from Keswick Dam 73 miles downstream to Tehama Bridge between August 11, 2014 and April 10, 2015, survey teams counted 798 stranded juvenile winter-run Chinook salmon. Of these, 105 were judged not likely to survive based on stranding site conditions and weather forecasts. This number is very small in comparison to the USFWS Juvenile Production Index (JPI), the estimated number of fry equivalents at RBDD, which was 502,506 fish for 2014 (up to December 3) (Kratville 2014, enclosure 2 of NMFS 2015). However, the numbers of stranded juveniles reported in the CDFW survey reports are estimates of observed stranded juveniles and "do not represent the exact total number of stranded fish or fish mortality in this reach or throughout the whole Upper Sacramento River Basin" (Jarrett and Killam 2015). They cannot, therefore, be meaningfully compared to the juvenile production estimate. If the CDFW juvenile stranding surveys continue and improve in the future, meaningful comparisons may be possible, allowing direct estimates of percent mortality resulting from juvenile stranding.

The NMFS 2009 includes ramping rate restrictions on flow releases from both Keswick Dam and Nimbus Dam to reduce the risk of juvenile stranding and redd dewatering. The restrictions for Keswick Dam are given as follows (NMFS 2009, Appendix 1):

> Reclamation proposes a minimum flow of 3,250 cfs from October 1 through March 31 and ramping constraints for Keswick release reductions from July 1 through March 31 as follows:
>
> - Releases must be reduced between sunset and sunrise.
> - When Keswick releases are 6,000 cfs or greater, decreases may not exceed 15 percent per night. Decreases also may not exceed 2.5 percent in one hour.
> - For Keswick releases between 4,000 and 5,999 cfs, decreases may not exceed 200 cfs per night. Decreases also may not exceed 100 cfs per hour.
> - For Keswick releases between 3,250 and 3,999 cfs, decreases may not exceed 100 cfs per night.
> - Variances to these release requirements are allowed under flood control operations.

The ramping restrictions for Nimbus Dam, Action II.4 of the RPA, together with their objective and rationale are given as follows:

**<u>Action II.4. Minimize Flow Fluctuation Effects</u>**

**Objective**: Reduce stranding and isolation of juvenile steelhead through ramping protocols.

**Action:** The following flow fluctuation objectives shall be followed:

1) From January 1 through May 30, at flow levels <5,000 cfs, flow reductions shall not exceed more than 500 cfs/day and not more than 100 cfs per hour.

2) From January 1 through May 30, Reclamation shall coordinate with NMFS, CDFG, and USFWS to fund and implement monitoring in order to estimate the incidental take of salmonids associated with reductions in Nimbus Dam releases.

3) Minimize the occurrence of flows exceeding 4,000 cfs throughout the year, except as may be necessary for flood control or in response to natural high precipitation events.

**Rationale:** Flow fluctuations in the lower American River have been documented to result in steelhead redd dewatering and isolation (Hannon *et al.,* 2003, Hannon and Deason 2008 as cited in National Marine Fisheries Service 2009), fry stranding, and fry and juvenile isolation (Water Forum 2005a). By limiting the rate of flow reductions, the risk of stranding and isolating steelhead is reduced. Two lower American River habitat evaluations indicate that releases above 4,000 cfs inundate several pools along the river that are isolated at flows below this threshold (CDFG 2001, Hall and Healey 2006 as cited in National Marine

Fisheries Service 2009). Thus, by maintaining releases below 4,000 cfs the risk of isolating juvenile steelhead is reduced.

All ramping restrictions for dams on the Sacramento River and its tributaries would be kept in place for the PA, and, therefore, it is expected that the juvenile stranding risk would be similar for the PA and the NAA. No further analyses regarding juvenile stranding were conducted

Details particular to each of the flow analysis methods implemented are provided below.

#### *5.D.2.3.2 Characterization of Flow*

The approach taken to characterize expected flows in the Sacramento and American Rivers for the PA and the NAA, and assessing the potential biological significance of changes in flow resulting from the PA, are based on CALSIM modeling.

#### *5.D.2.3.3 Weighted Usable Area Analysis Methods*

##### *5.D.2.3.3.1 Sacramento River*

The WUA curves used for Chinook salmon rearing habitat in the Sacramento River were obtained from a U.S. Fish and Wildlife Service (USFWS) report (U.S. Fish and Wildlife Service 2005b). As noted above, WUA is computed as the surface area of physical habitat available weighted by its suitability. Modeling assumptions used to derive WUA curves include that the suitability of physical habitat for salmon and steelhead rearing is largely a function of water depth, flow velocity, and the availability and type of cover. The race- or species-specific suitability of the habitat with respect to these variables is determined by observing the fish and is used to develop habitat suitability criteria (HSC) for each race or species. Hydraulic modeling is then used to estimate the amount of habitat available for different HSC levels at different river flows, and the results are used to develop rearing habitat WUA curves and tables (Leclerc et al. 1995; Bovee et al. 1998). These curves and tables are used to look up the amount of WUA available at different flows.

USFWS (2005b) provides WUA curves and tables for rearing winter-run, fall-run, and late fall–run Chinook salmon for three segments of the Sacramento River encompassing the reach from Keswick Dam to Battle Creek (Section 5.D.2.2, *Spawning Flows Methods*, Figure 5.D-86). Separate curves were developed for fry and juveniles, with fry defined as fish less than 60 millimeters and juveniles defined as greater than 60 millimeters. No WUA curves were developed for spring-run Chinook salmon or CCV steelhead, but, as discussed later, the fall-run curves were used to quantify spring-run rearing habitat and the late fall-run curves were used for steelhead. Figure 5.D-94 through RFM-6 show the flow versus rearing WUA results for fry and juvenile winter-run, fall-run, and late fall-run Chinook salmon in the three river segments (Segment 6 = Keswick to Anderson-Cottonwood Irrigation District [ACID] Dam, Segment 5 = ACID Dam to Cow Creek, and Segment 4 = Cow Creek to Battle Creek) as provided in USFWS 2006 (Section 5.D.2.2, *Spawning Flows Methods*, Figure 5.D-86). Note that for Segment 6, separate WUA curves were developed for periods when the ACID Dam boards were installed and for when the boards were out because installation of the boards affected water depths and velocities for some of the sampling transects used to develop the curves. All rearing WUA analyses were limited to juveniles less than a year old.

Because a number of tributaries enter the Sacramento River between Keswick Dam and Battle Creek, flows are generally different among the segments. For the USFWS studies, flows were measured directly at the sampling transects and were also estimated as the sum of Keswick Dam flow releases and tributary gage readings upstream of the transects. To estimate WUA for the effects analysis, the segment flows were estimated with CALSIM, using the midpoint location of each segment. For Segment 6, the WUA curves for the months when the ACID Dam boards are installed (April through October) were used with the flows for those months and the WUA curves for the months when the ACID Dam boards are out were used with the flows for the rest of the year.

Although fall-run rearing WUA curves were used as surrogates for spring-run rearing, CALSIM flows for the months of spring-run rearing, not those of fall-run rearing, were used to compute the spring-run WUA results. This caveat applies as well to the use of the late fall-run rearing WUA curves to compute CCV steelhead WUA results.

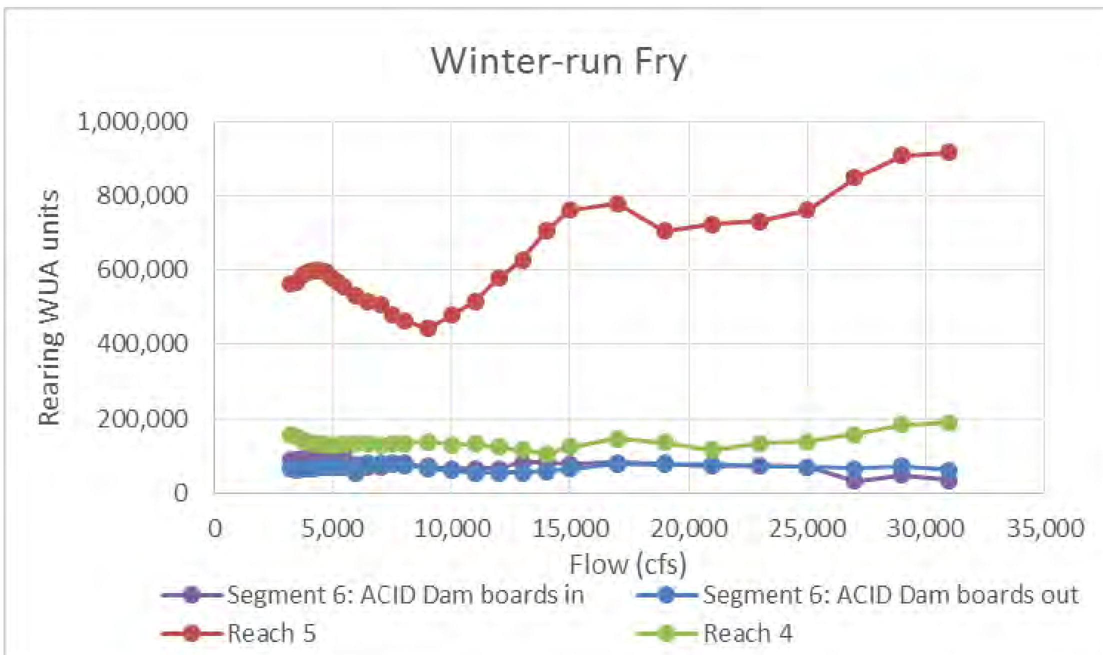



**Figure 5.D-94. Rearing WUA curves for Winter-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District.**

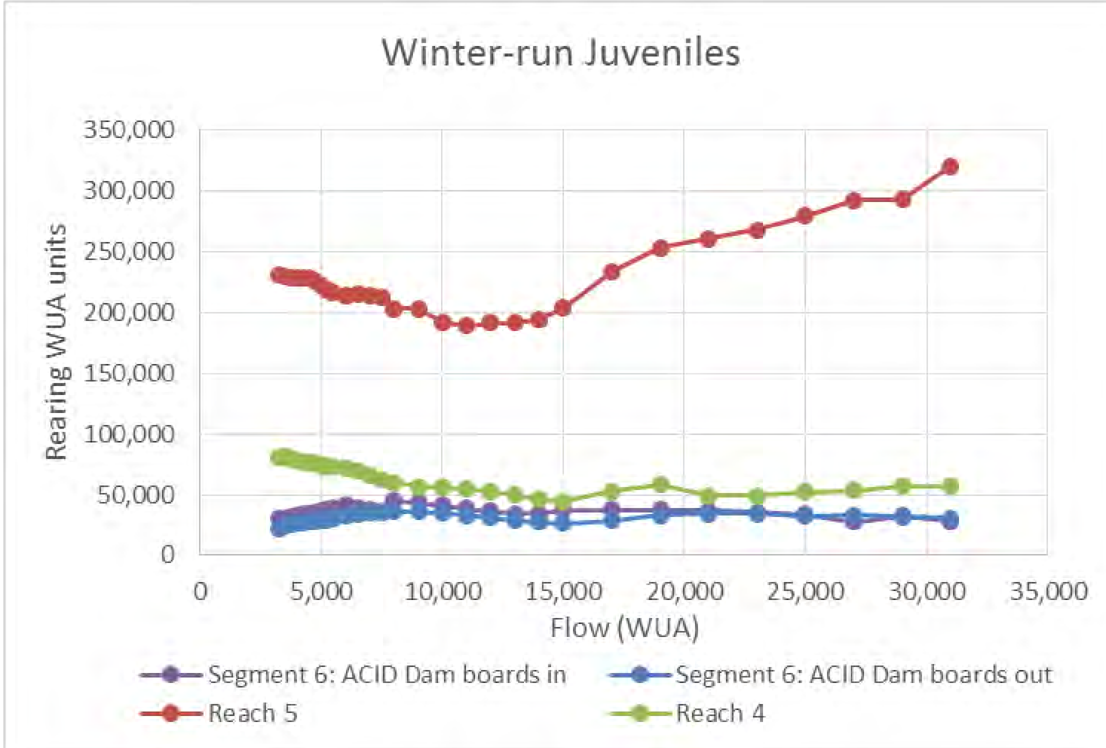



**Figure 5.D-95. Rearing WUA curves for Winter-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District.**

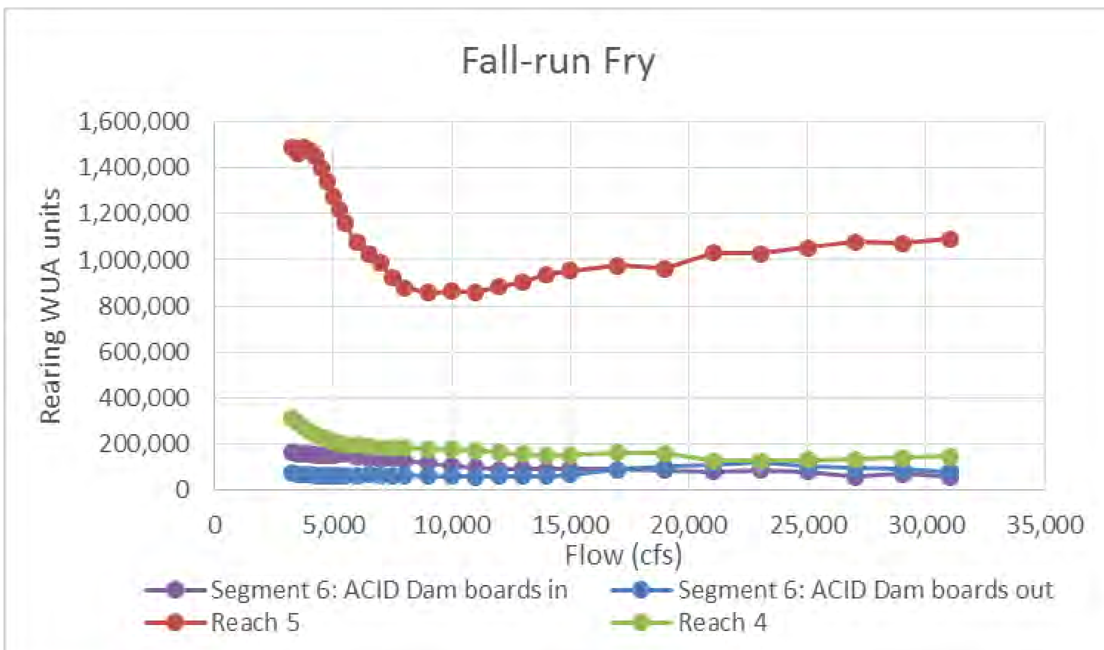



**Figure 5.D-96. Rearing WUA Curves for Fall-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6. (The fall-run curves were used to quantify spring-run Chinook salmon WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.**

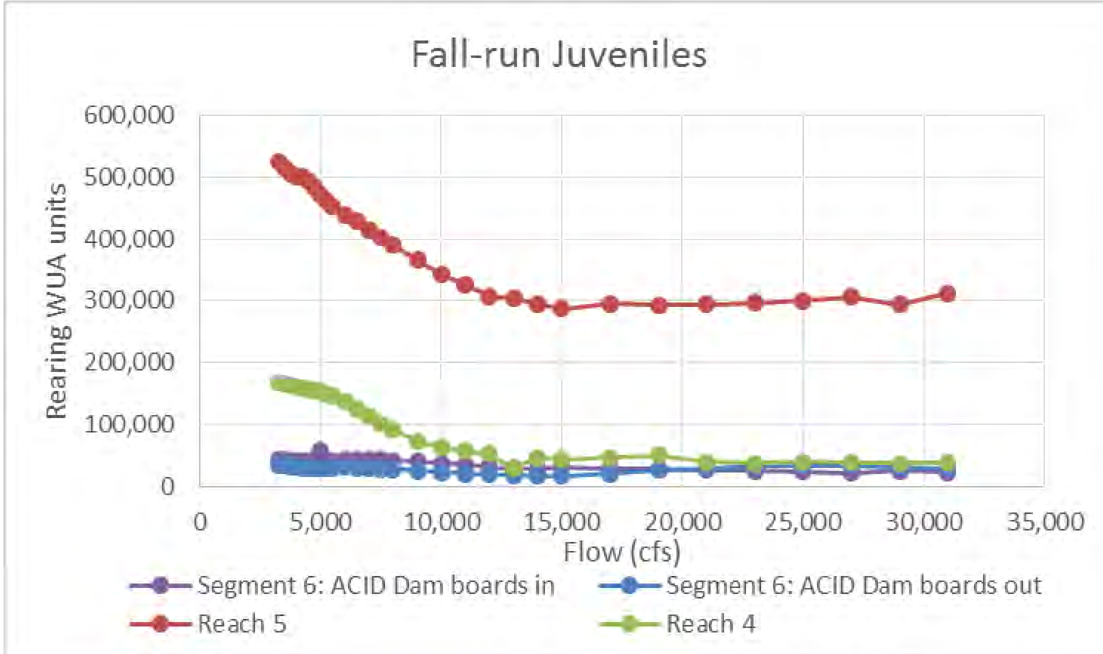



**Figure 5.D-97. Rearing WUA Curves for Fall-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6. (The fall-run curves were used to quantify spring-run Chinook salmon WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.**

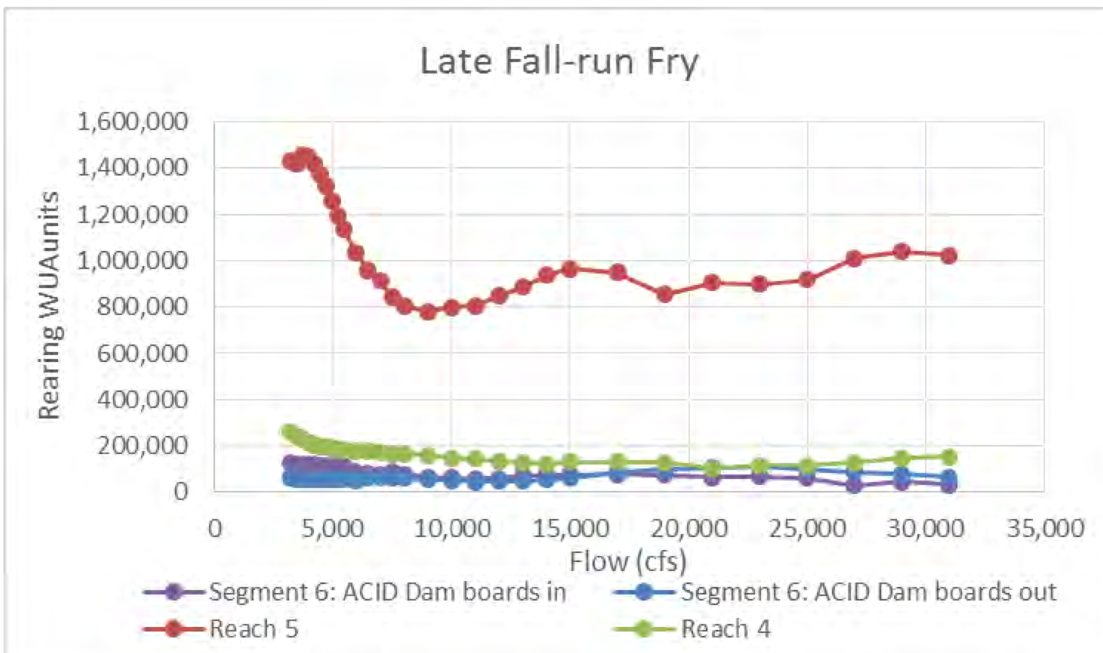



**Figure 5.D-98. Rearing WUA Curves for Late Fall-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6. (The late fall-run curves were used to quantify CCV steelhead rearing WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.**

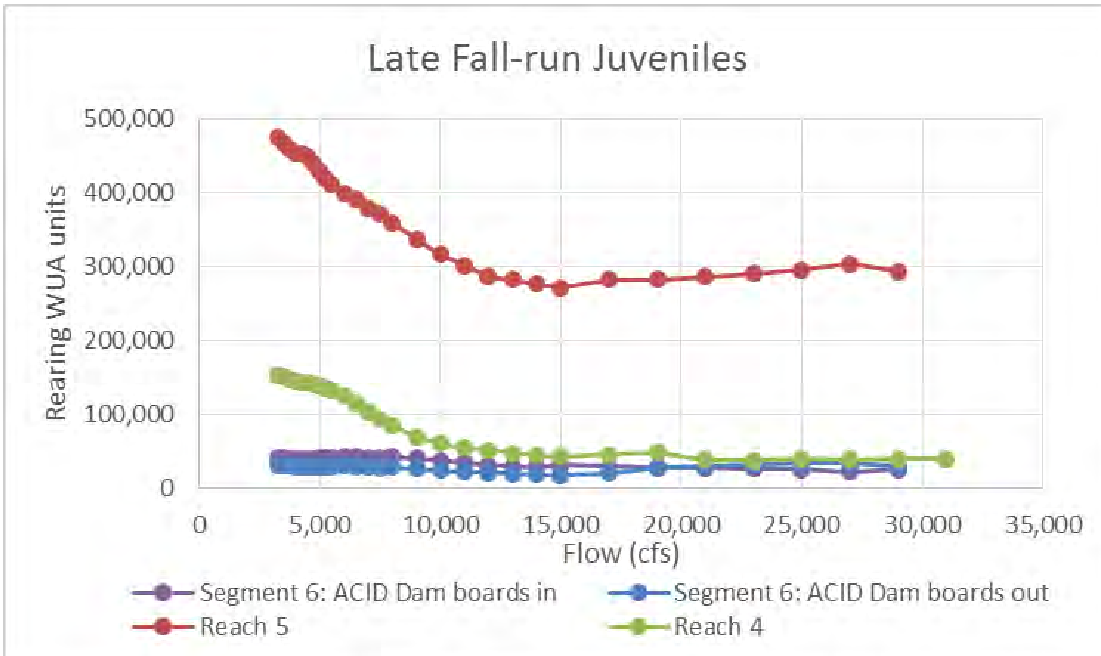



**Figure 5.D-99. Rearing WUA Curves for Late Fall-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6. (The late fall-run curves were used to quantify CCV steelhead rearing WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.**

As previously noted, there are no spring-run Chinook salmon– or CCV steelhead–rearing WUA curves in the USFWS documentation, so the fall-run and late fall-run Chinook salmon–rearing WUA curves were used as surrogates to model rearing habitat for spring-run and steelhead, respectively. These substitutions follow previous practice. For instance, the SacEFT model, which produces spawning and rearing WUA outputs for spring-run Chinook salmon and CCV steelhead, derives the spring-run WUA results using the fall-run Chinook salmon WUA curves as surrogates and the CCV steelhead WUA results using the late fall-run Chinook salmon WUA curves as surrogates (ESSA 2011; Robinson pers. comm.). Mark Gard, who led the USFWS studies that produced the Sacramento River WUA curves, has endorsed this practice for both spring-run Chinook salmon and CCV steelhead (Gard pers. comm.). It should be noted that this practice introduces additional uncertainty to the spring-run Chinook salmon and CCV steelhead results.

A potential limitation of the WUA curves presented above, as of all IFIM studies, is that they assume the channel characteristics of the river during the time of field data collection by USFWS (1995–1999), such as proportions of mesohabitat types, have remained in dynamic equilibrium to the present time and will continue to do so through the end of the PA (at least 15 years into the future). If the channel characteristics substantially change, the shape of the curves may no longer be applicable. A further limitation is that the curves were developed for the Sacramento River upstream of Battle Creek, but all races of Chinook salmon and CCV steelhead spend time rearing downstream of this part of the river.

Differences in rearing WUA under the PA and NAA for a given species or race were examined using exceedance plots of monthly mean WUA in each of the river segments for each water year type and all water year types combined for the fry and juvenile rearing periods (Table 5.D-62). Further, differences in rearing WUA in each segment under the PAA and NAA were examined using the grand mean rearing WUA for each month of the rearing periods under each water year type and all water year types combined. Differences in mean rearing WUA of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on Chinook salmon and CCV steelhead rearing habitat and warranting further investigation.

**Table 5.D-62. Fry and Juvenile Rearing Periods for Weighted Usable Area Analysis.**

| Race/Species | Fry (<60 mm) | Juvenile (>60 mm) |
|---|---|---|
| Winter-run Chinook salmon | July–October | September–November |
| Spring-run Chinook salmon | November–February | Year round |
| California Central Valley steelhead | February–May | Year round |
| Note: fry periods assume fry emerge three months after egg deposition and grow for two months before reaching juvenile size. Abbreviations: mm = millimeters. | | |

The USFWS WUA studies did not include sturgeon, and no other study providing WUA curves for green or white sturgeon (as a potential surrogate) in the Sacramento River has been located. Therefore, effects of the PA on rearing habitat for green sturgeon in the Sacramento River were evaluated by comparing flows under the PA and the NAA in the Sacramento River at Red Bluff and Wilkins Slough during the year-round larval and juvenile rearing period. Changes in flow can affect the instream area available for rearing, the quality of the habitat, and downstream dispersal to rearing habitat in the bay and Delta. There is some evidence that green sturgeon year class strength is positively correlated with Delta outflow, perhaps, in part, as a result of improved downstream dispersal that benefits from higher flows. In general, therefore, it is assumed in the effects analysis that reduced flow resulting from the PA would reduce the availability and quality of green sturgeon habitat and increased flow would increase the availability and quality of green sturgeon habitat, although the certainty of this relationship is unknown. Differences in mean flow of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on green sturgeon habitat and warranting further investigation.

#### *5.D.2.3.3.2 American River*

The USFWS (2003b) study of CCV steelhead spawning habitat WUA in the American River discussed in Section 5.D.2.2.4.2, *American River,* included no rearing habitat investigations, and no rearing habitat WUA curves have been located for CCV steelhead or any other salmonid in the American River. Therefore, effects of flow on rearing habitat for CCV steelhead in the American River were evaluated using flow simulations from CALSIM modeling for the year-round steelhead rearing period. Although, as evidenced by the rearing habitat WUA curves for Sacramento River winter-run, fall-run, and late fall-run Chinook salmon (Figure 5.D-94 through Figure 5.D-99), effects of river flow on rearing habitat are generally complex, it is assumed for the purposes of this effects analysis that increased flow would increase the availability and quality of rearing habitat and thereby benefit steelhead. Differences in mean flow of greater than 5% between the PA and NAA were flagged as potentially having a biologically meaningful effect on CCV steelhead rearing habitat and warranting further investigation. As noted for green sturgeon, the certainty of this relationship is unknown.

#### *5.D.2.3.4 SALMOD*

As described in Section 5.D.2.1.2.4, *SALMOD*, the SALMOD model was used to evaluate flow- and temperature-related mortality of early life stages and overall production of spring- and winter-run Chinook salmon in the Sacramento River. Attachment 5.D.2, *SALMOD Model*, describes the details of the model.

Flow-related mortality of *Fry and Juvenile Rearing* section of the results includes the fry, pre-smolt, and immature smolt life stages. For each of these life stages, mortality results of the NAA and PA are presented as exceedance plots and mean annual values, as well as differences between NAA and PA. The mean values are presented by water year type and for all water year types combined. A 5% difference between NAA and PA in mean number of a life stage lost was considered biologically meaningful.

### 5.D.2.4 Migration Flows Methods

This section describes procedures used in the effects analysis to evaluate potential flow-related effects of flow resulting from the No Action Alternative (NAA) and Proposed Action (PA) on migration of winter-run and spring-run Chinook salmon, California Central Valley (CCV) steelhead, and green sturgeon in the Sacramento and American Rivers. The specific life stage migrations included in the analysis include immigration of adult winter-run and spring-run Chinook salmon, CCV steelhead, and green sturgeon; emigration of juvenile winter-run and spring-run Chinook salmon and CCV steelhead; emigration of CCV steelhead kelts; emigration of juvenile and larval green sturgeon; and emigration of post-spawn green sturgeon adults. The specific potential effects evaluated are (1) flow conditions during the months of juvenile and adult migration periods that may adversely affect emigration or immigration of salmonids and green sturgeon and (2) the frequency of flows lower than specified adult migration thresholds that may adversely affect the immigration of the adult salmonids and green sturgeon.

Modeled flow results for key locations in the Sacramento and American Rivers are reported in Appendix 5A, *CALSIM Methods and Results*. Results in Appendix 5A are presented as (1) mean monthly exceedance plots; (2) box and whiskers plots, with mean, median, quartiles, and 25$^{th}$- and 75$^{th}$-percentile values indicated; and (3) a table of summary statistics and differences between NAA and PA for each statistic.

Flow potentially affects a number of conditions for migrating fish. For immigrating adult salmonids, flow potentially affects cues for locating natal streams, energy expenditure, water quality, crowding, and passage conditions (Quinn 2005; Milner et al. 2012). For emigrating juveniles and kelts, flow potentially affects the timing and rate of emigration, feeding, protective cover, resting habitat, temperature, turbidity, and other habitat factors. Crowding and stranding, especially in side-channel habitats, can also be affected (Quinn 2005; Williams 2006; del Rosario et al. 2013). For green sturgeon, potential effects of flow include energy expenditure, water quality, crowding, passage conditions, feeding, timing and rate of migration, and downstream dispersal of larvae to rearing habitat in the bay and Delta. However, although many of the effects of flow on salmonid and sturgeon migration are understood qualitatively, quantitative relationships between flow and migration are generally highly variable and poorly understood (Quinn 2005; Williams 2006; Milner et al. 2012). It is known that migration cues for

# Appendix C

**Salvage Density Model Documentation**

**(Note: Model description extracted from California WaterFix Biological Assessment Appendix 5.D)**

# 5.D Quantitative Methods and Detailed Results for Effects Analysis of Chinook Salmon, Central Valley Steelhead, Green Sturgeon, and Killer Whale

## 5.D.1 In-Delta Effects

### 5.D.1.1 Entrainment and Impingement

#### *5.D.1.1.1 North Delta Exports*

##### *5.D.1.1.1.1 Screen Passage Time*

Swanson et al. (2004) found that juvenile Chinook salmon mortality and injury rate in fish treadmill experiments were not statistically related to flow regime or screen contact rate. Although Swanson et al. (2004) provide equations to estimate screen contact rate for juvenile Chinook salmon, preliminary calculations for this effects analysis suggested that these equations did not perform well for the lengths of screen contemplated for the proposed NDD. Screen passage time is another useful measure of potential effects on Chinook salmon, with shorter passage times being desirable. To illustrate the potential passage time at the proposed north Delta intake screens, screen passage time for juvenile Chinook salmon of the smallest (4.4 centimeters [cm] SL [Standard Length ]) and largest (7.9 cm SL) sizes examined by Swanson et al. (2004) was calculated by dividing screen length by screen passage velocity, based on Swanson et al.'s (2004) equation for the latter.

> Screen passage velocity (cm/s) = 30.94 – 11.87(day/night; day =1, night = 2) - 1.32(sweeping velocity, cm/s) + 0.72(swimming velocity, cm/s) – 0.39(orientation, degrees) + 0.27(sweeping velocity × day/night); n = 124, $r^2$ = 0.9064, SEE = 6.56

Swimming velocity and orientation for the above equation were calculated using other equations from Swanson et al. (2004):

> Swimming velocity (cm/s) = 27.35 – 12.85(day/night; day =1, night = 2) - 1.25(standard length, cm) + 0.21(resultant water velocity [cm/s] × day/night); n = 142, $r^2$ = 0.7517, SEE = 4.09

> Orientation (degrees) = 112.7 – 41.1(day/night, day = 1, night = 2) + 3.6(temperature, °C) – 1.4(resultant water velocity, cm/s) -1.1(swimming velocity, cm/s) – 0.3(flow angle, degrees) + 0.6(resultant water velocity × day/night); n = 124, $r^2$ = 0.4877, SEE = 18.8

In the above equations, resultant water velocity was calculated as the square root of (approach velocity$^2$ + sweeping velocity$^2$) and flow angle was calculated as the arctangent of (approach velocity)/(sweeping velocity), as described by Swanson et al. (2004).

#### *5.D.1.1.2 South Delta Exports*

Two methods were used to assess potential differences in south Delta entrainment between NAA and PA: the salvage-density method and salvage estimates based on Zeug and Cavallo (2014). Regardless of the method used to assess potential south Delta entrainment differences between NAA and PA, note that there is uncertainty regarding the population-level significance of south Delta entrainment losses for salmonids and green sturgeon. For example, incidental take of winter-run Chinook salmon juveniles as a percentage of the juvenile production estimate entering the Delta since implementation of the NMFS (2009) BiOp has averaged 0.55% of the JPE (range 0.0-1.3%) and although there is uncertainty in the method of estimating JPE, low levels of entrainment loss such as those seen in 2014 are unlikely to endanger winter-run Chinook salmon (Anderson et al. 2014).

#### *5.D.1.1.2.1 Salvage-Density Method*

The salvage-density method relies on salvage data and was used to estimate changes in entrainment at the SWP/CVP export facilities. The same basic method has been used in recent effects analyses (e.g., the DMC/California Aqueduct Intertie [Bureau of Reclamation 2009]), with refinements as necessary for the present analysis. ***Note that the method essentially functions as a description of changes in export flows weighted by seasonal changes in salvage density of covered species; although it generates estimates of numbers of fish lost, these estimates should only be used to compare one operational scenario to another (i.e., proposed action [PA] vs. no action alternative [NAA]) in order to get a sense of how south Delta exports differ during the period of Delta occurrence of NMFS-managed fishes[1].***

##### 5.D.1.1.2.1.1 Preprocessing of Input Data

Historical monthly export data (acre-feet) for water years 1995–2009 were obtained from Reclamation's Central Valley Operations Total Tracy Pumping web page (http://www.usbr.gov/mp/cvo/vungvari/tracy_pump.pdf) and California Department of Water Resources' (DWR's) State Water Project Annual Reports of Operations (http://www.water.ca.gov/swp/operationscontrol/annual.cfm). Historical monthly salvage data for the water years 1995–2009 were provided by Sheila Greene (DWR) for all species (S. Greene pers. comm.). (Water year 2009 was excluded for some species because the data were not complete.) These data are expanded salvage data, i.e., the extrapolated estimates of the total number of fish salvaged based on a subsample that was actually identified, counted, and measured. These data provided the basic estimates of fish density (number of fish salvaged per volume of water exported) that were subsequently multiplied by simulated export data for the CALSIM modeling period (1922–2003) to assess differences between NAA and scenarios, as described in Appendix 5.B, *DSM Methods and Results*. It is acknowledged that expanded salvage estimates have inherent statistical error associated with the expansion of subsamples (Jahn 2011) but, consistent with typical analyses employing these data (e.g., Grimaldo et al. 2009), this statistical error has not been accounted for in the current salvage-density method. The salvage-density method does not account for spatial distribution of the fish populations, which could differ between NAA and PA because of other operational factors (e.g., north Delta diversions), and assumes a linear relationship between entrainment and export flows. The assumption of a linear relationship is made because of the lack of information on how salvage would increase with increasing flows. One study that examined entrainment in relation to export rate was that of Kimmerer (2008), who showed for hatchery-released Chinook salmon that percentage salvage or percentage entrainment loss was roughly linear up to total south Delta export flows of around 250–275 cubic meters/sec (approximately 8,800–9,700 cfs), depending on assumptions regarding prescreen losses (Kimmerer 2008: his Figures 9 and 10). For perspective on the current effects analysis modeling, the percentage of CALSIM-simulated months during the main entrainment

[1] For this reason, various complex methodological refinements suggested by a scientific panel reviewing the method as part of the phase III review of the public draft Bay Delta Conservation Plan have not been implemented, as these would not be justified given the fairly coarse intent of the analysis.

period for Chinook salmon and other covered species (December–June) in which average total south Delta exports were below 8,800 cfs and 9,700 cfs were as follows.

- NAA: 83% < 8,800 cfs, 86% < 9,700 cfs.
- PA: 95% < 8,800 cfs, 98% < 9,700 cfs.

The majority of months were below export flows at which Kimmerer's (2008) study of Chinook salmon suggested considerable nonlinear percentage salvage or entrainment loss would occur. Kimmerer's (2008) study does not provide an indication of export flow rates at which nonlinearity may occur for the other species included in this analysis.

Juvenile Chinook salmon were divided into races based on fork length on the date of salvage, according to the Delta model of length at date (Brown et al. 1996). It should be noted that these divisions are not without considerable overlap between races, especially for juvenile spring-run and fall-run Chinook salmon; extrapolations of numbers of fish salvaged by race should be regarded cautiously, particularly given the relative abundance of the adult stocks from which the juveniles originate (e.g., fall-run are considerably more abundant than spring-run, and therefore the relative proportions salvaged should reflect such differences but may not when based on length criteria). Techniques such as such rapid, real-time DNA analysis are under development and may allow better classification of race in the future (Harvey et al. 2014). Data for juvenile Chinook salmon salvage were extrapolated into total entrainment losses to reflect prescreen losses (75% at SWP and 15% at CVP), louver efficiency (size-specific equations based on primary water velocity through the intake screens [California Department of Water Resources and California Department of Fish and Game 1986: Appendix A]), and losses during transport to the release site (2% for younger fish, 0% for larger fish [California Department of Water Resources and California Department of Fish and Game 1986: Appendix A]). In similar fashion, steelhead also had various entrainment losses applied: prescreen losses of 75% at SWP and 15% at CVP, and louver losses of 50%.

#### 5.D.1.1.2.1.2 Normalization to Population Size

Winter-run Chinook salmon salvage and loss data for analysis were normalized, by measures of annual juvenile population abundance in the year of entrainment. This step aimed to adjust the salvage and loss to account for the abundance of the population (e.g., a relatively high number of fish would be expected to be entrained in a year of relatively high abundance). Normalization was undertaken by multiplying the raw monthly salvage or loss in a given month by a factor to account for the relative size of the population in that year compared to the average population size over the years from which salvage or loss data were available. The factor was the average population size in the years from which salvage data were available (1996–2009) divided by the juvenile population size appropriate to the year of salvage. Winter-run Chinook salmon estimates were normalized by the juvenile production estimate (National Marine Fisheries Service 2009). No normalization was undertaken for spring-run Chinook salmon, fall-/late fall-run Chinook salmon, steelhead, or green sturgeon because there are no suitable indices of juvenile annual abundance for these species.

### 5.D.1.1.2.1.3 Entrainment Index Calculation

For each species in each month at each facility, density (fish per thousand acre-foot [taf]) as entrainment loss or expanded salvage was simply calculated as the total loss or expanded salvage for the facility divided by the total volume of water exported in that month. It is acknowledged that the assumption of a linear relationship between entrainment and flow may be an oversimplification given the evidence for nonlinear relationships (e.g., Kimmerer 2008; see discussion above) and so, as previously described, ***the method essentially functions as a description of changes in export flows weighted by seasonal changes in salvage density of covered species***. The mean entrainment index in each month of each water-year type was calculated as follows: the salvage or loss density for a given month in a given water-year type was multiplied by the CALSIM-modeled export volume for the same month for all of the water years of that water-year type. For example, there were 5 wet years (1996–1999, 2006) in the data used to calculate salvage or loss densities and there were 26 wet years in the CALSIM modeling of 1922–2003. Using the month of January as an example, there were five unique wet January salvage or loss densities calculated. Each of these was then multiplied by each of the 26 wet January export volumes from CALSIM, giving a sample size of 130 from which to calculate means.

Although the salvage-density method does give estimates of entrainment loss or salvage in numbers of fish and there are a number of factors included in the calculations such as multipliers applied for prescreen loss and normalization to population size, ***it is most appropriate to view the results comparatively, i.e., to compare relative differences between scenarios as opposed to examining the estimates of total number of fish lost to entrainment or salvaged***. In essence, and as noted previously, the salvage-density method provides an entrainment index that reflects export pumping weighted by each covered species' seasonal pattern of abundance in the Delta, as reflected by historical salvage data.

### 5.D.1.1.2.1.4 Detailed Results

Presented below are detailed results tables from the salvage-density method for mean estimated entrainment loss by month for each water year type, grouped by facility (SWP and CVP) (Table 5.D-1 to Table 5.D-30). The results are discussed in Chapter 5, *Effects Analysis for Chinook Salmon, Central Valley Steelhead, Green Sturgeon, and Killer Whale*. Note that the results below also include fall-/late fall-run Chinook salmon, because of their consideration in the EFH analysis. As emphasized above, ***it is most appropriate to view the results comparatively, i.e., to compare relative differences between scenarios as opposed to examining the estimates of total number of fish lost to entrainment or salvaged***.

# Appendix D

**Reclamation Salmon Mortality Model Documentation**

**(Note: Model description extracted from California WaterFix Biological Assessment Appendix 5.D.1)**

## Attachment 5.D.1, Reclamation Salmon Mortality Model

## 5.D.1 Reclamation Salmon Mortality Model

### 5.D.1.1 Introduction

The Reclamation salmon mortality model computes salmon spawning losses in the five rivers, Trinity, Sacramento, Feather, American, and Stanislaus, based on output from the Reclamation Temperature and HEC5Q model estimates of water temperatures.

### 5.D.1.2 Key Processes

Temperature-exposure mortality criteria for three life stages (pre-spawned eggs, fertilized eggs, and pre-emergent fry) are used along with the spawning distribution data and output from the river temperature models to compute percentage of salmon spawning losses.

### 5.D.1.3 Model and Application

The Reclamation Salmon Mortality Model was created and developed exclusively for CVP/SWP systems in the Central Valley. The Reclamation Salmon Mortality Model simulates the early life stage mortality of Chinook Salmon along reaches of the Trinity (below Lewiston Dam to Burnt Ranch), Sacramento (below Keswick Dam to Princeton), Feather (below the Fish Dam to the Sacramento River confluence), American (below Nimbus Dam to the Sacramento River confluence), and Stanislaus Rivers (below Goodwin Dam to Riverbank). The model sets an initial spawning distribution along the different river reaches (as a percentage) and uses water temperature data to simulate egg development and mortality based on temperature relationships specified in the model. Inputs to the Reclamation Salmon Mortality model include water temperature from the temperature models (HEC5Q and Reclamation Temperature Model) provided at the river reaches defined in Table 5.D.1-1 through Table 5.D.1-5. Daily water temperature results for the Sacramento, American, and Stanislaus Rivers from the HEC5Q models and monthly water temperature results for the Trinity and Feather Rivers from the Reclamation Temperature Model are used as input to Reclamation Salmon Mortality Model. The model also uses California Department of Fish and Wildlife (CDFW) and U.S. Fish and Wildlife Service (USFWS) data on Chinook salmon spawning distribution and timing in the five rivers (Reclamation 1991, Loudermilk 1994, and Reclamation 1994). For the Sacramento River reaches, spawning distributions were provided by NMFS based on the 2003–2014 aerial redd survey data. As noted, the temperature-exposure mortality criteria for three life stages (pre-spawned eggs, fertilized eggs, and pre-emergent fry) are used along with the spawning distribution data (Table 5.D.1-1 through Table 5.D.1-5) and output from the Reclamation Temperature Model and HEC5Q to compute percentage of salmon spawning losses. Because the Reclamation Salmon Mortality model operates on a daily time-step, a procedure is required to utilize the monthly Reclamation Temperature Model output for Feather and Trinity Rivers. The salmon model computes daily temperatures based on linear interpolation between the monthly temperatures, which are assumed to occur on the $15^{th}$ day of the month. The final output from the Reclamation Salmon Mortality Model used in this analysis is the resulting annual percent mortality.

**Table 5.D.1-1. Upper Sacramento River Spawning Distributions**

| Reach | No. | River Reach | Spawning Distribution (%) | | | |
|---|---|---|---|---|---|---|
| | | | Fall | Late-Fall | Winter | Spring |
| UPPER | 1 | Keswick Dam – ACID Dam | 16.28% | 67.6% | 45.03% | 12.43% |
| | 2 | ACID Dam – Hwy 44 | 5.48% | 5.0% | 42.09% | 32.77% |
| | 3 | Hwy 44 – Upper Anderson Bridge | 12.26% | 3.7% | 12.23% | 27.66% |
| | 4 | Upr Anderson Bridge – Balls Ferry | 16.19% | 7.9% | 0.26% | 10.90% |
| | 5 | Balls Ferry – Jellys Ferry | 23.08% | 8.0% | 0.28% | 8.75% |
| | 6 | Jellys Ferry – Bend Bridge | 6.61% | 1.0% | 0.06% | 2.58% |
| | 7 | Bend Bridge – Red Bluff Diversion Dam | 3.48% | 0.5% | 0.00% | 0.83% |
| | **Total – Upper Salmon Reach** | | **83.37%** | **93.8%** | **99.95%** | **95.92%** |
| MIDDLE | 8 | Red Bluff Diversion Dam – Tehama Bridge | 10.82% | 3.1% | 0.05% | 4.08% |
| | 9 | Tehama Bridge – Woodson Bridge | 3.07% | 1.2% | 0.00% | 0.00% |
| | 10 | Woodson Bridge – Hamilton City | 1.82% | 1.1% | 0.00% | 0.00% |
| | **Total – Middle Salmon Reach** | | **15.71%** | **5.4%** | **0.05%** | **4.08%** |
| LOWER | 11 | Hamilton City – Ord Ferry | 0.82% | 0.00% | 0.00% | 0.00% |
| | 12 | Ord Ferry – Princeton | 0.10% | 0.00% | 0.00% | 0.00% |
| | **Total – Lower Salmon Reach** | | **0.92%** | **0.00%** | **0.00%** | **0.00%** |

NOTE:
Sacramento River salmon spawning distributions were revised based on average 2003-2014 Redd survey data, provided by David Swank at National Marine Fisheries Service (NMFS) in April 2015.

**Table 5.D.1-2. Lower Feather River Spawning Distributions**

| Salmon Reach | No. | River Reach | Spawning Distribution (%) |
|---|---|---|---|
| UPPER | 1 | Fish Dam – RM 65.0 | 20 |
| | 2 | RM 65.0 – RM 62.0 | 20 |
| | 3 | RM 62.0 – Upstream of Afterbay | 20 |
| | **Total – Upper Salmon Reach** | | **60** |
| LOWER | 4 | Downstream of Afterbay – RM 55.0 | 10 |
| | 5 | RM 55.0 – Gridley | 10 |
| | 6 | Gridley – RM 47.0 | 10 |
| | 7 | RM 47.0 – Honcut Creek | 10 |
| | 8 | Honcut Creek – Yuba River | 0 |
| | 9 | Yuba River – Mouth | 0 |
| | **Total – Lower Salmon Reach** | | **40** |

**Table 5.D.1-3. Trinity River Spawning Distributions**

| No. | River Reach | Spawning Distribution (%) |
|---|---|---|
| 1 | Lewiston Dam – Old Bridge | 22 |
| 2 | Old Bridge – Brown's Mountain Bridge | 20 |
| 3 | Brown's Mountain Bridge – Steel Bridge | 18 |
| 4 | Steel Bridge – Douglas City | 15 |
| 5 | Douglas City – Canyon Creek | 16 |
| 6 | Canyon Creek – North Fork | 9 |
| 7 | North Fork – Big Bar Bridge | 0 |
| 8 | Big Bar Bridge – Big French Creek | 0 |
| 9 | Big French Creek – Burnt Ranch | 0 |

**Table 5.D.1-4. Lower American River Spawning Distributions**

| No. | River Reach | Spawning Distribution (%) |
|---|---|---|
| 1 | Nimbus Dam – Sunrise Blvd | 31 |
| 2 | Sunrise Blvd – A. Hoffman/Cordova | 59 |
| 3 | A. Hoffman/Cordova – Arden | 5 |
| 4 | Arden – Watt Ave | 3 |
| 5 | Watt Ave – Filtration Plant | 1 |
| 6 | Filtration Plant – H St | 0 |
| 7 | H St – Paradise | 1 |
| 8 | Paradise – 16th St | 0 |
| 9 | 16th St – Mouth | 0 |

**Table 5.D.1-5. Lower Stanislaus River Spawning Distributions**

| No. | River Reach | Spawning Distribution (%) |
|---|---|---|
| 1 | Goodwin Dam – Knights Ferry | 8.8 |
| 2 | Knights Ferry – RM 51.33 | 18.6 |
| 3 | RM 51.33 – RM 48.67 | 18.6 |
| 4 | RM 48.67 – Orange Blossom Bridge | 18.6 |
| 5 | Orange Blossom Bridge – RM 43.67 | 9.8 |
| 6 | RM 43.67 – RM 41.33 | 9.7 |
| 7 | RM 41.33 – Oakdale R.A. | 9.7 |
| 8 | Oakdale R.A. – RM 36.50 | 3.1 |
| 9 | RM 36.50 – Riverbank | 3.1 |

Temperature units (TU), defined as the difference between river temperatures and 32°F, are calculated daily by the mortality model and used to track life-stage development (Table 5.D.1-6). Eggs are assumed to hatch upon exposure to 750 TUs following fertilization. Fry are assumed to emerge from the gravel after exposure to 750 TUs following egg hatching into the pre-emergent fry stage. The temperature mortality rates for fertilized eggs (Table 5.D.1-7), the most sensitive life stage, range from 8% in 24 days at 57°F to 100% in 7 days at 64°F or above (Reclamation 1994). Most salmon spawning generally occurs above the North Fork on the Trinity River, above Red Bluff Diversion Dam on the Sacramento River main stem for all four Chinook salmon runs, above Watt Avenue on the American River, and above Riverbank Bridge on the Stanislaus River. Fall-run Chinook salmon spawning usually occurs from mid-October through December, peaking about mid-November. Winter-run Chinook salmon usually spawn in the Sacramento River during May–July and spring-run Chinook salmon during August–October.

**Table 5.D.1-6. Life-Stage Development Criteria**

| Life-Stage | Exposure Duration |
|---|---|
| Fertilized eggs hatch | 750 TUs |
| Fry emerge from gravel | 750 TUs |

**Table 5.D.1-7. Salmon Mortality Criteria**

| Life-Stage | Mortality | Exposure Duration |
|---|---|---|
| Fertilized eggs | 8% | 24 days at 57°F |
| Fertilized eggs | 100% | 7 days at 64°F or above |

## 5.D.1.4 Model Mathematics

The model employs an “absolute” daily or “instantaneous” daily mortality rate for the reference period using the following equation (Hydrologic Consultants, Inc. 1996):

$$Mi = (1-Mn)^{(1/n)}$$

Where:

Mi = daily mortality rate

Mn = mortality rate after exposure time n = exposure time in days

A more in depth discussion of the model equation is available from Hydrologic Consultants, Inc., 1996.

## 5.D.1.5 Rationale

The Reclamation Salmon Mortality Model has been applied to past CVP/SWP system operational performance evaluations (Reclamation 1994 and 2004) and Reclamation has expertise in the application of Reclamation Salmon Mortality model and companion temperature models.

This tool is one of many fisheries models available for application to the CVP/SWP systems. The results are provided as complementary information to the historical observations and the other fishery mortality, population, and life-cycle models presented.

### 5.D.1.6 Quality Assurance and Data Quality Assessment

The development of the Reclamation Salmon Mortality Model was a collaborative and iterative effort by Reclamation, USFWS, and the (CDFW) (Reclamation 1991). This interaction serves as the quality assurance and data quality assessment for the model. A formal process documenting the quality assurance and data quality assessment is unavailable. At the present, a peer review of the model has not been performed.

### 5.D.1.7 Assumptions

The following assumptions are listed in an excerpt documenting the Chinook Salmon Mortality Model (Hydrologic Consultants, Inc. 1996):

> *These fishery assumptions stated in the USFWS memorandum dated January 19, 1990 are listed below.*
>
> 1 *Survival of salmon fry and juveniles is density independent at the average spawning population levels existing from the early 1960's through the 1980's. Numerical estimates of mainstream spawner populations are based upon spawning area surveys and counts at Red Bluff Diversion Dam.*
>
> 2 *The temperature-mortality relationship for unfertilized eggs in the female salmon spawner is the same as for fertilized eggs reaching the eyed stage (USBR 1991, p.A109, Figure 2).*
>
> 3 *The percent of the adult salmon population entering the project area is estimated by the records of passage over Red Bluff Diversion Dam (USBR 1991, pp. A106-107, Table 1).*
>
> 4 *Time of spawning for each run of Chinook salmon displayed in Table 2 (USBR 1991 pp. A110-111) is estimated for the fall-run, late fall-run and winter-run by aerial redd counts and spawning area surveys. Time of spawning for spring-run is estimated by spawning records recorded in the Baird Hatchery at the turn of the century.*
>
> 5 *Sacramento River salmon spawning distributions displayed in Tables 3 through 7 (USBR 1991, pp. A112, and A115-A1118) are from aerial surveys of the spawning grounds. Effort was relatively consistent during the 1980's.*
>
> 6 *Development from fertilized egg to hatching requires 750 ($^{o}$F) temperature units, and another 750 ($^{o}$F) temperature units from hatching to emergent fry (32mm), for a total of 1500 ($^{o}$F) temperature units from egg to emergent fry.*

7 *Mortality of eggs exposed at various temperatures and exposure durations is displayed in Table 8 (USBR 1991, p. A119).*

8 *Temperature induced mortality for pre-emergent fry is displayed in Table 9 (USBR 199, p. A120). There is virtually a total lack of data to base this relationship on other than the apparent increased tolerance of pre-emergent fry as compared to eggs.*

9 *Project benefits in terms of increased adult stock sizes will be determined by applying the percent increase in survival to emergence to three different stock sizes in each of four water year types as proposed in Table 10 (USBR 1991, p. A122).*

Specific details of the assumptions, such as estimated temperature and exposure duration mortality relationships, arrival, and temperature interpolation, are compiled in the Chinook Salmon Mortality Model (Hydrologic Consultants, Inc. 1996).

## 5.D.1.8 Model Testing

Internal testing of the Reclamation Salmon Mortality model has been performed in the past; however, a formal report documenting the testing of the model is unavailable.

### 5.D.1.8.1 Sensitivity/Uncertainty of Model Inputs

No sensitivity or uncertainty analyses were performed on the model inputs.

## 5.D.1.9 Limitations

The Reclamation Salmon Mortality model is limited to temperature effects on early life stages of Chinook salmon. It does not evaluate potential direct or indirect temperature impacts on later life stages, such as emergent fry, smolts, juvenile out-migrants, or adults. Also, it does not consider other factors that may affect salmon mortality, such as in-stream flows, gravel sedimentation, diversion structures, predation, ocean harvest, etc.

Since the Reclamation Salmon Mortality Model is the terminal model in the sequence of two previous models (CalSim II and the Reclamation Temperature Model or the HEC5Q model), the limitations of the previous models should also be taken into consideration. Sensitivity or uncertainty analyses were not performed on the Reclamation Temperature or the Reclamation Salmon Mortality models.

## 5.D.1.10 Future Development

No future development to the Reclamation Salmon Mortality Model is planned at this time.

## 5.D.1.11 Reporting Metrics

Metrics used were percent salmon mortality by river by water year type (based on the 40-30-30 indexing).

## 5.D.1.12 References

Bureau of Reclamation. 1991. Shasta Outflow Temperature Control PR/ES, Appendix A - Modeling, Appendix B - Environmental (Part I - Fisheries). May. Sacramento, CA, May.

Bureau of Reclamation. 1994. CVPIA-PEIS, Impact Assessment Methodology for Fish, Draft Working Paper #3. December. Sacramento, CA.

Bureau of Reclamation, 2004. Long-Term Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment. June 30.

Hydrologic Consultants, Inc. 1996. Water Forum Issue Paper Chinook Salmon Mortality Model: Development, Evaluation, and Application as One Tool to Assess the Relative Effects of Alternative Flow and Diversion Scenarios on the Lower American River.

Loudermilk, W. E. for Neillands, W. G., "...chinook salmon spawning distribution and timing in the Stanislaus River for CVPIA-PEIS Modeling", CA Department of Fish and Game, Fresno, CA, letter to USBR, July 21, 1994.

# Appendix E

## Methods for SIT Model Floodplain Habitat Analyses for the Rivers and Bypasses Included in the ROC on LTO Analyses

**Methods for SIT Model Floodplain Habitat Analyses for the Rivers and Bypasses Included in the ROC on LTO Analyses (name of each river or bypass is linked to the SIT GitHub site with information on the floodplain habitat analysis of that river or bypass)**

Sacramento River

The entire area of potential juvenile Chinook salmon rearing habitat, including the 253.3 miles of Sacramento River channel and its floodplain, was modeled using the Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model, refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model. The surface area of the active river channel was subtracted from total inundated area to estimate the inundated floodplain area. Using CalSim II estimates of Sacramento River flow, the CVFED model maps the area inundated at each flow and provides fine-scale, spatially explicit estimates of flow velocity, depth and roughness for the entire inundated area. The model sums the surface areas of all locations (cells) possessing high quality velocity and depth conditions for rearing Chinook salmon juveniles, as defined in Table 1.

**Table 1. Habitat variables influencing capacity for each habitat type.**

| Habitat | Variable | Habitat* | Variable range |
|---|---|---|---|
| Mainstem | Velocity | High | <= 0.15 m/s |
| | | Low | > 0.15 m/s |
| | Depth | High | > 0.2 m, <= 1 m |
| | | Low | <= 0.2 m, > 1 m |
| | Roughness | High | > 0.04 |
| | | Low | <= 0.04 |

*Ranges of high and low habitat quality were based on published studies of habitat use by Chinook salmon fry across their range.

The rearing habitat surface areas were estimated for the four major CVPIA reaches of the Sacramento River, described as follows (the CalSim II node used to model flow for the reach is given in parentheses):

- Upper Sacramento River (CalSim Node = C104). Keswick Dam to Red Bluff, 59.3 miles.
- Upper-mid Sacramento River (CalSim Node = C115). Red Bluff to Wilkins Slough, 122.3 miles.
- Lower-mid Sacramento River (CalSim Node = C134 and Node C160). Wilkins Slough to the American River confluence, 58.0 miles.
- Lower Sacramento River (CalSim Node = C166). American River confluence to Freeport, 13.7 miles.

Note that these reaches are different than those that were used for the Sacramento River CVFED modeling, which are: Keswick Dam to Battle Creek (28.9 miles), Battle Creek to the Feather River confluence (186.5 miles), and the Feather River confluence to Freeport (33.9 miles [or 33.4?]). The rearing habitat surface area results from the modeling for these three reaches were scaled using the proportional overlap (in river miles) between them and the CVPIA reaches. For example, the results for the first CVPIA reach, Keswick Dam to Red Bluff (59.3 miles), were computed as the sum of the results from the first modeling reach, Keswick Dam to Battle Creek (28.9 miles), and 0.163 times the results from the second modeling reach, Battle Creek to the Feather River confluence (186.5 miles). The results for the Battle Creek to the Feather River confluence are multiplied by 0.163 because 0.163 is the channel distance from Keswick to Red Bluff minus the channel from Keswick to Battle Creek (59.3-28.9 = 30.4) divided by the distance from Battle Creek to the Feather River confluence, 186.5.

American River

The entire area of potential juvenile Chinook salmon rearing habitat, including the 22.81 miles of the lower American River channel and its floodplain, was modeled using the CVFED HEC-RAS hydraulic model. The active channel surface area of 670.2 acres, estimated through remote sensing analysis, was subtracted from total inundated area to estimate the inundated floodplain area. Juvenile Chinook salmon rearing habitat quality was not determined for the modeled area, so the surface area of high quality habitat was assumed to be 27 percent of the total inundated area, based on results from the San Joaquin River, reported in SJRRP (2012).

Stanislaus River

The entire area of potential juvenile Chinook salmon rearing habitat, including the 60.31 miles of lower Stanislaus River channel and its floodplain, was modeled using the SRH-2D hydraulic model. The active channel area of 409.1 acres, estimated through remote sensing analysis, was subtracted from total inundated area to estimate the inundated floodplain area. Juvenile Chinook salmon rearing habitat quality was not determined for the modeled area, so the surface area of high quality habitat was assumed to be 27 percent of the total inundated area, based on results from the San Joaquin River, reported in SJRRP (2012).

San Joaquin River

The entire area of potential juvenile Chinook salmon rearing habitat in the San Joaquin River, including the 45.68 miles of river channel and its floodplain, was modeled using Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model (for Combined Upper and Lower San Joaquin River). The active channel area of 534.2 acres, estimated through remote sensing analysis, was subtracted from total inundated area to estimate inundated floodplain area. Juvenile Chinook salmon rearing habitat quality was not determined for the modeled area, so the surface area of high quality habitat was assumed to be 27 percent of the total inundated area, based on results from a San Joaquin River Restoration Program study SJRRP (2012).

Yolo Bypass

The entire area of potential juvenile Chinook salmon rearing habitat within the Yolo Bypass; including stream channels, ponds, canals, and ditches, and the floodplain; was modeled using the Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model, refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model. The surface areas of the stream channels, ponds, canals and ditches was subtracted from total inundated area to estimate the inundated floodplain area. Using CalSim II estimates of Yolo Bypass flow, the CVFED model maps the area inundated at each flow and provides fine-scale, spatially explicit estimates of flow velocity, depth and roughness for the entire inundated area. The model sums the surface areas of all locations (cells) possessing high quality velocity and depth conditions for rearing Chinook salmon juveniles, as defined in Table 1.

**Table 1. Habitat variables influencing capacity for each habitat type.**

| Habitat | Variable | Habitat* | Variable range |
|---|---|---|---|
| Mainstem | Velocity | High | <= 0.15 m/s |
| | | Low | > 0.15 m/s |
| | Depth | High | > 0.2 m, <= 1 m |
| | | Low | <= 0.2 m, > 1 m |
| | Roughness | High | > 0.04 |
| | | Low | <= 0.04 |

*Ranges of high and low habitat quality were based on published studies of habitat use by Chinook salmon fry across their range.

The rearing habitat surface areas were estimated for two major reaches of the Yolo Bypass: Fremont Weir to the Sacramento Weir, and the Yolo Bypass downstream of the Sacramento Weir. The CalSim II nodes used to represent flow in these two reaches are D160 and C157, respectively.

Sutter Bypass

The entire area of potential juvenile Chinook salmon rearing habitat within the Sutter Bypass; including stream channels, basins, ponds, canals, and ditches, and the floodplain; was modeled using the Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model, refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model. The surface areas of the stream channels, basins, ponds, canals and ditches was subtracted from total inundated area to estimate the inundated floodplain area. Using CalSim II estimates of Sutter Bypass flow, the CVFED model maps the area inundated at each flow and provides fine-scale, spatially explicit estimates of flow velocity, depth and roughness for the entire inundated area. The model sums the surface areas of all locations (cells) possessing high quality velocity and depth conditions for rearing Chinook salmon juveniles, as defined in Table 1.

**Table 1. Habitat variables influencing capacity for each habitat type.**

| Habitat | Variable | Habitat* | Variable range |
|---|---|---|---|
| Mainstem | Velocity | High | <= 0.15 m/s |
| | | Low | > 0.15 m/s |
| | Depth | High | > 0.2 m, <= 1 m |
| | | Low | <= 0.2 m, > 1 m |
| | Roughness | High | > 0.04 |
| | | Low | <= 0.04 |

*Ranges of high and low habitat quality were based on published studies of habitat use by Chinook salmon fry across their range.

The rearing habitat surface areas were estimated for four major reaches of the Sutter Bypass: upstream of Moulton Weir, Moulton Weir to Colusa Weir, Colusa Weir to Tisdale Weir, and downstream of Tisdale Weir. The CalSim II nodes used to represent flow in these four reaches are D117, C135, C136A, and C137, respectively.

# Appendix F

**New Melones Stepped Release Plan**

**Daily Hydrographs for Critical, Dry, Below Normal,**

**Above Normal and Wet Year Types**

New Melones Stepped Release Plan Daily Hydrographs for Critical Water Year Types

| OCT | CFS | NOV | CFS | DEC | CFS | JAN | CFS | FEB | CFS | MAR | CFS | APR | CFS | MAY | CFS | JUN | CFS | JUL | CFS | AUG | CFS | SEP | CFS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 725 | 1 | 150 | 1 | 150 | 1 | 150 | 1 | 150 |
| 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 725 | 2 | 150 | 2 | 150 | 2 | 150 | 2 | 150 |
| 3 | 200 | 3 | 200 | 3 | 200 | 3 | 400 | 3 | 200 | 3 | 200 | 3 | 200 | 3 | 725 | 3 | 150 | 3 | 150 | 3 | 150 | 3 | 150 |
| 4 | 200 | 4 | 200 | 4 | 200 | 4 | 400 | 4 | 200 | 4 | 200 | 4 | 200 | 4 | 725 | 4 | 150 | 4 | 150 | 4 | 150 | 4 | 150 |
| 5 | 200 | 5 | 200 | 5 | 200 | 5 | 200 | 5 | 400 | 5 | 200 | 5 | 200 | 5 | 725 | 5 | 150 | 5 | 150 | 5 | 150 | 5 | 150 |
| 6 | 200 | 6 | 200 | 6 | 200 | 6 | 200 | 6 | 400 | 6 | 200 | 6 | 200 | 6 | 725 | 6 | 150 | 6 | 150 | 6 | 150 | 6 | 150 |
| 7 | 200 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 725 | 7 | 150 | 7 | 150 | 7 | 150 | 7 | 150 |
| 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 725 | 8 | 150 | 8 | 150 | 8 | 150 | 8 | 150 |
| 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 725 | 9 | 150 | 9 | 150 | 9 | 150 | 9 | 150 |
| 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 725 | 10 | 150 | 10 | 150 | 10 | 150 | 10 | 150 |
| 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 725 | 11 | 150 | 11 | 150 | 11 | 150 | 11 | 150 |
| 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 725 | 12 | 150 | 12 | 150 | 12 | 150 | 12 | 150 |
| 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 550 | 13 | 150 | 13 | 150 | 13 | 150 | 13 | 150 |
| 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 450 | 14 | 150 | 14 | 150 | 14 | 150 | 14 | 150 |
| 15 | 500 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 350 | 15 | 300 | 15 | 150 | 15 | 150 | 15 | 150 | 15 | 150 |
| 16 | 750 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 500 | 16 | 150 | 16 | 150 | 16 | 150 | 16 | 150 | 16 | 150 |
| 17 | 1000 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 725 | 17 | 150 | 17 | 150 | 17 | 150 | 17 | 150 | 17 | 150 |
| 18 | 1250 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 725 | 18 | 150 | 18 | 150 | 18 | 150 | 18 | 150 | 18 | 150 |
| 19 | 1250 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 725 | 19 | 150 | 19 | 150 | 19 | 150 | 19 | 150 | 19 | 150 |
| 20 | 1250 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 725 | 20 | 150 | 20 | 150 | 20 | 150 | 20 | 150 | 20 | 150 |
| 21 | 1250 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 725 | 21 | 150 | 21 | 150 | 21 | 150 | 21 | 150 | 21 | 150 |
| 22 | 1250 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 725 | 22 | 150 | 22 | 150 | 22 | 150 | 22 | 150 | 22 | 150 |
| 23 | 1250 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 725 | 23 | 150 | 23 | 150 | 23 | 150 | 23 | 150 | 23 | 150 |
| 24 | 1250 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 725 | 24 | 150 | 24 | 150 | 24 | 150 | 24 | 150 | 24 | 150 |
| 25 | 1250 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 725 | 25 | 150 | 25 | 150 | 25 | 150 | 25 | 150 | 25 | 150 |
| 26 | 1000 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 725 | 26 | 150 | 26 | 150 | 26 | 150 | 26 | 150 | 26 | 150 |
| 27 | 750 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 725 | 27 | 150 | 27 | 150 | 27 | 150 | 27 | 150 | 27 | 150 |
| 28 | 500 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 725 | 28 | 150 | 28 | 150 | 28 | 150 | 28 | 150 | 28 | 150 |
| 29 | 200 | 29 | 200 | 29 | 200 | 29 | 200 | | | 29 | 200 | 29 | 725 | 29 | 150 | 29 | 150 | 29 | 150 | 29 | 150 | 29 | 150 |
| 30 | 200 | 30 | 200 | 30 | 200 | 30 | 200 | | | 30 | 200 | 30 | 725 | 30 | 150 | 30 | 150 | 30 | 150 | 30 | 150 | 30 | 150 |
| 31 | 200 | | | 31 | 200 | 31 | 200 | | | 31 | 200 | | | 31 | 150 | | | 31 | 150 | 31 | 150 | | |
| **Acre-Feet** | 35504 | | 11901 | | 12298 | | 13091 | | 11901 | | 12298 | | 27372 | | 24595 | | 8926 | | 9223 | | 9223 | | 8926 |
| | | | | | | | | | | | | | | | | | | | | **Water Year Total** | | **185256 Acre-Feet** | |

New Melones Stepped Release Plan Daily Hydrographs for Dry Water Year Types

| OCT | CFS | NOV | CFS | DEC | CFS | JAN | CFS | FEB | CFS | MAR | CFS | APR | CFS | MAY | CFS | JUN | CFS | JUL | CFS | AUG | CFS | SEP | CFS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 1000 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 |
| 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 1000 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 |
| 3 | 200 | 3 | 200 | 3 | 200 | 3 | 400 | 3 | 200 | 3 | 200 | 3 | 200 | 3 | 1000 | 3 | 200 | 3 | 200 | 3 | 200 | 3 | 200 |
| 4 | 200 | 4 | 200 | 4 | 200 | 4 | 400 | 4 | 200 | 4 | 200 | 4 | 200 | 4 | 1000 | 4 | 200 | 4 | 200 | 4 | 200 | 4 | 200 |
| 5 | 200 | 5 | 200 | 5 | 200 | 5 | 400 | 5 | 400 | 5 | 200 | 5 | 200 | 5 | 1000 | 5 | 200 | 5 | 200 | 5 | 200 | 5 | 200 |
| 6 | 200 | 6 | 200 | 6 | 200 | 6 | 200 | 6 | 400 | 6 | 200 | 6 | 200 | 6 | 1000 | 6 | 200 | 6 | 200 | 6 | 200 | 6 | 200 |
| 7 | 200 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 400 | 7 | 200 | 7 | 200 | 7 | 1000 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 200 |
| 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 350 | 8 | 1000 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 200 |
| 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 500 | 9 | 1000 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 |
| 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 750 | 10 | 1000 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 |
| 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 1000 | 11 | 1000 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 |
| 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 1000 | 12 | 1000 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 |
| 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 1000 | 13 | 1000 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 |
| 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 1000 | 14 | 1000 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 |
| 15 | 500 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 1000 | 15 | 1000 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 |
| 16 | 750 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 1000 | 16 | 800 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 |
| 17 | 1000 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 1000 | 17 | 600 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 |
| 18 | 1250 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 1000 | 18 | 450 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 |
| 19 | 1250 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 1000 | 19 | 300 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 |
| 20 | 1250 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 1000 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 |
| 21 | 1500 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 1000 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 |
| 22 | 1500 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 1000 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 |
| 23 | 1500 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 1000 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 |
| 24 | 1250 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 1000 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 |
| 25 | 1250 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 1000 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 |
| 26 | 1250 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 1000 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 |
| 27 | 1000 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 1000 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 |
| 28 | 750 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 1000 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 |
| 29 | 500 | 29 | 200 | 29 | 200 | 29 | 200 | | | 29 | 200 | 29 | 1000 | 29 | 200 | 29 | 200 | 29 | 200 | 29 | 200 | 29 | 200 |
| 30 | 200 | 30 | 200 | 30 | 200 | 30 | 200 | | | 30 | 200 | 30 | 1000 | 30 | 200 | 30 | 200 | 30 | 200 | 30 | 200 | 30 | 200 |
| 31 | 200 | | | 31 | 200 | 31 | 200 | | | 31 | 200 | | | 31 | 200 | | | 31 | 200 | 31 | 200 | | |
| **Acre-Feet** | 39074 | | 11901 | | 12298 | | 13488 | | 12298 | | 12298 | | 45620 | | 38777 | | 11901 | | 12298 | | 12298 | | 11901 |
| | | | | | | | | | | | | | | | | | | | | **Water Year Total** | | **234149 Acre-Feet** | |

New Melones Stepped Release Plan Daily Hydrographs for Below Normal Water Year Types

| OCT | CFS | NOV | CFS | DEC | CFS | JAN | CFS | FEB | CFS | MAR | CFS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 250 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 |
| 2 | 250 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 |
| 3 | 250 | 3 | 200 | 3 | 200 | 3 | 400 | 3 | 200 | 3 | 200 |
| 4 | 250 | 4 | 200 | 4 | 200 | 4 | 400 | 4 | 200 | 4 | 200 |
| 5 | 250 | 5 | 200 | 5 | 200 | 5 | 400 | 5 | 400 | 5 | 200 |
| 6 | 250 | 6 | 200 | 6 | 200 | 6 | 400 | 6 | 400 | 6 | 200 |
| 7 | 250 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 400 | 7 | 200 |
| 8 | 250 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 400 | 8 | 200 |
| 9 | 250 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 |
| 10 | 250 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 |
| 11 | 250 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 |
| 12 | 250 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 |
| 13 | 250 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 |
| 14 | 250 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 |
| 15 | 500 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 |
| 16 | 750 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 |
| 17 | 1000 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 |
| 18 | 1250 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 |
| 19 | 1500 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 |
| 20 | 1500 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 |
| 21 | 1500 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 |
| 22 | 1500 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 |
| 23 | 1500 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 |
| 24 | 1500 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 |
| 25 | 1500 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 |
| 26 | 1500 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 |
| 27 | 1500 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 |
| 28 | 1250 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 |
| 29 | 1000 | 29 | 200 | 29 | 200 | 29 | 200 | | | 29 | 200 |
| 30 | 750 | 30 | 200 | 30 | 200 | 30 | 200 | | | 30 | 200 |
| 31 | 500 | | | 31 | 200 | 31 | 200 | | | 31 | 200 |
| **Acre-Feet** | 47603 | | 11901 | | 12298 | | 13884 | | 12694 | | 12298 |

| APR | CFS | MAY | CFS | JUN | CFS | JUL | CFS | AUG | CFS | SEP | CFS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 400 | 1 | 1500 | 1 | 900 | 1 | 250 | 1 | 250 | 1 | 250 |
| 2 | 750 | 2 | 1500 | 2 | 600 | 2 | 250 | 2 | 250 | 2 | 250 |
| 3 | 1000 | 3 | 1500 | 3 | 600 | 3 | 250 | 3 | 250 | 3 | 250 |
| 4 | 1250 | 4 | 1500 | 4 | 600 | 4 | 250 | 4 | 250 | 4 | 250 |
| 5 | 1500 | 5 | 1500 | 5 | 600 | 5 | 250 | 5 | 250 | 5 | 250 |
| 6 | 1700 | 6 | 1500 | 6 | 600 | 6 | 250 | 6 | 250 | 6 | 250 |
| 7 | 2000 | 7 | 1500 | 7 | 450 | 7 | 250 | 7 | 250 | 7 | 250 |
| 8 | 2000 | 8 | 1500 | 8 | 450 | 8 | 250 | 8 | 250 | 8 | 250 |
| 9 | 2000 | 9 | 1500 | 9 | 450 | 9 | 250 | 9 | 250 | 9 | 250 |
| 10 | 2000 | 10 | 1500 | 10 | 450 | 10 | 250 | 10 | 250 | 10 | 250 |
| 11 | 1500 | 11 | 1500 | 11 | 300 | 11 | 250 | 11 | 250 | 11 | 250 |
| 12 | 1500 | 12 | 1500 | 12 | 300 | 12 | 250 | 12 | 250 | 12 | 250 |
| 13 | 1500 | 13 | 1500 | 13 | 300 | 13 | 250 | 13 | 250 | 13 | 250 |
| 14 | 1500 | 14 | 1250 | 14 | 300 | 14 | 250 | 14 | 250 | 14 | 250 |
| 15 | 1500 | 15 | 1250 | 15 | 250 | 15 | 250 | 15 | 250 | 15 | 250 |
| 16 | 1500 | 16 | 1250 | 16 | 250 | 16 | 250 | 16 | 250 | 16 | 250 |
| 17 | 1500 | 17 | 1250 | 17 | 250 | 17 | 250 | 17 | 250 | 17 | 250 |
| 18 | 1500 | 18 | 1250 | 18 | 250 | 18 | 250 | 18 | 250 | 18 | 250 |
| 19 | 2000 | 19 | 1250 | 19 | 250 | 19 | 250 | 19 | 250 | 19 | 250 |
| 20 | 2000 | 20 | 1000 | 20 | 250 | 20 | 250 | 20 | 250 | 20 | 250 |
| 21 | 2000 | 21 | 1000 | 21 | 250 | 21 | 250 | 21 | 250 | 21 | 250 |
| 22 | 2000 | 22 | 1000 | 22 | 250 | 22 | 250 | 22 | 250 | 22 | 250 |
| 23 | 1500 | 23 | 1000 | 23 | 250 | 23 | 250 | 23 | 250 | 23 | 250 |
| 24 | 1500 | 24 | 1000 | 24 | 250 | 24 | 250 | 24 | 250 | 24 | 250 |
| 25 | 1500 | 25 | 1000 | 25 | 250 | 25 | 250 | 25 | 250 | 25 | 250 |
| 26 | 1500 | 26 | 1000 | 26 | 250 | 26 | 250 | 26 | 250 | 26 | 250 |
| 27 | 1500 | 27 | 900 | 27 | 250 | 27 | 250 | 27 | 250 | 27 | 250 |
| 28 | 1500 | 28 | 900 | 28 | 250 | 28 | 250 | 28 | 250 | 28 | 250 |
| 29 | 1500 | 29 | 900 | 29 | 250 | 29 | 250 | 29 | 250 | 29 | 250 |
| 30 | 1500 | 30 | 900 | 30 | 250 | 30 | 250 | 30 | 250 | 30 | 250 |
| | | 31 | 900 | | | 31 | 250 | 31 | 250 | | |
| **Acre-Feet** | 92430 | | 76364 | | 21620 | | 15372 | | 15372 | | 14876 |

**Water Year Total** 346711 Acre-Feet

New Melones Stepped Release Plan Daily Hydrographs for Above Normal Water Year Types

| OCT | CFS | NOV | CFS | DEC | CFS | JAN | CFS | FEB | CFS | MAR | CFS | APR | CFS | MAY | CFS | JUN | CFS | JUL | CFS | AUG | CFS | SEP | CFS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 250 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 400 | 1 | 1500 | 1 | 900 | 1 | 250 | 1 | 250 | 1 | 250 |
| 2 | 250 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 750 | 2 | 1500 | 2 | 600 | 2 | 250 | 2 | 250 | 2 | 250 |
| 3 | 250 | 3 | 200 | 3 | 200 | 3 | 400 | 3 | 200 | 3 | 200 | 3 | 1000 | 3 | 1500 | 3 | 600 | 3 | 250 | 3 | 250 | 3 | 250 |
| 4 | 250 | 4 | 200 | 4 | 200 | 4 | 400 | 4 | 200 | 4 | 200 | 4 | 1250 | 4 | 1500 | 4 | 600 | 4 | 250 | 4 | 250 | 4 | 250 |
| 5 | 250 | 5 | 200 | 5 | 200 | 5 | 400 | 5 | 400 | 5 | 200 | 5 | 1500 | 5 | 1500 | 5 | 600 | 5 | 250 | 5 | 250 | 5 | 250 |
| 6 | 250 | 6 | 200 | 6 | 200 | 6 | 400 | 6 | 400 | 6 | 200 | 6 | 1700 | 6 | 1500 | 6 | 600 | 6 | 250 | 6 | 250 | 6 | 250 |
| 7 | 250 | 7 | 200 | 7 | 200 | 7 | 200 | 7 | 400 | 7 | 200 | 7 | 2000 | 7 | 1500 | 7 | 450 | 7 | 250 | 7 | 250 | 7 | 250 |
| 8 | 250 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 400 | 8 | 200 | 8 | 2000 | 8 | 1500 | 8 | 450 | 8 | 250 | 8 | 250 | 8 | 250 |
| 9 | 250 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 2000 | 9 | 1500 | 9 | 450 | 9 | 250 | 9 | 250 | 9 | 250 |
| 10 | 250 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 2000 | 10 | 1500 | 10 | 450 | 10 | 250 | 10 | 250 | 10 | 250 |
| 11 | 250 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 1500 | 11 | 1500 | 11 | 300 | 11 | 250 | 11 | 250 | 11 | 250 |
| 12 | 250 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 1500 | 12 | 1500 | 12 | 300 | 12 | 250 | 12 | 250 | 12 | 250 |
| 13 | 250 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 1500 | 13 | 1500 | 13 | 300 | 13 | 250 | 13 | 250 | 13 | 250 |
| 14 | 250 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 1500 | 14 | 1250 | 14 | 300 | 14 | 250 | 14 | 250 | 14 | 250 |
| 15 | 500 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 1500 | 15 | 1250 | 15 | 250 | 15 | 250 | 15 | 250 | 15 | 250 |
| 16 | 750 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 1500 | 16 | 1250 | 16 | 250 | 16 | 250 | 16 | 250 | 16 | 250 |
| 17 | 1000 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 1500 | 17 | 1250 | 17 | 250 | 17 | 250 | 17 | 250 | 17 | 250 |
| 18 | 1250 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 1500 | 18 | 1250 | 18 | 250 | 18 | 250 | 18 | 250 | 18 | 250 |
| 19 | 1500 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 2000 | 19 | 1250 | 19 | 250 | 19 | 250 | 19 | 250 | 19 | 250 |
| 20 | 1500 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 2000 | 20 | 1000 | 20 | 250 | 20 | 250 | 20 | 250 | 20 | 250 |
| 21 | 1500 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 2000 | 21 | 1000 | 21 | 250 | 21 | 250 | 21 | 250 | 21 | 250 |
| 22 | 1500 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 2000 | 22 | 1000 | 22 | 250 | 22 | 250 | 22 | 250 | 22 | 250 |
| 23 | 1500 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 1500 | 23 | 1000 | 23 | 250 | 23 | 250 | 23 | 250 | 23 | 250 |
| 24 | 1500 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 1500 | 24 | 1000 | 24 | 250 | 24 | 250 | 24 | 250 | 24 | 250 |
| 25 | 1500 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 1500 | 25 | 1000 | 25 | 250 | 25 | 250 | 25 | 250 | 25 | 250 |
| 26 | 1500 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 1500 | 26 | 1000 | 26 | 250 | 26 | 250 | 26 | 250 | 26 | 250 |
| 27 | 1500 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 1500 | 27 | 900 | 27 | 250 | 27 | 250 | 27 | 250 | 27 | 250 |
| 28 | 1250 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 1500 | 28 | 900 | 28 | 250 | 28 | 250 | 28 | 250 | 28 | 250 |
| 29 | 1000 | 29 | 200 | 29 | 200 | 29 | 200 | | | 29 | 200 | 29 | 1500 | 29 | 900 | 29 | 250 | 29 | 250 | 29 | 250 | 29 | 250 |
| 30 | 750 | 30 | 200 | 30 | 200 | 30 | 200 | | | 30 | 200 | 30 | 1500 | 30 | 900 | 30 | 250 | 30 | 250 | 30 | 250 | 30 | 250 |
| 31 | 500 | | | 31 | 200 | 31 | 200 | | | 31 | 200 | | | 31 | 900 | | | 31 | 250 | 31 | 250 | | |
| **Acre-Feet** | 47603 | | 11901 | | 12298 | | 13884 | | 12694 | | 12298 | | 92430 | | 76364 | | 21620 | | 15372 | | 15372 | | 14876 |
| | | | | | | | | | | | | | | | | | | | | **Water Year Total** | | **346711 Acre-Feet** | |

New Melones Stepped Release Plan Daily Hydrographs for Wet Water Year Types

| OCT | CFS | NOV | CFS | DEC | CFS | JAN | CFS | FEB | CFS | MAR | CFS | APR | CFS | MAY | CFS | JUN | CFS | JUL | CFS | AUG | CFS | SEP | CFS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 300 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 200 | 1 | 3000 | 1 | 3000 | 1 | 1200 | 1 | 300 | 1 | 300 | 1 | 300 |
| 2 | 300 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 200 | 2 | 350 | 2 | 3000 | 2 | 3000 | 2 | 1200 | 2 | 300 | 2 | 300 | 2 | 300 |
| 3 | 300 | 3 | 200 | 3 | 200 | 3 | 400 | 3 | 200 | 3 | 700 | 3 | 3000 | 3 | 3000 | 3 | 1200 | 3 | 300 | 3 | 300 | 3 | 300 |
| 4 | 300 | 4 | 200 | 4 | 200 | 4 | 400 | 4 | 200 | 4 | 1200 | 4 | 3000 | 4 | 3000 | 4 | 1200 | 4 | 300 | 4 | 300 | 4 | 300 |
| 5 | 300 | 5 | 200 | 5 | 200 | 5 | 400 | 5 | 400 | 5 | 1800 | 5 | 2300 | 5 | 2300 | 5 | 1200 | 5 | 300 | 5 | 300 | 5 | 300 |
| 6 | 300 | 6 | 200 | 6 | 200 | 6 | 400 | 6 | 400 | 6 | 2300 | 6 | 1500 | 6 | 1500 | 6 | 1200 | 6 | 300 | 6 | 300 | 6 | 300 |
| 7 | 300 | 7 | 200 | 7 | 200 | 7 | 400 | 7 | 400 | 7 | 3000 | 7 | 1200 | 7 | 1500 | 7 | 1200 | 7 | 300 | 7 | 300 | 7 | 300 |
| 8 | 300 | 8 | 200 | 8 | 200 | 8 | 200 | 8 | 400 | 8 | 3000 | 8 | 800 | 8 | 1500 | 8 | 1200 | 8 | 300 | 8 | 300 | 8 | 300 |
| 9 | 300 | 9 | 200 | 9 | 200 | 9 | 200 | 9 | 400 | 9 | 3000 | 9 | 800 | 9 | 1500 | 9 | 1000 | 9 | 300 | 9 | 300 | 9 | 300 |
| 10 | 300 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 200 | 10 | 3000 | 10 | 800 | 10 | 1500 | 10 | 1000 | 10 | 300 | 10 | 300 | 10 | 300 |
| 11 | 300 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 200 | 11 | 3000 | 11 | 800 | 11 | 1500 | 11 | 1000 | 11 | 300 | 11 | 300 | 11 | 300 |
| 12 | 300 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 200 | 12 | 3000 | 12 | 800 | 12 | 1500 | 12 | 1000 | 12 | 300 | 12 | 300 | 12 | 300 |
| 13 | 300 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 200 | 13 | 1200 | 13 | 800 | 13 | 1500 | 13 | 1000 | 13 | 300 | 13 | 300 | 13 | 300 |
| 14 | 300 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 200 | 14 | 800 | 14 | 800 | 14 | 1500 | 14 | 1000 | 14 | 300 | 14 | 300 | 14 | 300 |
| 15 | 500 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 200 | 15 | 800 | 15 | 800 | 15 | 1200 | 15 | 1000 | 15 | 300 | 15 | 300 | 15 | 300 |
| 16 | 750 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 200 | 16 | 800 | 16 | 800 | 16 | 1200 | 16 | 1000 | 16 | 300 | 16 | 300 | 16 | 300 |
| 17 | 1000 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 200 | 17 | 800 | 17 | 800 | 17 | 1200 | 17 | 1000 | 17 | 300 | 17 | 300 | 17 | 300 |
| 18 | 1250 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 200 | 18 | 800 | 18 | 800 | 18 | 1200 | 18 | 1000 | 18 | 300 | 18 | 300 | 18 | 300 |
| 19 | 1500 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 200 | 19 | 800 | 19 | 800 | 19 | 1200 | 19 | 1000 | 19 | 300 | 19 | 300 | 19 | 300 |
| 20 | 1500 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 200 | 20 | 800 | 20 | 800 | 20 | 1200 | 20 | 1000 | 20 | 300 | 20 | 300 | 20 | 300 |
| 21 | 1500 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 200 | 21 | 800 | 21 | 800 | 21 | 1200 | 21 | 1000 | 21 | 300 | 21 | 300 | 21 | 300 |
| 22 | 1500 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 200 | 22 | 800 | 22 | 800 | 22 | 1200 | 22 | 1000 | 22 | 300 | 22 | 300 | 22 | 300 |
| 23 | 1500 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 200 | 23 | 800 | 23 | 800 | 23 | 1200 | 23 | 1000 | 23 | 300 | 23 | 300 | 23 | 300 |
| 24 | 1500 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 200 | 24 | 800 | 24 | 800 | 24 | 1200 | 24 | 750 | 24 | 300 | 24 | 300 | 24 | 300 |
| 25 | 1500 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 200 | 25 | 800 | 25 | 800 | 25 | 1200 | 25 | 750 | 25 | 300 | 25 | 300 | 25 | 300 |
| 26 | 1500 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 200 | 26 | 800 | 26 | 800 | 26 | 1200 | 26 | 500 | 26 | 300 | 26 | 300 | 26 | 300 |
| 27 | 1500 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 200 | 27 | 1200 | 27 | 1500 | 27 | 1200 | 27 | 500 | 27 | 300 | 27 | 300 | 27 | 300 |
| 28 | 1250 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 200 | 28 | 1500 | 28 | 2300 | 28 | 1200 | 28 | 500 | 28 | 300 | 28 | 300 | 28 | 300 |
| 29 | 1000 | 29 | 200 | 29 | 200 | 29 | 200 | | | 29 | 2300 | 29 | 3000 | 29 | 1200 | 29 | 300 | 29 | 300 | 29 | 300 | 29 | 300 |
| 30 | 750 | 30 | 200 | 30 | 200 | 30 | 200 | | | 30 | 3000 | 30 | 3000 | 30 | 1200 | 30 | 300 | 30 | 300 | 30 | 300 | 30 | 300 |
| 31 | 500 | | | 31 | 200 | 31 | 200 | | | 31 | 3000 | | | 31 | 1200 | | | 31 | 300 | 31 | 300 | | |
| **Acre-Feet** | 48992 | | 11901 | | 12298 | | 14281 | | 13091 | | 93521 | | 83306 | | 95603 | | 55934 | | 18446 | | 18446 | | 17851 |
| | | | | | | | | | | | | | | | | | | | | **Water Year Total** | | **483669 Acre-Feet** | |

# Appendix G

## U.S. Fish and Wildlife Service Actions at Federal Fish Hatcheries

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Pacific Southwest Region
2800 Cottage Way, Suite W-2606
Sacramento, California 95825

In Response Reply To:
FWS/R8/

JUN 1 9 2019

Maria Rea
Assistant Regional Administrator, California Central Valley Office
NOAA Fisheries West Coast Region
650 Capitol Mall, Suite 5-100
Sacramento, CA 95814

Dear Ms. Rea,

This letter provides an update on four efforts that the Fish and Wildlife Service has been engaged in regarding Coleman and Livingston Stone National Fish Hatcheries and their contribution to the management and restoration of Chinook salmon in the Sacramento River and Battle Creek. These efforts are: (1) improving Livingston Stone National Fish Hatchery; (2) implementing the Battle Creek Reintroduction Plan; (3) designing and constructing a fish trapping and sorting facility at Coleman NFH; and (4) studying alternative release strategies for Coleman NFH produced fall-run Chinook salmon. The attached summary includes a brief description of each effort, including progress to date and expectations for completion and funding. All of these efforts are underway and at least partially funded, with most of the funding provided by the Bureau of Reclamation with additional funding and support from other partners.

The Service and Reclamation have a long established partnership supporting these and related efforts. For the last several decades, Reclamation has provided about five million dollars annually to support all aspects of Chinook salmon and Steelhead production at Coleman and Livingston Stone NFHs, including funding for hatchery operations and maintenance, fish health monitoring, and evaluation of the success of the hatcheries in meeting their objectives. This operational funding has been sufficient to help support all of the efforts identified above. When this operational funding falls short of the support necessary for high priority efforts, Reclamation has provided additional funding, including funding for improving Livingston Stone NFH and for studying alternative release strategies.

The Service has also partnered with other agencies and stakeholders to support these efforts. The California Department of Fish and Wildlife and the Service recently entered into an agreement that provides the Service with more than fourteen million dollars to support implementation of the Battle Creek Reintroduction Plan and designing and constructing a fish trapping and sorting facility at Coleman NFH, as well as other efforts identified in the State's Sacramento Valley Salmon Resiliency Strategy. Other examples of partnered support include contributions by the Department of Fish and Wildlife, University of California at Davis, and the commercial and sport fishing communities to the study of alternative release strategies for Coleman NFH fall-run Chinook salmon.

The Fish and Wildlife Service will continue to work with Reclamation and our other partners to complete all of the efforts identified above. Given our long-term commitment to these efforts and the history of support from Reclamation and others, we believe that we will complete most of these efforts and make substantial progress on the remaining efforts over the next ten years.

Sincerely,

Dan Castleberry
Assistant Regional Director – FAC

This Attachment provides an update on four efforts that the Fish and Wildlife Service is engaged in at Coleman and Livingston Stone National Fish Hatcheries and their contribution to the management and restoration of Chinook salmon in the Sacramento River and Battle Creek. These efforts are: (1) improving Livingston Stone National Fish Hatchery; (2) implementing the Battle Creek Reintroduction Plan; (3) designing and constructing a fish trapping and sorting facility at Coleman NFH; and (4) studying alternative release strategies for Coleman NFH produced fall-run Chinook salmon. Brief descriptions of each effort are included below. Staff from multiple agencies, including the National Marine Fisheries Service and Bureau of Reclamation have been involved in, or are aware of all of these efforts. Several of these efforts have supporting documentation that NMFS and Reclamation staff likely have in their files, many of which they helped draft.

**1. Improving Livingston Stone National Fish Hatchery** (corresponds to action number 2 on NMFS initial Draft Solutions List). This series of actions would improve the capacity of Livingston Stone NFH to rear winter-run Chinook salmon for both the mainstem Sacramento and Battle Creek programs. Several of these actions are focused on providing improved capacity and infrastructure to better address needs under drought conditions. A few could improve the overall biosecurity and efficiency of the hatchery.

*(1). Securing an emergency or alternate water supply when Shasta and Keswick reservoirs reach elevations below the current penstock* – This action is primarily to address drought conditions where reservoir elevations could drop to the extent that the hatchery water supply is no longer accessing cold water. To date, the idea of improving water supply from the penstocks at Shasta Dam has been discussed, but not implemented. Previous ideas considered by Reclamation for ensuring supply of cold water during the last drought included pumping water up from the river. Current ideas for improving water supply include: a) replacing and upgrading valves, controllers, and alarms to ensure the water supply is more secure and staff are better able to respond to water alarms; and, b) connecting Penstock 5 (which is lower than the other penstocks) to the hatchery water system to allow greater flexibility to provide more cold water during low lake levels and during penstock maintenance outages. Replacing and upgrading valves, controllers, and alarms would improve biosecurity and efficiency at the hatchery under all conditions. Connecting Penstock 5 would focus primarily on addressing drought conditions. An initial estimate of the cost of these improvements is $250K. The Service and Reclamation have discussed these actions in concept, but chose to address cold water concerns during the prior drought by renting chillers.

*(2). Acquiring water chillers to ensure that adequate water temperature are provided during critical winter-run Chinook salmon life stages* - During the drought in 2014 and 2015, Reclamation funded the rental of two commercial-size chillers to ensure adequate water temperatures for adult holding, egg incubation, and juvenile rearing. Those chillers were rented during the summer and fall and used on a just few occasions. Subsequently Reclamation has funded a small permanent chiller to ensure temperatures for egg incubation only. Demand of Livingston Stone NFH to hold adult broodstock has increase significantly with the addition of the captive brood and Battle Creek programs. Installing chillers at critical times during drought conditions for adult holding and juvenile rearing is essential to ensure that the increased demand can be met during drought years. The cost estimate for purchasing chillers is $2M, but it may be more cost effective to rent chillers when they are needed. Renting chillers would minimize the cost of storing and maintaining the chillers went they are not needed, especially if drought conditions do not occur for several years in succession.

*(3). Acquiring more physical space to adequately rear increased production to help the population withstand the drought and to successfully operate the Captive Broodstock Program* – At the request of the National Marine Fisheries Service and California Department of Fish and Wildlife, Livingston Stone NFH increased production during the recent drought to compensate for expected high temperature-dependent mortality of winter-run Chinook salmon spawning naturally in the river. Around the same time, the same agencies requested that the hatchery re-initiate the captive broodstock program. As the drought abated, there was no longer a need to continue increased production. The broodstock program ultimately occupied the space available to accommodate increased production, reducing the hatchery's flexibility to increase production for drought or other purposes in the future. In 2016, a multi-agency work team concluded Livingston Stone NFH would need to expand by 8 to 10 circular tanks to raise an additional 350,000 fish if the hatchery were to engage in the same drought operations they did in the recent drought. Increasing the capacity of Livingston Stone NFH would require expanding to the west side of the hatchery road, additional piping to that side of the property, and additional water. Construction cost is estimated to be $750K and an additional 6cfs would need to be supplied.

*(4). Modifications/improvements to Keswick Dam Fish Trap* - The Keswick Dam fish trap has two major infrastructure components: the fish trap and the elevator. Both components are independent of one another and need to be lined up exactly to collect fish. If not lined up exactly, fish can get underneath or behind the trap, although instances of fish getting there are rare and likely due to operator error. An investigation to find a way to better connect these two pieces during fish transfer could identify an approach to reducing the risk of fish getting below or behind the trap. The cost estimate of these improvements is $80,000. The Service will discuss the potential need for improvements with Reclamation, and if improvements are necessary, is confident that the agencies can identify the funds necessary to implement the improvements.

*(5). Modifications/improvements to Anderson-Cottonwood Irrigation Dam (ACID) Fish Trap or investigations/assessment of new adult trapping facility/location* - Several years ago, Reclamation funded, and the Service operated the ACID trap, a fish trap on the north side of the Sacramento River at Caldwell Park. To date, only two salmon have been collected at that site and the Service ceased operating the trap this year. Collecting winter-run Chinook salmon on the south side of the Sacramento River via a trap in the ACID ladder could be investigated. An investigation would need to take place before deciding whether or not to construct a trap at the ladder and the cost of the investigation is estimated to be $50K.

*(6). Improvements to the water treatment facility* - The Service has previously completed studies on providing a UV treatment plant at Livingston Stone NFH to help combat pre-spawn mortality of captive and wild adult broodstock. UV treatment is a common biosecurity measure at hatcheries, especially facilities where salmon spawn in the hatchery's water supply. However, UV treatment was never established at Livingston Stone NFH, in part because salmon do not spawn above the hatcheries intake. The Pacific Southwest Region of the Service has UV treatment at its two other hatcheries: Coleman NFH and Lahontan NFH. If UV were deemed necessary, a UV treatment plant at Livingston Stone NFH is estimated to cost about $2M to install and an additional $60K a year to operate and maintain. Recently, the hatchery begun to discuss the potential need for a drum screen to remove solids in the hatchery's effluent. The drum screen could allow the Service more flexibility in the use of medicated feed to prevent and treat disease. A preliminary cost estimate for constructing a drum filter for the current operations at Livingston Stone NFH is $150K. The Service has not

discussed the potential need for a drum filter with Reclamation or our other partners, and so is not ready to move forward with this action at this time.

*(7). Ongoing monitoring and research* – The Service partners with the California Department of Fish and Wildlife for much of the monitoring for winter-run Chinook salmon on the Sacramento River. Service efforts include coded-wire tagging and marking Livingston Stone NFH-produced winter-run Chinook salmon, acoustic tagging a subset of those fish, rotary screw trapping at Red Bluff Diversion Dam, and carcass surveys on the mainstem Sacramento River. Reclamation covers the costs for all of the Service efforts, mostly out of the operational funding agreement for Coleman and Livingston Stone NFHs and the BiOp monitoring agreement with our Red Bluff Fish and Wildlife Office. Both of these are long-term agreements with a history of renewal.

**2. Implementing the Battle Creek Reintroduction Plan** (corresponds to action number 10 on NMFS initial Draft Solutions List). In 2017, Livingston Stone NFH had excess winter-run Chinook salmon broodstock on station. This occurred because extra captive broodstock were being kept in the event additional fish were needed to supplement the mainstem Sacramento River program because of drought conditions. When it turned out the extra captive broodstock were not needed for the Sacramento program, the agencies decided to use those fish to produce juveniles for release into Battle Creek to jumpstart the reintroduction of winter-run Chinook salmon in advance of the implementation of the Battle Creek Reintroduction Plan and the complete restoration of Battle Creek. In the spring of 2018, Coleman NFH released 215,000 juvenile winter-run Chinook salmon into upper Battle Creek. Subsequently, the agencies decided to continue this jumpstart program and Coleman NFH has integrated the production of approximately 200,000 winter-run Chinook salmon juveniles into its annual operations. This currently involves spawning broodstock and rearing eggs at Livingston Stone NFH, then transferring fry to Coleman NFH for further rearing and release. Coleman NFH has spent $100K on water chilling infrastructure to help ensure consistent optimal rearing conditions for winter-run Chinook salmon and to eventually be able to spawn fish and rear eggs on station. To date, personnel costs and funding for all aspects of the jump-start program, including feed, rearing, tagging, transportation of fish, and infrastructure have been accomplished with Coleman NFH's operational funding provided annually by Reclamation. The Battle Creek Reintroduction Plan itself includes estimates of costs for implementing the plan amounting to $3.365M in one-time construction and acquisition costs and $650K in annual costs. The Reintroduction Plan states that these estimates are conceptual and probably low. Two of the four tasks in the Service's recently signed agreement with the California Department of Fish and Wildlife contribute to implementing the Battle Creek Reintroduction Plan, and give the Service access to about $14M to cover mostly the one-time construction and acquisition costs. This funding should be adequate to fully address those costs. As the Reintroduction Plan proceeds further into implementation, additional funding will likely be needed to cover the annual costs.

**3. Designing and constructing a fish trapping and sorting facility at Coleman National Fish Hatchery** (corresponds to action number 11 on NMFS initial Draft Solutions List). The Service assembled a multi-agency team to design a fish trapping and sorting facility at the Coleman NFH Weir to minimize handling and migration delay of listed species during Coleman NFH's Fall-run Chinook (FCS) spawning operations, and to allow for passage, monitoring, and management of fish passage during times when spawning operations are not taking place. The project is currently envisioned to be constructed in two phases, with the first phase establishing the ability to pass fish through the fish sorting facility year round, which would allow for monitoring and management during times when the spawning operations are not being conducted. The second phase would allow for selective bypassing of the spawning building during spawning operations and automation of many of the processes. To date, with Reclamation funding of $500K and input from the partnered agencies, the Service has completed 65% design of Phase I with an anticipated 100% design completion date of August, 2019. Completing design of Phase II will cost an estimated $600K and construction costs are estimated to be approximately $13M. One of the four tasks in the Service's recently signed agreement with the California Department of Fish and Wildlife contributes to completing the permitting required for Phase 1 of the trapping and sorting facility, and gives the Service access to a portion of the $14M to cover permitting costs. Funds to construct the facility have yet to be identified.

**4. Studying alternative release strategies for Coleman NFH produced fall-run Chinook salmon** (corresponds to action number 34 on NMFS initial Draft Solutions List). This action is the study of alternative release strategies for Coleman NFH fall-run Chinook salmon to determine if trucking to an alternative release site can increase juvenile survival to the ocean and adult returns to the Sacramento River without unacceptable levels of straying. To date, the Service has implemented one year of a three-year study, largely through the use of Coleman NFH operational funds, acoustic tags provided by Reclamation, tag surgeries provided by UC Davis, and net pen operations provided by stakeholders and the California Department of Fish and Wildlife's Mokelumne River Hatchery. The current plan is to run the study for another two years. Coleman NFH will provide fish and trucking out of their operational funding. We anticipate net pen support will continue to be provided by stakeholders and the state. The Service is establishing the capacity to conduct surgeries and has an agreement with Reclamation to provide acoustic tags. The only remaining items that require funding are coded-wire tagging, which will require $90K annually for two years and acoustic tagging data analysis, a one-time cost of $25K. The Service anticipates that we can work with our partners to adequately fund these items.

# Appendix H

## Selected Delta-Related References Relevant to Water Project-Related Effects in the South Delta

**<u>Selected Delta-related references relevant to water project-related effects in the south Delta</u>**
*Prepared by Barb Byrne, NMFS California Central Valley Office*
*August 2018*

***Note:*** *Takeaway bullets and quotes have been selected as being most relevant to the recently proposed draft Initial Actions in the reinitiation effort related to OMR management or the I:E ratio and do not represent all key conclusions of the citations.*

**1) California Department of Water Resources (2014). Stipulation Study: Steelhead Movement and Survival in the South Delta with Adaptive Management of Old and Middle River Flows. Prepared by David Delaney, Paul Bergman, Brad Cavallo, and Jenny Melgo (Cramer Fish Sciences) under the direction of Kevin Clark (DWR). February 2014.**

http://baydeltaoffice.water.ca.gov/announcement/Final_Stipulation_Study_Report_7Feb2014.pdf

*Takeaway Bullet:* I believe that the conclusions drawn in this report are overbroad and only weakly caveated in the report. Analysis focused primarily on junctions with the San Joaquin River rather than on movement behavior within south Delta channels yet draws broad conclusions about effects of OMR in general.

*Quote (p. ES-4):* The statement "Under the OMR flow treatments tested in this study, there appeared to be little influence of OMR flows tested on steelhead tag travel times on the route-level and steelhead tag movement at the junctions and routes examined in this study (p. ES-3)" is technically correct but may be misleading to those not aware that the bulk of the analysis was in the mainstem San Joaquin River route and thus not necessarily applicable to the OMR corridor itself. Despite the limited range of OMR flows, small sample sizes, and focus on conditions in the mainstem San Joaquin River, the executive summary goes on to conclude (in my opinion, improperly) that "There is little evidence that altering OMR flows within the range that we examined in this study would alter fish behavior in a meaningful way".

*Caveat:* Limitations in the range of OMR conditions tested, changes to OMR within treatment periods, and relatively low power tests should be taken into consideration when interpreting the results of the stipulation study. The report reflects the outcomes of the statistical analysis of selected hypotheses at a few locations in the south Delta and, in my opinion, does not support broad conclusions about fish movement in the interior Delta in relation to OMR flows.

**2) del Rosario, R. B., Y. J. Redler, K. Newman, P. L. Brandes, T. Sommer, K. Reece and R. Vincik (2013). "Migration Patterns of Juvenile Winter-run-sized Chinook Salmon (*Oncorhynchus tshawytscha*) through the Sacramento–San Joaquin Delta." <u>San Francisco Estuary and Watershed Science</u> 11(1).**

https://escholarship.org/uc/item/36d88128

*Takeaway Bullet:* Winter-run Chinook salmon enter the Delta as early as October in some years and may make their way to the south Delta and be exposed to water-project-related hydrodynamic effects.

*Quote (from abstract): "*Winter-run passed Knights Landing…between October and April, with substantial variation in peak time of entry that was strongly associated with the first high flows of the migration season. Specifically, the first day of flows of at least 400 m3 s-1 [~14,000 cfs] at Wilkins Slough (rkm 190) coincided with the first day that at least 5% of the annual total catch was observed at Knights Landing. … Differences in timing of cumulative catch at Knights Landing and Chipps Island indicate that apparent residence time in the Delta ranges from 41 to 117 days, with longer apparent residence times for juveniles arriving earlier at Knights Landing."

*Caveat:* Juvenile Chinook salmon were identified to race based on the length-at-date classification system, which has some uncertainty, but probably less so in the October and November time-frame when winter-run Chinook are essentially the only young-of-year Chinook run present in the system.

**3) Hankin, D., D. Dauble, J. Pizzimenti, and P. Smith (2010). The Vernalis Adaptive Management Program (VAMP): Report of the 2010 Review Panel. Prepared for the Delta Science Program. May 13, 2010.**

http://www.sjrg.org/peerreview/review_vamp_panel_report_final_051110.pdf

*Takeaway Bullet:* Complex hydrodynamics in the Delta, multiple stressors affecting salmonid survival, and a limited range of experimental conditions limit the inferences possible from the VAMP studies.

*Quotes:*
*(p. 9)* "Regarding export objectives, our feeling is that it makes sense during VAMP to continue limiting exports to some fraction of San Joaquin River flow at Vernalis so that the entire flow of the San Joaquin River is not diverted and so that reverse flows, if they occur, are not large. We cannot, however, offer any guidance as to what the Vernalis flow/export ratio should be…However, we do not believe that migration through Old River and subsequent salvage trucking and release is a desirable route for downstream migrating smolts. To the maximum extent possible, migration through the mainstem San Joaquin channel should be encouraged."

*(p. 3)* "The complexities of Delta hydraulics in a strongly tidal environment, and high and likely highly variable impacts of predation, appear to affect survival rates more than the river flow, by itself, and greatly complicate the assessment of effects of flow on survival rates of smolts. And overlaying these complexities is an apparent strong trend toward reduced survival rates at all flows over the past ten years in the Delta. Nevertheless, the evidence supports a conclusion that increased flows generally have a positive effect on survival and that it is desirable, to the extent feasible, to reduce or eliminate downstream passage through the Old River channel. The panel understands, of course, that flow, exports, and the placement of barriers in the Delta are the variables affecting survival that are most easily managed."

*Caveat:* See takeaway bullet.

**4) Johnson, R. C., S. Windell, P. L. Brandes, J. L. Conrad, J. Ferguson, P. A. L. Goertler, B. N. Harvey, J. Heublein, J. A. Israel, D. W. Kratville, J. E. Kirsch, R. W. Perry, J.**

**Pisciotto, W. R. Poytress, K. Reece and B. G. Swart (2017). "Science Advancements Key to Increasing Management Value of Life Stage Monitoring Networks for Endangered Sacramento River Winter-Run Chinook Salmon in California." San Francisco Estuary and Watershed Science 15(3).**

https://doi.org/10.15447/sfews.2017v15iss3art1

*Takeaway Bullet:* Our ability to evaluate risks to listed salmonids at finer spatial and temporal scales may require changes to our monitoring.

*Quote (from abstract): "*We concluded that the current monitoring network was insufficient to diagnose when (life stage) and where (geographic domain) chronic or episodic reductions in SRWRC cohorts occur, precluding within- and among-year comparisons. …We identified six system-wide recommended actions to strengthen the value of data generated from the existing monitoring network to assess resource management actions: (1) incorporate genetic run identification; (2) develop juvenile abundance estimates; (3) collect data for life history diversity metrics at multiple life stages; (4) expand and enhance real-time fish survival and movement monitoring; (5) collect fish condition data; and (6) provide timely public access to monitoring data in open data formats."

*Caveat:* Most of the recommended actions will require additional resources for implementation.

**5) Monismith, S., M. Fabrizio, M. Healey, J. Nestler, K. Rose and J. Van Sickle (2014). Workshop on the Interior Delta Flows and Related Stressors: Panel Summary Report. Prepared for the Delta Science Program. July 2014.**

http://deltacouncil.ca.gov/sites/default/files/documents/files/Int-Flows-and-Related-Stressors-Report.pdf

*Takeaway Bullet:* The migration of both Chinook fry and smolts may be disrupted by interior Delta flow fields; steelhead may also be affected but less so given their larger size.

*Quotes:*
*(p. 37):* "Chinook salmon fry are not strong swimmers and typically hold in shallow embayments or use structures to keep from being carried along by the prevailing current. Kjelson et al. (1982) noted that beach seine catches of Chinook salmon fry in the Delta dropped significantly at night, suggesting fry were moving away from shallow nearshore areas at night. Larger fry were captured further offshore, near the surface during the day but broadly distributed in the water column at night. If the fry move away from shore at night they would lose visual and tactile clues to their position and would likely simply be carried by the currents. This is characteristic of salmon fry (and smolt) behavior during downstream migration, which occurs primarily at night due to passive drift, but may be less functional in the tidal Delta. In the historic Delta, with its extensive marshes and many blind ending dendritic channels, simply drifting at night might not take the fry very far. In the modern Delta, however, with open trapezoidal channels and high-velocity tidal currents, fry might be carried a considerable distance in the Delta and find themselves in unfavorable habitats when light returns."

*(p. 39-40):* "Although Chinook salmon smolts do not go with the flow strictly in proportion to discharge they do make use of flow during migration. This raises the possibility that they could be confused by reverse flows in OMR. Because of the reverse flows in OMR when exports are large, the smolts are likely to receive mixed signals from tidal flux as water could be moving toward the pumps on both flood and ebb tides depending on the operation of the gates to Clifton Court Forebay (CCF). In this case, smolts may find themselves virtually trapped within OMR over several tidal cycles and potentially attracted into CCF because of inappropriate signals from water chemistry and flow. Since conveyance through the Delta is designed to ensure high quality of export waters (i.e., low salinity) it may be that near the pumps there is insufficient salinity signal on the tidal flow to direct the smolts and they simply go with the flow toward the pumps expecting that it is carrying them downstream. Salmon also make use of compass orientation during their migrations although the extent to which they might use this ability in the Delta is uncertain. It is possible that they might recognize that moving southward in OMR was inappropriate but whether they would be motivated to make some kind of corrective action is unknown."

*(p. 44):* "It appears that steelhead, which are larger than Chinook salmon smolts, are less affected by interior Delta flow fields, move through the Delta more quickly than Chinook salmon and experience greater survival. Nevertheless, steelhead are entrained into CCF and into the export pumps suggesting that some of the cues and clues they receive during their migration through the Delta lead them in the wrong direction."

*Caveat:* The report notes that "*(p. 74)* the vast majority of inferences about the effects of flows in the Delta on listed species are based on correlation analyses. Although correlation analysis is a useful first step when searching for relationships among variables, it often tells little or nothing about cause and effect" and "*(p. 75)* Fish in the Delta are subject to a large number of stressors and untangling the independent effects of these stressors has proven very difficult."

**6) Perry, R. W., R. A. Buchanan, P. L. Brandes, J. R. Burau and J. A. Israel (2016). "Anadromous Salmonids in the Delta: New Science 2006–2016." San Francisco Estuary and Watershed Science 14(2).**

http://dx.doi.org/10.15447/sfews.2016v14iss2art7

*Takeaway Bullet:* This paper covers a lot of topics relevant to the draft proposed Initial Action so have not selected a single takeaway bullet. My selected quote emphasizes the point that more is known about the behavior of salmonid smolts compared to salmonid parr or fry.

*Quotes:*
*(from abstract)* "Although much has been learned, knowledge gaps remain about how very small juvenile salmon (fry and parr) use the Delta. Understanding how all life stages of juvenile salmon grow, rear, and survive in the Delta is critical for devising management strategies that support a diversity of life history strategies."

*Caveat:* None specific to this paper; each of the studies summarized in this paper have their own associated caveats.

**7) Salmonid Scoping Team (2017). Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta. Volume 1: Findings and Recommendations. January 2017.**

http://www.westcoast.fisheries.noaa.gov/central_valley/water_operations/OCAPreports.html

*Takeaway Bullet:* See selected quotes for key takeaways.

*Quotes:*
*(p. ES-6):* "Water export operations contribute to salmonid mortality in the Delta via direct mortality at the facilities, but direct mortality does not account for the majority of the mortality experienced in the Delta; the mechanism and magnitude of indirect effects of water project operations on Delta mortality outside the facilities is uncertain."

*(p. ES-6):* "The evidence of a relationship between exports and through-Delta survival is inconclusive; the key findings presented in this table are supported by medium or high basis of knowledge, but our basis of knowledge on the relationship between exports and through-Delta survival is low (Appendix E, Section E.6.2.1)."

*(p. ES-7):* "It is unknown whether equivocal findings regarding the existence and nature of a relationship between exports and through-Delta survival is due to the lack of a relationship, the concurrent and confounding influence of other variables, or the effect of low overall survival in recent years. These data gaps support a recommendation for further analysis of available data, as well as additional investigations to test hypotheses regarding export effects on migration and survival of Sacramento and San Joaquin River origin salmonids migrating through the Delta."

*(p. ES-10):* "Uncertainty in the relationships between I:E, E:I, and OMR reverse flows and through-Delta survival may be caused by the concurrent and confounding influence of correlated variables, overall low survival, and low power to detect differences (Appendix E, Section E.2.3)."

*(p. ES-10):*

"• I:E: The relationship between Delta survival of San Joaquin River Chinook salmon and I:E is variable but generally positive for lower I:E values (e.g., I:E less than 3) (Appendix E, Section E.11, Figure E.11-1). Results of these studies are confounded by the use of flow ratios since the same I:E ratio can represent different absolute flow and export rates. These results are further confounded by installation and operations of various South Delta barriers. Data are available from only two years of AT studies using steelhead (Appendix E, Section E.11-4).

• Exports: There was a weak positive association between the through-Delta survival of San Joaquin Chinook salmon and combined exports using the CWT data set, but comparisons are complicated by the correlation between exports and San Joaquin River inflow (Appendix E, Section E.6.2.1)."

*Caveat (p. ES-12):* "Current understanding of juvenile salmon and steelhead survival in the Delta is constrained by a variety of factors…" [See the list of "Constraints on Understanding" on pages ES-12 to ES-13]

**8) Salmonid Scoping Team (2017). Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta. Volume 2: Responses to Management Questions. January 2017.**

http://www.westcoast.fisheries.noaa.gov/central_valley/water_operations/OCAPreports.html

*Takeaway Bullet: If the in-season risk assessments in the draft proposed Initial Actions result in a start to OMR management later than January 1, ESA-listed salmonids (winter-run in most years, spring-run in many years, and steelhead in some years) may not have protection equal to that provided by implementation of the 2009 NMFS BiOp.*

*Quote (p. ES-2):* "Although not capturing the seasonal variation in juvenile movement, the January 1 onset of Old and Middle rivers (OMR) reverse flow management coincides with the presence of winter-run Chinook salmon in most years, spring-run Chinook salmon in many years, and steelhead in some years (Figures 4-1, 4-2, 4-3, and 4-4 in Section 4). If OMR reverse flow management were initiated based on first detection in the Delta rather than a fixed date, OMR reverse flow management would often begin earlier than January 1 for the protection of winter-run or spring-run Chinook salmon, and later than January 1 for the protection of steelhead. The January 1 trigger date provides a general approximation of a date by which juvenile winter-run Chinook have likely entered the Delta and, based on its simplicity for triggering management actions, has utility."

*Caveat:* See some technical disagreements about OMR management described on pages ES-2 to ES-3

1). **Vogel, D. 2002. Juvenile Chinook salmon radio-telemetry study in the Southern Sacramento-San Joaquin Delta, December 2000-January 2001.**

Take Home Bullet: Fish released at Woodward Island on Old River during higher export conditions (~8,000 to 11,000 cfs) encountered more negative ambient flow conditions in Old River and consistently moved farther south towards the Projects than fish released under low export conditions (2,000 to 4,700 cfs) with more positive net flow conditions in Old River.

Quote: "The single most evident difference in results between the two medium export experiments and the two low export experiments was the behavior of radio-tagged fish during the first day after release. Radio-tagged salmon in releases 1 and 2 (medium export) experienced minimal or no positive (downstream) flow on the first day whereas fish releases 3 and 4 (low export) experienced long periods of high positive flow. The medium export levels dampened out or nearly eliminated any positive or north flows in Old River. Most fish in releases 1 and 2 exhibited a rapid, southerly migration responding to the high negative flow conditions. In contrast, most fish in releases 3 and 4 moved back and forth (i.e. north and south in Old River in response to the ebb (positive) and flood (negative) flow conditions and remained detectable in Old River for a longer duration than those fish in releases 1 and 2."(Page 20)

Caveat: Final disposition of the radio tagged fish was difficult to discern using mobile tracking only during the day. Night time tracking was not feasible in this study. However, if fish were last detected in close proximity to the Projects, it was assumed that they were entrained either into Clifton Court Forebay or the CVP if they were not detected the next morning.

2) **Vogel, D. 2005. The effects of Delta hydrodynamics conditions on San Joaquin River juvenile salmon.**

Take Home Bullets:
1) The overwhelming effects of tidal flows and site specific hydrodynamic conditions at critical channel junctions are likely masking any relationships between survival based solely on Vernalis flows or export levels.
2) Environmental noise overwhelms any survival relationship signal and makes detection of a statistical relationship between physical parameters nearly impossible without increasing sample size or replicates (i.e. low recovery of CWT fish in the VAMP experiments).
3) Fish moved into junctions in proportions that were not anticipated based on flow splits, and that once fish had left the mainstem San Joaquin River into one of the South Delta distributaries, they typically did not re-enter the mainstem at a later date. The lowest entrainment of fish occurred when the net reverse flows and SWP and CVP exports were lowest.

Quote:

"The "zone of influence" delineating exactly where in the central and south Delta that exports have an overriding influence on salmon "entrainment" into the south Delta is presently unknown and would vary depending on export levels. The smolt telemetry study conducted in December 2000-January 2001 provided empirical evidence that the zone of influence extends at least as far north as the northwestern tip of Woodward Island, a distance of approximately nine river miles north of the CC gates. The two smolt telemetry studies conducted in the mainstem San Joaquin River suggest that the zone of influence is probably much further north (e.g., Turner Cut and Columbia Cut) but the unknown specific regions would depend on many complex and interrelated hydrodynamic variables (e.g., exports, river flows, tides, tidal prisms, localized channel velocities, channel geometry, etc.) combined with fish behavior." (Page 11).

"Also it appears that some smolts, once they move into those south channels do not re-emerge back into the San Joaquin to continue normal migration toward salt water. This latter phenomenon is also not understood. Because of net reverse flows that fish encounter in specific channels south of the San Joaquin River, outmigrating salmon apparently have difficulty re-emerging back into the mainstem. The magnitude of the net reverse flows increases with closer proximity to the south Delta export facilities. Once salmon enter this region of the Delta, the fish likely experience high mortality rates caused by predation and entrainment into unscreened diversions and the export facilities. Some fish are known to be survive the migration all the way to the export facilities, are salvaged, and transported out to the western Delta or San Francisco Bay. However, the proportion of total numbers of salmon unsuccessfully navigating these interior Delta channels is unknown." (Pages 15-16)

Caveats: The report utilizes data from both CWT fish and radio-tagged fish to draw conclusions. It was pointed out that the CWT studies were of low resolution due to the low recovery rates at the terminal sampling location and the lack of internal sampling locations – it could only draw conclusions from point A (release site) to point B (terminal sampling site) with no information regarding what happened in between those two points. The radio tag telemetry studies had higher resolution due to active mobile tracking, but also had issues with low sample numbers and difficulty of tracking fish during the night. However, radio telemetry provided much greater information regarding the movements of fish within the overall migratory route. This initial data reflects the trends of information gained in later studies using acoustic tag technology.

**3.) San Joaquin River Group Authority 2007. 2006 Annual Technical Report.**

Take Home Bullets:

1) Data reinforces the benefit of installing a temporary barrier at the head of Old River which provides protection to juvenile salmon migrating out of the SJ River basin and prevents them from entering the Old River channel.
2) San Joaquin River flows, and flows relative to exports, between April 15 and June 15 was positively correlated to adult escapement in the San Joaquin River basin 2.5 years later. Both relationships were statistically significant ($p<0.01$) with the ratio of flow to exports accounting for slightly more of the variability in escapement than flow alone ($r^2 = 0.58$, vs. $r^2 = 0.42$).
3) With HORB in place, increasing Vernalis flows increased survival of upstream release groups relative to downstream release groups and was statistically significant ($p< 0.01$).
4) Without the HORB in place, there was no clear relationship between the survival rates as measured by differential recovery rates/ combined differential recovery rates for upstream versus downstream releases and flow using the Chipps Island, Antioch, and ocean recoveries for the Mossdale and Durham Ferry releases relative to the Jersey Point releases. There was more variability associated with smolt survival at any given flow without the HORB since the

flow and proportion of fish moving into the Old River channel varies more without the HORB.

5) Flows alone explained survival better than flows relative to exports alone, but the flow/export ratio did increase the fit of the survival correlation and reduced variability in the model.
6) Total absolute prediction error is about 15% less using the model that incorporated the flow/export variable, indicating that it better predicts the survival data than the model using flow alone.
7) Increasing temperature in the San Joaquin River appears to be a confounding factor in determining the role of exports and flow, particularly in late season releases.

Quotes:

"One potential explanation for these results is that the level of exports were low and did not vary enough during these experiments to provide sufficient differences to be detected in our measurements of smolt survival. Exports ranged between 1,450 and 2,350 cfs during these experiments which is much lower than those incorporated into the adult escapement relationships. Another complication is that exports and San Joaquin River flows were correlated with higher exports observed during times of higher flows (Figure 5-16). It is also likely the relationship of exports to smolt survival is different with the HORB in place than when it is absent.…..the HORB was not installed during the majority of the years incorporated into the adult relationships." (page 60)

"These adult relationships would indicate that as you increase flows and decrease exports relative to flows there should be corresponding increases in smolt survival and adult escapement 2 ½ years later." (page 63).

"It is not surprising that there is some uncertainty and noise in these relationships because escapement data does not incorporate the varying age classes within annual escapement, the impact of declining ocean harvest in recent years, and the imprecision in the escapement estimates." (page 63).

Caveats:
As indicated in the report, the lack of recoveries of fish at the terminal sampling points decreases the sensitivity of the study to detect relationships between the different parameters of interest. Statistically significant relationships are typically only seen for "strong" relationships where the signal of the relationship can be detected over the "noise" in the environment, subtle relationships are typically not seen as statistically significant due to the signal being overwhelmed by the environmental noise. Likewise, the VAMP studies did not test all of the flow and export combinations that were initially proposed, thus the ability to discriminate the nature of relationships between the parameters of interest are diminished due to an over representation of only a few parameter pairings, and a lack of pairings at the extremes of the parameter pairings, which would allow for better resolution of parameter effects and relationships.

4) **Newman, K.B., 2008, An Evaluation of Four Sacramento-San Joaquin River Delta juvenile salmon survival studies.**

Take Home Bullets:
1) Newman used Bayesian Hierarchical models (BHMs) to reanalyze data from the four different studies (DCC gate operations, Interior Delta survival, Delta Action 8, and VAMP). The BHMs accounted for unequal sampling variation and between release variations. Recoveries from multiple locations were analyzed in combination. The BHM framework is more statistically efficient and coherent compared to previous analyses.

2) Results from the reanalysis of the Delta Action 8 studies indicate that there was a negative association between export volume and relative survival; that is a 98% chance that as exports increased, relative survival decreased. Environmental variation in the relative survival was very large, however, and a paired low export release could have a high probability of a lower relative survival than a paired high export release due to differences in the environmental parameters and their influence on the relative survival of the paired release.

3) For the VAMP studies, (a) The expected probability of surviving to Jersey Point was consistently larger for fish staying in the San Joaquin River (i.e., passing Dos Reis) than fish entering Old River, but the magnitude of the difference varied between models some-what; (b) thus if the HORB effectively keeps fish from entering Old River, survival of out-migrants should increase; (c) there was a positive association between flow at Dos Reis and subsequent survival from Dos Reis and Jersey Point release sites, and if data from 2003 and later were eliminated from analysis the strength of the association increased and a positive association between flow in Old River and survival in Old River appeared; (d) associations between water export levels and survival probabilities were weak to negligible given the magnitude of environmental noise.

4) In general, data limitations inherent to release-recovery data, i.e., that only one capture is possible, relatively low capture probabilities, relatively high environmental variation, and in the case of VAMP the lack of balance in the release strategy, affect the accuracy of estimates of effects on survival.

5) Given the apparently high environmental variation, it may take many replications of temporally paired releases to more accurately quantify the effects of DCC gate position, exports, flow, and HORB on survival.

Quotes:
1) (For the Delta Action 8 Studies) "The key parameter is $\beta_1$ (the coefficient for exports in the logistic regression of $\theta$; see equation 29). It had a 98% probability of being negative, indicative of a negative association between the relative survival of Georgiana Slough and Ryde releases ($\theta$) and exports." And "The plot shows the decline in mean $\theta$ as exports increases (when exports are at 2000 cfs, mean $\theta$ is 0.62, and when exports are at 10,000 cfs, mean $\theta$ is 0.31)." (Page 59)

2) (For the VAMP Studies) "The expected survival probability down Old River was always less than the survival down the San Joaquin River. Different models yielded somewhat different expected values, but the survival down Old River was generally, if not always, lower than those for the San Joaquin." (Page 62).

3) "Covariate values affect precision, too. For the DA 8 studies, increasing the number of observations at the "extremes" of export levels will increase the precision in the estimate of the slope parameter ($\beta_1$ in Equation 29). Similarly, for the VAMP studies, increasing the number of observations at the "extremes" of flow and exports will increase the precision of the related (partial) slope parameters (Equations 43-46)." (Page 68).

4) "However, with HORB in, survival of releases made above the head of Old River was significantly related to flow, but the relationship with exports and flow/exports was inconsistent and sometimes paradoxical (e.g., exports were positively associated with survival, weakly statistically significant using Antioch and Chipps Island recoveries and insignificant using ocean recoveries). The fact that the presence of the HORB affected the relationships with flow suggests an interaction between flow and HORB." (Page 75).

5) "For the various models fitted, there were two in-common conclusions: (1) flow is positively associated with the probability of surviving from Dos Reis to Jersey Point and (2) the survival probability for that reach is generally greater than the survival probability for fish traveling down Old River. Assuming that the HORB effectively keeps out-migrating salmon from entering Old River, the second conclusion implies that the HORB can increase salmon survival. For fish that do enter Old River, there was some evidence that flow in Old River was positively associated with survival between Old River and Jersey Point, but the evidence was not as consistently strong as for the Dos Reis to Jersey Point reach. There was little evidence for any association between exports and survival, and what evidence there was pointed towards a somewhat surprising positive association with exports." (Page 75-76).

Caveats:

There is an apparent paradoxical relationship for export effects and survival – it is a negative relationship for salmon coming from the Sacramento River side of the Delta as depicted in the results for the Delta Action 8 studies, yet has either a negligible or slightly positive relationship for fish migrating out of the San Joaquin River basin. This may be an artifact of the relationship between higher flows in the San Joaquin River fostering higher survival for SJ basin fish, and the relationship between high flows in the SJ River and increased export levels at the Projects. It is possible that the higher survival is due mainly to higher flows, and not do to a positive relationship with exports.

5) **Newman and Brandes, 2010. Hierarchical modeling of juvenile Chinook salmon survival as a function of Sacramento-San Joaquin Delta water exports.**

Take Home Bullets:

1) Study used temporally paired releases of LFR Chinook salmon in the Delta: Sacramento River at Ryde and within Georgiana Slough, downstream from its junction with the Sacramento River (15 paired releases over the period between 1993 and 2005).

2) Reanalysis of earlier work (Brandes and McLain, 2001), this time only using the LFR Chinook salmon releases; and using Bayesian hierarchical modeling for the statistical analysis.

3) Analysis looked for the relationship of exports by the south Delta Projects on survival of fish released at the different release points using Chipps Island trawl recoveries (recaptured relatively immediately after release) and the ocean and inland recovery data of study fish over the next 2-4 years.

4) Analysis of the data found a consistently negative relationship between the level of exports and survival of fish released in Georgiana Slough (which are presumed to enter the central and south Delta waterways where the effects of the exports are manifested). There is an 86 – 92% probability that the relationship is negative based on the Bayesian modeling.

5) A consistently greater fraction of fish that were released in Georgiana Slough were recovered in salvage at the Projects compared to those fish released at the Ryde location, and this fraction increased with greater export levels.

6) The analysis of this data also pointed out how the low signal to environmental noise ratio diminishes the sensitivity of the analysis to detect the relationships between the parameters of interest and find statistically significant relationships. There was very little difference between models that had exports and those which did not.

Quotes:
1) “The recovery fractions for the Georgiana Slough releases were consistently less than those for the Ryde releases, with the exception of the fraction recovered at the fish facilities.”

2) “(A)t the fish facilities, Georgiana Slough releases were about 16 times more likely to be recovered. Also, the fraction of fish facility recoveries from the Georgiana Slough releases tended to increase (from about 0.001 to 0.025) as exports increased from 2,000 cfs to 10,000 cfs (1 cfs = 0.028 m3/s ), although there was considerable variability at any given level of exports (Figure 3). This suggested a higher probability of ending up at the pumps with greater exports.”

3) “Regarding the relationship between relative survival and export level, the point estimates of the effects of exports were consistently negative and for the BHMs the probability that the effects are negative was 86–92%. However, as a result of the low signal-to-noise ratio, the DIC values and posterior model probabilities indicate that the predictive ability of models without exports is equivalent to that of models with exports.”

Caveats:
As with other studies using CWT fish, the low absolute number of fish recovered in monitoring efforts impacts the ability of the study to detect relationships between the parameters of interest. These studies are limited by the low signal to environmental noise ratios that are typically present in these types of studies. Improving the sensitivity of these studies requires either using better methods (i.e. better/newer technology) or increasing the sample sizes/replications substantially to detect relationships, which would likely require many more years of studies to have a sufficient number of replicates to increase the sensitivity of the study. The failure to reach a statistically significant relationship does not automatically exclude that a true relationship exists between the parameters, it could very likely be obscured by the low signal to noise ratio.

**6) Dauble et al. 2010. The Vernalis Adaptive Management Program (VAMP): Report of the 2010 Review Panel.**

Take Home Bullets:

1) Simple solutions are unlikely to consistently enhance survival of salmon smolts through the Delta over time. The Delta has complex hydraulics in a strongly tidal environment, and high and likely variable predation effects, that are likely to affect survival rates more than river flow by itself.

2) The panel, however, found that increasing flows in the San Joaquin generally has a positive effect on smolt survival through the Delta and that reducing or eliminating downstream passage through the Old River channel was desirable. The Panel also understood that flow, exports, and the placement of a barrier at the Head of Old River were the variables affecting survival that were most easily manipulated and managed.

3) Apparent downstream migration survival of juvenile Chinook salmon was very poor during 2005 and 2006 even though Vernalis flows were unusually high (10,390 cfs and 26,020 cfs, respectively). These recent data serve as an important indicator that high Vernalis flow, by itself, cannot guarantee strong downstream migrant survival.

4) The panel observed that there is an apparent decline in smolt survival over the 10 year period between 2000 and 2010 at several different levels of San Joaquin River flows ranging from very low to high and that this may be the “new” future smolt survival environment.

5) The panel found that although exports did not have a detectable statistical relationship with survival, that the study results should still be considered inconclusive due to the abbreviated range of conditions under which the data was collected.

6) The panel found that both the empirical evidence and logical inference support the conclusion that installation of a barrier at the head of Old River improves survival of downstream migrating Chinook salmon smolts.

Quotes:

1) “(R)ecent data serve as an important indicator that high Vernalis flow, by *itself*, cannot guarantee strong downstream migrant survival.”

2) “analyses (summarized in SRJTC, 2008) and Bayesian hierarchical modeling (BHM) analyses (Newman, 2008) were unable to detect any statistical associations between exports and smolt survival through the Delta using the VAMP CWT study data. For a number of reasons, however, we do not believe these findings should be interpreted as meaning that exports, especially at high levels, have no effect on survival rates. CWT study data were not collected over an adequate range of export levels to achieve enough statistical power to identify an export effect.”

3) "The five years (2000-2004) of actual VAMP CWT studies done with a HORB in place investigated a range of exports only between 1,450 and 2,250 cfs. We believe this is much too narrow a range in exports to allow detection of a statistically significant export-survival relationship for the San Joaquin River."

4) "We believe that any "Export" effect must be masked by this "Old River" effect, and that the lower survival observed for the Old River route is at least partially attributable to export effects, both direct and indirect. One reason we believe this is that while predation might naturally be higher along Old River, the export facilities themselves seem to attract additional predators to the south Delta. A second reason is that the data show that the numbers of CWT study smolts detected in the salvage at the fish facilities are always higher for releases on upper Old River versus Dos Reis. Thus there are clear differences in direct entrainment losses between the two routes. Finally, if a fish traveling the Old River route does successfully navigate past the fish facilities during periods of high exports, it is then subjected to the reverse net flows, caused by exports, in the reaches of Old and Middle Rivers north of the facilities. It is difficult to imagine that migrating salmon smolts, cueing mostly on flow direction, will not have greater difficulty navigating to the north through these reaches to San Francisco Bay in a direction that might appear as "upstream" to their senses. Losses of smolts due to altered hydrodynamic conditions or migration cues in the Delta related to exports are referred to as "indirect" losses or mortality."

5) "Although lack of an ability to detect an "Export effect" on survival rates can be in large part attributed to lack of variation in recent export flows, we are reluctant to recommend substantial increases in export flows so as to improve the ability to detect an export effect. Among other things, the potential negative consequences of increased exports during downstream migration of juvenile Chinook salmon (and also on survival of juvenile delta smelt) probably outweigh any possible increase in knowledge."

Caveats:
These comments and findings are the results of deliberations by an independent science review panel convened to assess the VAMP studies.

7) **High level Summary of the Six-year Steelhead Study for the years 2011-2015**

- Four years of the total six years of studies have been written up as either final or draft reports
    - Final Reports available for 2011-2015
    - Finals for years 2014 and 2015 sent July 30, 2018
- Studies released acoustically tagged hatchery steelhead into the San Joaquin River at Durham Ferry and tracked them through the Delta system using multiple releases and multiple acoustic receiver locations throughout the lower San Joaquin River and Delta.
    - 2011 – Five releases, total of 2,196 fish tagged and released at Durham Ferry from late March through mid-June.
    - 2012 – Three release, total of 1,435 fish tagged and released at Durham Ferry from early April through mid-May.
    - 2013 – Three releases, total of 1,425 fish tagged and released at Durham Ferry from early March through early May.

  - 2014 – Three release, total of 1,432 fish tagged and released at Durham Ferry from late March through late May.
  - 2015 – Three releases, total of 1,427 fish tagged and released at Durham Ferry from early March to late April.
- Studies occurred during a wet year (2011) and four dry/critically dry years (2012-2015; the first four years of the 5-year drought).
  - Flows during the wet year (2011) were typically above 10,000 cfs at Vernalis, and peaked at approximately 29,000 cfs.
  - Flows during 2012 through 2015 were considerably less, never exceeding 5,000 cfs at at Vernalis, and typically less than 2,500 cfs for most of the period of interest.
  - The HOR barrier was installed during 2012, 2014, and 2015. In 2014 the HOR barrier went in after the first release of fish occurred. With the barrier in, few fish were entrained into the Old River route at the junction of Old River and the San Joaquin River. In 2015, the barrier went in shortly after the second release of fish in late March, being present for the passage of approximately 35% of the released fish past the bifurcation of Old River and the mainstem San Joaquin River.
- During the wet year (2011) survival was better than the drought years (2012-2015) for both the San Joaquin River route ($S_A$) and the Old River route ($S_B$), as well as total survival ($S_{total}$) through the system.
  - Absolute survival through the San Joaquin River route was better than the Old River route in 4 of the 5 study years (2011, 2012, 2014, and 2015).
  - Survival through the sub-routes; south Delta and middle Delta ($S_{SD}$ and $S_{MD}$), were variable and release group dependent. Clear distinctions between the Old River and San Joaquin River routes were not consistent.
- The presence of the HOR barrier was important in determining the proportion of fish entering Old River in relation to those remaining in the San Joaquin River route.
  - During low flow years, when the barrier was out, (2013, first release in 2014, first and second release in 2015), and fish were released into the system at Durham Ferry, higher numbers of fish entered the Old River route at the HOR junction. This appears to be a function of river stage, tides, and shunting of flow into the Old River channel.
  - When flows were high (2011) the distribution of fish into Old River and the San Joaquin were nearly equal.
- Water temperatures were elevated in 4 out of the 5 study years (2012-2015) during the fish releases.
  - Waters temperatures (as measured at Mossdale) were consistently lower in 2011 compared to 2012-2015 during fish releases.
  - Water temperatures in 2012 were consistently above 18$^oC$ for the second and third releases. Water temperatures following the first release were between 15 and 18$^oC$.
  - Water temperatures in 2013 were slightly below 15$^oC$ during the first release, but were above 15$^oC$ during the second and third releases.
  - Water temperatures in 2014 were between 15 and 18$^oC$ during the three releases, with spikes following the first and third releases.

  - Water temperatures in 2015 were between 16 and 20ºC for the first release in early March, between 17 and 20 ºC for the late March release, and 19 and 23ºC for the late April release.
- Survival, as measured per kilometer travelled, is generally as follows:
  - Overall cumulative mortality is higher in the reaches between Durham Ferry and Mossdale, which is common between the Old River route and the San Joaquin River route. The survival per kilometer is approximately 96% or higher but accounts for approximately 40-60% of overall mortality.
  - Cumulative mortality in the San Joaquin River route is inconsistent, with some years having high mortality in the reach between Mossdale and the Stockton Deepwater Ship Channel (Garwood Bridge/ Navy Bridge) and again in the lower reaches of the San Joaquin River route (MacDonald Island to Chipps Island).
  - Increased cumulative mortality in the Old River route occurs between the entrance to the Old River corridor (Old River south) and Chipps Island via the fish collection facilities.

**Briefing on Six-year Study**
June 26, 2018

## Key Messages

### *Six-Year Study*

- Four years of the total six years of studies have been written up as either final (2011-2013) or draft (2014) reports.  Final reports just released in May/June 2018.
- Conditions during study years dominated by drought conditions.
- Survival results *(more details in Attachment 1, prepared by Jeff Stuart)*:
    - Through-Delta steelhead survival (for all routes combined) was highest in the Wet year (2011, and ranged from 15% (in 2013) to 54% (in 2011).
    - Absolute survival through the San Joaquin River route was better than the Old River route in three of the four analyzed study years (2011, 2012, and 2014) but not statistically significant (some power limitations?).
    - Reports do not provide analysis of survival as a function of the I:E ratio or OMR flow[1], though do evaluate total Delta survival as a function of Vernalis flow and some routing proportions as a function of local flows.
- Routing results:
    - Not surprisingly, the proportion of study fish in the San Joaquin River route was highest in the years when the HORB was installed.

### *SWFSC mini-project on Six-Year Study data*

- Heads-up that SWFSC did a mini-analysis *(more details in Attachment 2, prepared by Caren Barceló)* to understand the relationship between detections at different receivers (detections being a surrogate for fish movement) and environmental variables (e.g. flow, turbidity, temperature, diel phase).
    - Preliminary results were that flow, conductivity and turbidity were the variables that most often had the strongest relationship (positive or negative) with the arrival rate of steelhead; associations differed for specific receivers.

### *Chinook releases in the San Joaquin River*

- USFWS led studies of Chinook releases in the San Joaquin River, and measured through-Delta survival, in 2009-2015.
- For 2010-2013, through-Delta Chinook survival was <5% for all releases and survival was often higher in the Old River route (*see Attachment 3, prepared by Barb Byrne).*

[1] The 2013 report notes, for example, that "[The NMFS 2009 BiOp] identified flow at Vernalis, export volume, and the ratio of Vernalis flow-to-export as variables to test during this study as priority variables.  Separating the effects of these covariates is difficult because the variables are likely to be correlated."

**Overview of Six-year Study**

- Studies released acoustically tagged **hatchery steelhead** into the San Joaquin River at Durham Ferry (most releases were from **late March to late May**) and tracked them through the Delta system using multiple releases and multiple acoustic receiver locations throughout the lower San Joaquin River and Delta (Figure 1).

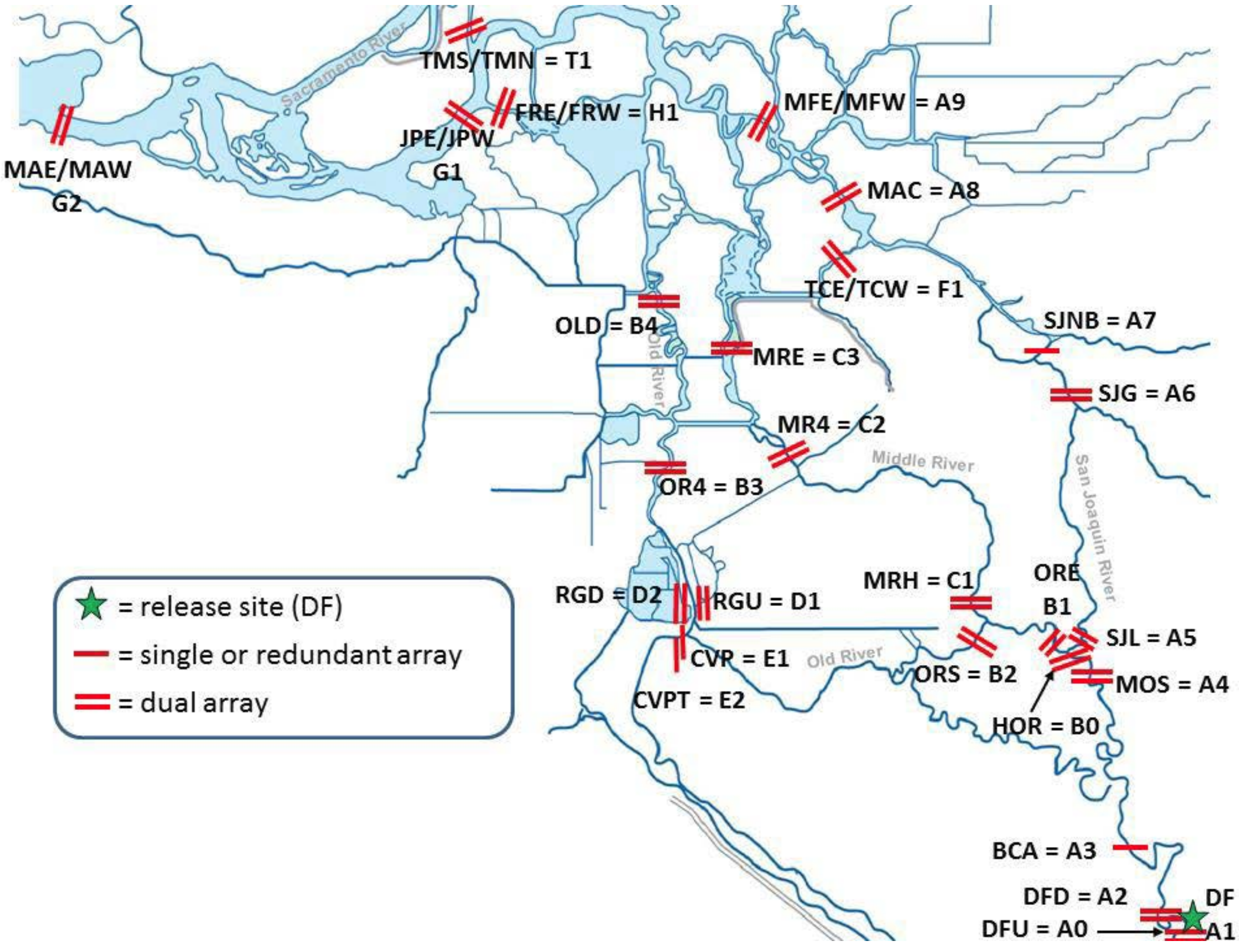



***Figure 1**: Locations of Acoustic Receivers for the 2012 study. Each year's study had a small number of additional/ removed or relocated acoustic receiver locations but the release location at Durham Ferry (DF) and westernmost receivers near Chipps Island (MAE & MAW) were consistent throughout.*

- Studies occurred during a Wet year (2011) and five Dry or Critical years (2012-2016), as summarized in Table 1.

***Table 1:*** *Overview of hydrologic conditions and report status for the Six-year Study*

| Water Year | HORB status | San Joaquin yeartype | I:E ratio in effect | 14-day OMR range (in cfs, 4/1-5/31) | Vernalis flow range (in cfs, 4/1-5/31) | Status of report |
|---|---|---|---|---|---|---|
| 2011 | Out | Wet | Vernalis flow offramp 4/1-5/10; 4:1 from 5/11-5/31 | 2,391 to 9,520 | 9635 to 28,575 | Final (May 2018) |
| 2012 | In | Dry | Joint Stipulation Study* in lieu of I:E ratio | -4,218 to -1,710 | 1,577 to 4,418 | Final (May 2018) |
| 2013 | Out | Critical | 1:1 | -4,050 to -130 | 859 to 4,176 | Final (June 2018) |
| 2014 | In | Critical | 1:1 | -4,750 to -1,650 *(based on Index)* | 510 to 3,035 | Draft (May 2018) |
| 2015 | In | Critical | 1:1 | -1,860 to -1,170 *(based on Index)* | 254 to 1,433 | *No report available* |
| 2016 | In | Dry | 1:1 | -3,720 to -1,860 *(based on Index)* | 733 to 3,215 | *No report available* |

*OMR requirements in Joint Stipulation Study ranged from -1,250 cfs to -5,000 cfs.

- Survival and routing estimates (Table 2) show that:
    - Through-Delta steelhead survival (for all routes combined) was highest in the Wet year (2011, and ranged from 15% (in 2013) to 54% (in 2011). See Figure 2.
    - Absolute survival through the San Joaquin River route was better than the Old River route in three of the four study years (2011, 2012, and 2014) but not statistically significant[2].
    - Not surprisingly, the proportion of study fish in the San Joaquin River route was highest in the years when the HORB was installed.

---

[2] Power to detect survival differences between routes (excerpt from p.11 of the 2012 Report): "Buchanan (2010) recommended a sample size of 475 for estimating survival to Chipps down the Old River and San Joaquin routes if survival in the Old River route was low (0.05). Additionally, if survival between Durham Ferry and Chipps Island was higher (0.15) and survival between Durham Ferry and the Old River junction was high (0.9), a release of 475 at Durham Ferry would be able to detect a 50% difference between survival in the San Joaquin River and Old River routes. Thus, a release group of 475 at Durham Ferry was expected to provide accurate information about route entrainment and survival for examining biotic and abiotic factors influencing juvenile steelhead survival."

***Table 2****: Summary of hatchery steelhead survival estimates from Six-Year Study: 2011 - 2014*

| Study Year | Proportion using Route | | Survival Probability Estimate | | | HORB Status | Water Year Type |
|---|---|---|---|---|---|---|---|
| | San Joaquin River route | Old River route | San Joaquin River Route | Old River route | Total Survival (any route) | | |
| 2011 | 0.51 | 0.49 | 0.55 | 0.52 | 0.54 | Out | Wet |
| 2012 | 0.94 | 0.06 | 0.33 | 0.07 | 0.32 | In | Dry |
| 2013 | 0.12 | 0.88 | 0.11 | 0.15 | 0.15 | Out | Critical |
| 2014 | 0.92 | 0.08 | 0.25 | 0.19 | 0.24 | In | Critical |

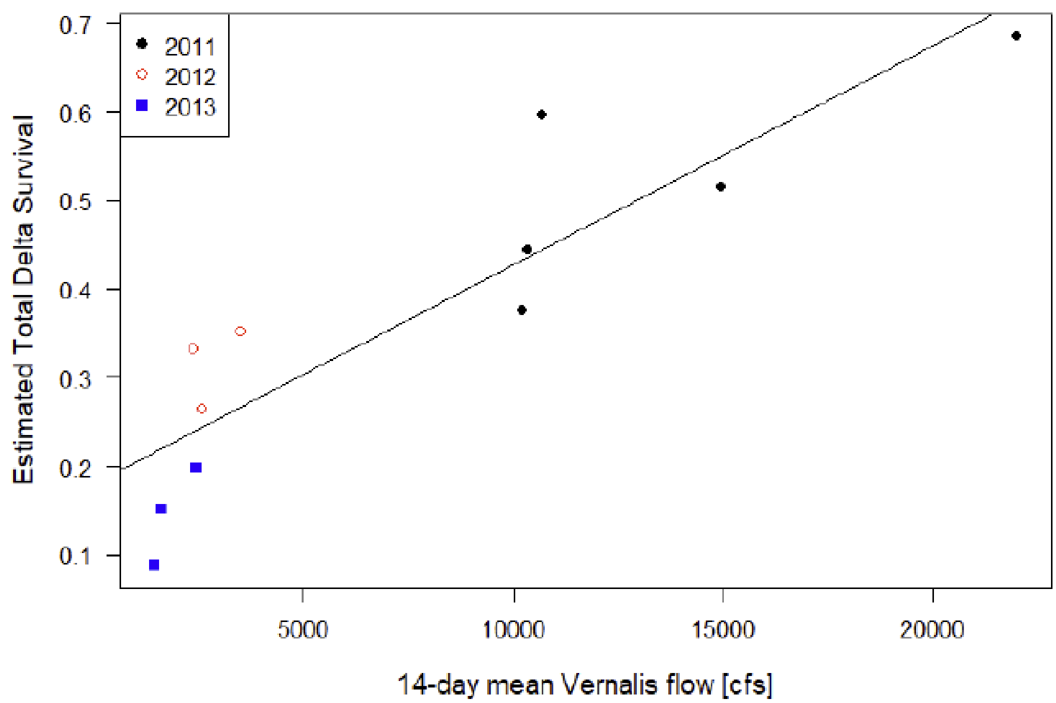



Figure 27. Estimated total delta survival (Mossdale to Chipps Island) for acoustic-tagged steelhead in the 2011, 2012, and 2013 Six-Year Study, versus 14-day mean San Joaquin River flow at Vernalis. Survival and flow data are from Tables 26 and 27. The line is the best fit linear predictor of survival as a function of 14-day Vernalis flow for these data ($r^2 = 0.8007$).

***Figure 2****: Estimated total Delta survival for hatchery steelhead from the 2011-2013 study years. (Figure 27 from the 2013 report)*

- Other details available in Attachment 1:
    - o Water temperatures were elevated (59 degrees F or higher) in three out of the four analyzed study years (2012-2014) during the fish releases.
    - o Survival estimates by release group are provided in “heat-map” tables.
    - o Releases are plotted along Vernalis flows and Mossdale water temperatures.

**<u>Highlights from 2011-2014 results from Six-Year Study</u>**

*(summarizing 689 pages of draft and final reports)*

- Four years of the total six years of studies have been written up as either final or draft reports
  - Final Reports available for 2011-2013
  - Draft report available for 2014
- Studies released acoustically tagged hatchery steelhead into the San Joaquin River at Durham Ferry and tracked them through the Delta system using multiple releases and multiple acoustic receiver locations throughout the lower San Joaquin River and Delta. (see Table 1 and Figure 1)
  - 2011 – Five releases, total of 2,196 fish tagged and released at Durham Ferry from late March through mid-June.
  - 2012 – Three release, total of 1,435 fish tagged and released at Durham Ferry from early April through mid-May.
  - 2013 – Three releases, total of 1,425 fish tagged and released at Durham Ferry from early March through early May.
  - 2014 – Three release, total of 1,432 fish tagged and released at Durham Ferry from late March through late May.
- Studies occurred during a wet year (2011) and three dry/critically dry years (2012-2014; the first three years of the 5-year drought) (see Figure 2).
  - Flows during the wet year (2011) were typically above 10,000 cfs at Vernalis, and peaked at approximately 29,000 cfs.
  - Flows during 2012 through 2014 were considerably less, never exceeding 5,000 cfs at at Vernalis, and typically less than 2,500 cfs for most of the period of interest.
  - The HOR barrier was installed during 2012 and 2014. In 2014 the HOR barrier went in after the first release of fish occurred. With the barrier in, few fish were entrained into the Old River route at the junction of Old River and the San Joaquin River (see Table 2 and Table 3a and 3b).
- During the wet year (2011) survival was better than the drought years (2012-2014) for both the San Joaquin River route ($S_A$) and the Old River route ($S_B$), as well as total survival ($S_{total}$) through the system. See Tables 2 and 3a and b.
  - Absolute survival through the San Joaquin River route was better than the Old River route in 3 of the 4 study years (2011, 2012, and 2014) but not statistically significant.
  - Survival through the sub-routes; south Delta and middle Delta ($S_{SD}$ and $S_{MD}$), were variable and release group dependent. Clear distinctions between the Old river and San Joaquin River routes were not consistent.
- The presence of the HOR barrier was important in determining the proportion of fish entering Old River (see Tables 2 and 3a, 3b) in relation to those remaining in the San Joaquin River route.
  - During low flow years, when the barrier was out, (2013, first release in 2014), and fish were released into the system at Durham Ferry, higher numbers of fish entered the Old River route at the HOR junction. This appears to be a function of river stage, tides, and shunting of flow into the Old River channel.

- When flows were high (2011) the distribution of fish into Old River and the San Joaquin were nearly equal.
- Water temperatures were elevated in 3 out of the 4 study years (2012-2014) during the fish releases (see Figures 3-6).
    - Waters temperatures (as measured at Mossdale) were consistently lower in 2011 compared to 2012-2014 during fish releases.
    - Water temperatures in 2012 were consistently above 18°C for the second and third releases. Water temperatures following the first release were between 15 and 18°C.
    - Water temperatures in 2013 were slightly below 15°C during the first release, but were above 15°C during the second and third releases.
    - Water temperatures in 2014 were between 15 and 18°C during the three releases, with spikes following the first and third releases.
- Survival, as measured per kilometer travelled, is depicted in Tables 4 and 5, cumulative mortality /survival in Figures 7-12.
    - Overall cumulative mortality is higher in the reaches between Durham Ferry and Mossdale (Figures 7-12), which is common between the Old River route and the San Joaquin River route. The survival per kilometer is approximately 96% or higher (Table 4) but accounts for approximately 40-60% of overall mortality (Figures 7-12).
    - Cumulative mortality in the San Joaquin River route is inconsistent, with some years having high mortality in the reach between Mossdale and the Stockton Deepwater Ship Channel (Garwood Bridge/ Navy Bridge) and again in the lower reaches of the San Joaquin River route (MacDonald Island to Chipps Island).
    - Increased cumulative mortality in the Old River route occurs between the entrance to the Old River corridor (Old River south) and Chipps Island via the fish collection facilities (Figures 8,10, and12).

**Table 1**: Number of steelhead with acoustic tags released for each study year. Note that because of differences in routing with HORB in vs. out, the sample size for the survival estimates in the San Joaquin River route vs. the Old River route is very different.

| Study Year | Total # Tags Released | Release Groups | Date of Release | Number Tags Released | Number Assigned to Old River Route | Number Assigned to San Joaquin River route |
|---|---|---|---|---|---|---|
| 2011 | 2,196 | 1 | 3/22 – 3/26 | 477 | | |
| HORB out | | 2 | 5/3 – 5/7 | 474 | | |
| | | 3 | 5/17 – 5/21 | 477 | | |
| | | 4 | 5/22 – 5/26 | 480 | | |
| | | 5 | 6/15 – 6/17 | 285 | | |
| | | | | | | |
| 2012 | 1,435 | 1 | 4/4 – 4/7 | 477 | 20 | 304 |
| HORB in | | 2 | 5/1 – 5/6 | 478 | 11 | 297 |
| | | 3 | 5/17 – 5/23 | 480 | 17 | 150 |
| | | | | | | |
| 2013 | 1,425 | 1 | 3/6 – 3/9 | 476 | 278 | 16 |
| HORB out | | 2 | 4/3 – 4/6 | 477 | 279 | 31 |
| | | 3 | 5/8 – 5/11 | 472 | 265 | 40 |
| | | | | | | |
| 2014 | 1,432 | 1 | ~3/26 – 3/29 | 474 | | |
| HORB in | | 2 | ~4/26 -4/29 | 480 | | |
| | | 3 | ~5/20 -5/23 | 478 | | |

**Table 2**: Summary of 6-Year Steelhead Parameters: 2011 - 2014

| Study Year | Proportion using Route | | Survival Probability Estimate | | | HORB Status | Water Year Type |
|---|---|---|---|---|---|---|---|
| | SJR ($\psi_A$) | OR ($\psi_B$) | SJR Route ($S_A$) | Old River Route ($S_B$) | Total Survival ($S_{Total}$) | | |
| 2011 | 0.51 | 0.49 | 0.55 | 0.52 | 0.54 | Out | Wet |
| 2012 | 0.94 | 0.06 | 0.33 | 0.07 | 0.32 | In | Dry |
| 2013 | 0.12 | 0.88 | 0.11 | 0.15 | 0.15 | Out | Critical |
| 2014 | 0.92 | 0.08 | 0.25 | 0.19 | 0.24 | In | Critical |

Model Parameters estimated:

$P_{hi}$ = detection probability: probability of detection at telemetry station i within route h, conditional on surviving to station i, where i = ia, ib for the upstream, downstream receivers in a dual array, respectively.

$S_{hi}$ = perceived survival probability: joint probability of migration and survival from telemetry station i to i+1 within route h, conditional on surviving to station i.

$\boldsymbol{\Psi_{hi}}$ = route selection probability: probability of a fish entering route h at junction l (l =1, 2, 3), conditional on fish surviving to junction l.

$\boldsymbol{\Phi_{kj, hi}}$ = transition probability: joint probability of migration, route selection, and survival; the probability of migrating, surviving, and moving from station j in route k to station i in route h, conditional on survival to station j in route k.

$\boldsymbol{\lambda}$ = joint transition and detection probability: joint probability of moving downstream from Chipps Island, surviving to Benicia Bridge, and detection at Benicia Bridge, conditional on survival to Chipps Island.

**Table 3a**: Performance metric estimates for tagged juvenile steelhead for study years 2011 -2012, excluding predator – type detections. Standard errors in parentheses.

| Parameter | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | | | | | | | 2012 | | | |
| | Release Group | | | | | | | Release Group | | | |
| | 1 | 2 | 3 | 4 | 5 | Pop Est. | | 1 | 2 | 3 | Pop Est |
| $\Psi_{AA}$ | 0.47 (0.03) | 0.35 90.03) | 0.37 (0.03) | 0.36 (003) | | 0.39 (0.02) | | 0.72 (0.04) | 0.75 (0.03) | 0.58 (0.04) | 0.68 (0.02) |
| $\Psi_{AF}$ | 0.05 (0.01) | 0.16 (0.02) | 0.12 (0.02) | 0.17 (0.02) | | 0.12 (0.01) | | 0.21 (0.04) | 0.23 (0.03) | 0.26 (0.02) | 0.26 (0.02) |
| $\Psi_{BB}$ | 0.44 (0.0) | 0.46 (0.03) | 0.49 (0.03) | 0.45 (0.03) | | 0.46 (0.02) | | 0.06 (0.01)[a] | 0.03 (0.01)[a] | 0.06 (0.01)[a] | 0.06 (0.01)[a] |
| $\Psi_{BC}$ | 0.04 (0.01) | 0.03 (0.01) | 0.01 (0.01) | 0.03 (0.02) | | 0.03 (0.01) | | 0.00[a] | 0.00[a] | 0.00 [a] | 0.00 [a] |
| $S_{AA}$ | 0.72 (0.04) | 0.68 (0.05) | 0.51 (0.05) | 0.69 (0.05) | | 0.65 (0.02) | | 0.33 (0.03) | 0.43 (0.03) | 0.45 (0.05) | 0.40 (0.02) |
| $S_{AF}$ | 0.33 (0.12) | 0.27 (0.07) | 0.26 (0.07) | 0.59 (0.07) | | 0.36 (0.04) | | 0.10 (0.04) | 0.14 (0.04) | 0.21 (0.05) | 0.15 (0.03) |
| $S_{BB}$ | 0.68 (0.04) | 0.50 (0.05) | 0.44 (0.04) | 0.55 (0.05) | | 0.54 (0.02) | | 0.07 (0.04) | 0.10 (0.07) | 0.05 (0.03) | 0.07 (0.03) |
| $S_{BC}$ | 0.67 (0.08) | 0.30 (0.13) | 0.48 (0.06) | 0.22 (0.17) | | 0.42 (0.06) | | NA | NA | NA | NA |
| $\Psi_{A}$ | 0.52 (0.03) | 0.51 (0.03) | 0.49 (0.03) | 0.53 (0.03) | 0.52 (0.05) | 0.51 (0.02) | | 0.94 (0.01)* | 0.97 (0.01)* | 0.92 (0.02)* | 0.94 (0.01)* |
| $\Psi_{B}$ | 0.48 (0.03) | 0.49 (003) | 0.51 (0.03) | 0.47 (0.03) | 0.48 (0.05) | 0.49 (0.02) | | 0.06 (0.01)* | 0.03 (0.01)* | 0.08 (0.02)* | 0.06 (0.01)* |
| $S_{A}$ | 0.69 (0.04) | 0.55 (0.04) | 0.45 (0.04) | 0.66 (0.04)* | 0.32 (0.06) | 0.55 (0.02) | | 0.28 (0.03) | 0.33 (0.03) | 0.36 (0.04) | 0.33 (0.02) |
| $S_{B}$ | 0.68 (0.04) | 0.48 (0.04) | 0.44 (0.04) | 0.53 (0.05)* | 0.44 (0.07) | 0.52 (0.02) | | 0.07 (0.04) | 0.10 (0.07) | 0.05 (0.03) | 0.07 (0.03) |
| $S_{Total}$ | 0.69 (0.03) | 0.52 (0.03) | 0.44 (0.03) | 0.60 (0.03) | 0.38 (0.05) | 0.54 (0.01) | | 0.26 (0.02) | 0.35 (0.03) | 0.33 (0.04) | 0.32 (0.02) |
| $S_{A(MD)}$ | 0.82 (0.03)* | 0.50 (0.04)* | 0.39 (0.04)* | 0.52 (0.04)* | | 0.56 (0.02) | | 0.32 (0.03) | 0.46 (0.03) | 0.45 (0.04) | 0.41 (0.02) |
| $S_{B(MD)}$ | 0.53 (0.04)* | 0.05 (0.02)* | 0.09 (0.03)* | 0.06 (0.02)* | | 0.18 (0.01) | | 0.00[a] | 0.00 | 0.00 | 0.00 |
| $S_{Total(MD)}$ | 0.68 (0.03) | 0.28 (0.03) | 0.24 (0.03) | 0.30 (0.03) | | 0.37 (0.01) | | 0.30 (0.03) | 0.45 (0.03) | 0.41 (0.04) | 0.39 (0.02) |
| $S_{A(SD)}$ | 0.89 (0.03) | 0.83 (0.03) | 0.74 (0.04) | 0.85 (0.03) | | 0.83 (0.02) | | 0.78 (0.04) | 0.82 (0.02) | 0.89 (0.03) | 0.83 (0.02) |
| $S_{B(SD)}$ | 0.91 (0.03) | 0.75 (0.04) | 0.71 (0.04) | 0.77 (0.04) | | 0.78 (0.02) | | 0.80 (0.08) | 0.62 (0.17) | 0.23 (0.11) | 0.55 (0.07) |
| $S_{Total(SD)}$ | 0.90 (0.02) | 0.79 (0.03) | 0.72 (0.03) | 0.81 (0.03) | | 0.81 (0.01) | | 0.78 (0.04) | 0.81 (0.02) | 0.84 (0.03) | 0.81 (0.02) |

* Significantly different at $\alpha = 0.05$

[a] No tags were detected in subroute “C” or insufficient tags were detected to subroute “C” for use in analysis. No estimate for survival in subroute C was available.

**Table 3b**: Performance metric estimates for tagged juvenile steelhead for study years 2013 -2014, excluding predator – type detections. Standard errors in parentheses.

| Parameter | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2013 | | | | 2014 | | | |
| | Release Groups | | | | Release Groups | | | |
| | 1 | 2 | 3 | Pop Est. | 1 | 2 | 3 | Pop Est |
| $\Psi_{AA}$ | NA[a] | 0.07(0.02) | 0.11 (0.02) | NA[a] | NA[a] | 0.66 (0.03) | 0.77 (0.08) | 0.71 (0.04) |
| $\Psi_{AF}$ | NA[a] | 0.06 (0.02) | 0.05 (0.02) | NA[a] | NA[a] | 0.30 (0.03) | 0.11 (0.07) | 0.21 (0.04) |
| $\Psi_{BB}$ | 0.89 (0.02) | 0.85 (0.02) | 0.83 (0.02) | 0.86 (0.01) | 0.87 (0.03) | 0.04 (0.01) | NA[a] | NA[a] |
| $\Psi_{BC}$ | 0.03 (0.01) | 0.02 (0.01) | 0.01 (0.01) | 0.02 (<0.01) | 0.04 (0.02) | 0.00 (<0.01) | NA[a] | NA[a] |
| $S_{AA}$ | NA[a] | 0.19 (0.07) | 0.31 (0.07) | NA[a] | NA[a] | 0.57 (0.03) | 0.07 )0.03) | 0.32 (0.02) |
| $S_{AF}$ | NA[a] | 0.06 (0.05) | 0.00 | NA[a] | NA[a] | 0.13 (0.03) | NA[a] | NA[a] |
| $S_{BB}$ | 0.17 (0.02) | 0.08 (0.02) | 0.20 (0.03) | 0.15 (0.01) | 0.20 (0.04) | 0.33 (0.09) | NA[a] | NA[a] |
| $S_{BC}$ | 0.07 (0.05) | 0.06 (0.04) | 0.06 (0.06) | 0.06 (0.03) | 0 | NA[a] | NA[a] | NA[a] |
| $\Psi_{A}$ | 0.08 (0.02) | 0.12 (0.02) | 0.16 (0.02) | 0.12 (0.01) | 0.09 (0.02) | 0.96 (0.01) | 0.88 (0.03) | 0.92 (0.02) |
| $\Psi_{B}$ | 0.92 (0.02) | 0.88 (0.02) | 0.84 (0.02) | 0.88 (0.01) | 0.91 (0.02) | 0.04 (0.01) | 0.12 (0.03) | 0.08 (0.02) |
| $S_{A}$ | 0.00 | 0.13 (0.05) | 0.20 (0.06) | 0.11 (0.03) | 0 | 0.43 (0.03) | 0.06 (0.02) | 0.25 (0.02) |
| $S_{B}$ | 0.16 (0.02) | 0.08 (0.02) | 0.20 (0.02) | 0.15 (0.01) | 0.19 (0.03) | 0.31 (0.09) | 0.07 (0.07) | 0.19 (0.06) |
| $S_{Total}$ | 0.15 (0.02) | 0.09 (0.02) | 0.20 (0.02) | 0.15 (0.01) | 0.18 (0.03) | 0.43 (0.03) | 0.06 (0.02) | 0.24 (0.02) |
| $S_{A(MD)}$ | 0.00 | 0.13 (0.05) | 0.24 (0.06) | 0.12 (0.03) | NA[a] | 0.44 (0.03) | 0.07 (0.03) | 0.26 (0.02) |
| $S_{B(MD)}$ | 0.01 (0.01) | 0.01 (0.1) | 0.06 (0.02) | 0.03 (0.01) | NA[a] | 0 | NA[a] | NA[a] |
| $S_{Total(MD)}$ | 0.01 (0.01) | 0.03 (0.01) | 0.09 (0.02) | 0.04 (0.01) | NA[a] | 0.43 (0.03) | NA[a] | NA[a] |
| $S_{A(SD)}$ | NA[a] | 0.23 (0.07) | 0.37 (0.07) | NA[a] | NA[a] | 0.77 (0.02) | 0.16 (0.04) | 0.46 (0.02) |
| $S_{B(SD)}$ | 0.53 (0.03) | 0.56 (0.03) | 0.75 (0.03) | 0.61 (0.02) | 0.56 (0.04) | 0.83 (0.09) | NA[a] | NA[a] |
| $S_{Total(SD)}$ | NA[a] | 0.52 (0.03) | 0.69 (0.03) | NA[a] | NA[a] | 0.77 (0.02) | NA[a] | NA[a] |

[a] NA estimates resulted when there were too few tags detected in the route to estimate route selection and/or survival.

**Table 4**: Heat Map Depicting Steelhead Survival Rates ($S^{(1/km)}$) Through San Joaquin River Reaches to Chipps Island.

| Reach Name | km | Survival Estimate per km ($S^{(1/km)}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | 2014 |
| | | CAMT SST | 6-year Rpt | CAMP SST | 6-year Rpt | 6-year Rpt | 6-year Rpt |
| Durham Ferry to Banta Carbona | 11 | 0.962 | 0.9765 | 0.967 | 0.986 | 0.988 | 0.973 |
| Banta Carbona to Mossdale | 10 | 0.982 | 0.985 | 0.978 | 0.980 | 0.985 | 0.980 |
| Mossdale to Lathrop/Old River | 4 | 0.985 | 0.985 | 0.995 | 0.995 | 0.995 | 0.966 |
| Lathrop to Garwood Bridge (SJR) | 18 | 0.995 | 0.995 | 0.997 | 0.997 | 0.948 | 0.974 |
| Garwood Bridge to Navy Bridge | 3 | 0.993 | 0.993 | 0.990 | 0.990 | 0.958 | 0.976 |
| Navy Bridge to Turner Cut/MacDonald Island | 15 | 0.997 | 0.997 | 0.994 | 0.994 | 0.984 | 0.984 |
| MacDonald Island to Medford Island | 5 | 0.942 | 0.949 | 0.923 | 0.941 | | |
| Turner Cut to Jersey Point (includes interior Delta route but not SJR route) | 28 | 0.958 | 0.957 | 0.934 | 0.933 | | |
| Medford to Jersey Point | 21 | 0.992 | | 0.987 | | | |
| Jersey Point to Chipps Island | 22 | 0.997 | | 0.989 | | | |

Note: Darker red boxes have lower survival values and lighter boxes indicate higher survival rates (white ≥ 99% survival/km). Missing values reflect sparse data in the reach in question or the study had deficiencies that prevented estimates to be made.

**Table 5**: Heat Map depicting Survival Rates ($S^{(1/km)}$) through Old River Reaches to Chipps Island.

| Reach Name | km | Survival Estimate per km ($S^{(1/km)}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | 2014 |
| | | CAMT SST | 6-year Rpt | CAMP SST | 6-year Rpt | 6-year Rpt | 6-year Rpt |
| Old River (Head) to Middle River Head/ Old River (south) | 6 | 0.990 | 0.9897 | 0.977 | 0.977 | 0.990 | 0.948 |
| Old River (South) to CVP/CCF/HWY4 | 20 | 0.994 | 0.988 | 0.977 | 0.977 | 0.981 | 0.983 |
| Old River (HWY4) to Jersey Point | 60 | 0.992 | 0.992 | 0.958 | | 0.972 | 0.978 |
| CVP Holding Tank to Chipps Island | 15 | 0.988 | 0.992 | 0.973 | 0.965 | 0.987 | 1.0/0.98 |
| CCF Radial Gate (interior) to Chipps Island | 24 | 0.979 | 0.983 | 0.924 | 0.914 | 0.957 | 0/ 0.95 |

Note: Darker red boxes have lower survival values and lighter boxes indicate higher survival rates (white ≥ 99% survival/km). Missing values reflect sparse data in the reach in question or the study had deficiencies that prevented estimates to be made.

Yellow highlighted cells have two survival estimates. Estimate from the first release in 2014 have a survival rate of 98% from the CVP holding tank to Chipps Island, and a survival rate of 95% from the CCFB interior radial gates to Chipps Island based on a joint tag survival and fish survival estimates due to premature tag failures occurring in the first release group. The 100 % survival for the CVP estimate is based on the second and third releases with a total of 12 fish detected in the holding tank and 12 fish detected at Chipps Island. The zero survival for the

CCFB radial gate to Chipps Island is based on 3 fish detected at the interior radial gate with none subsequently detected at Chipps Island.

**Figure 1**: Locations of Acoustic Receivers (general locations) as each study had a small number of additional/ removed or relocated acoustic receiver locations. (2012 study locations used as an example).

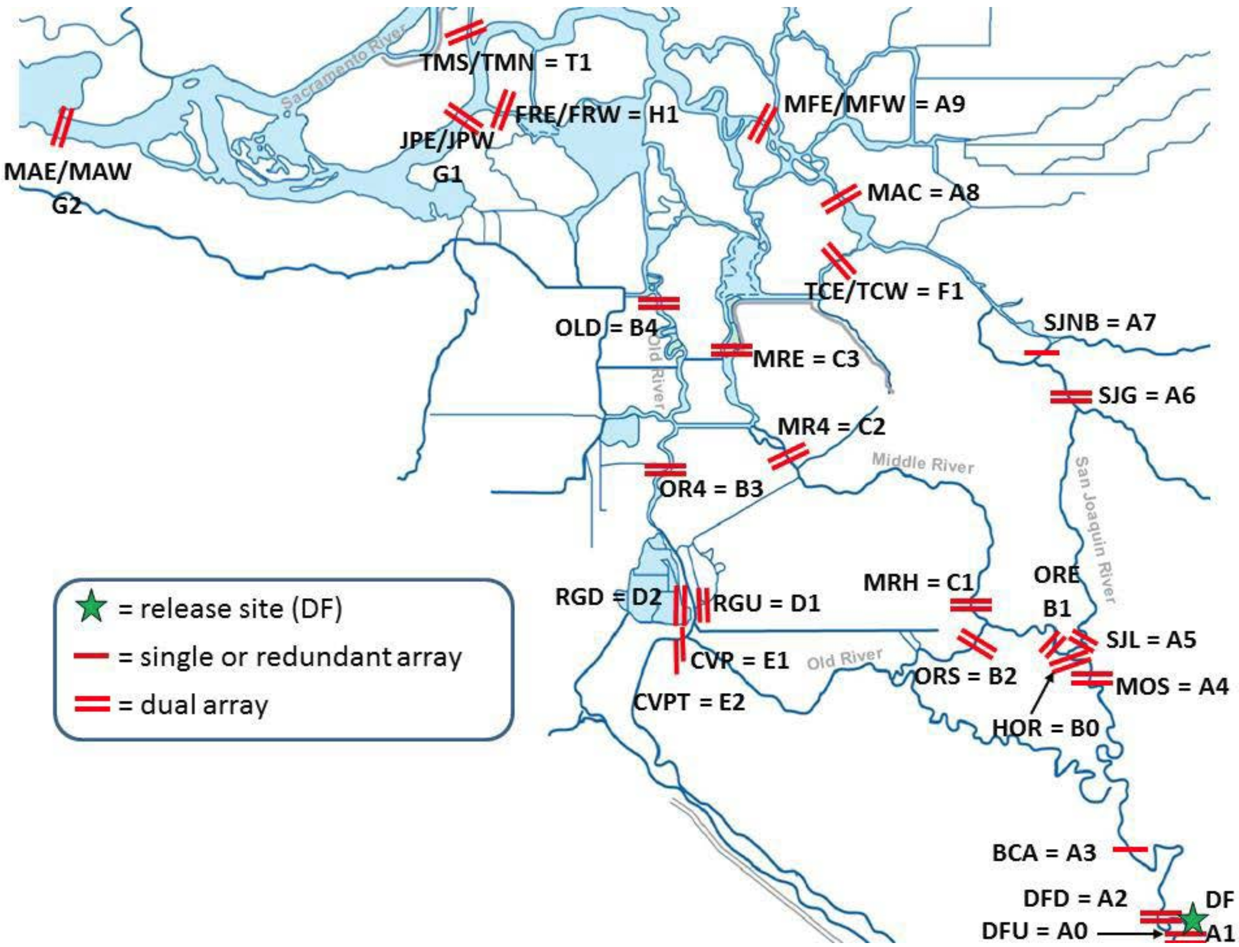


Figure 2: March through June Vernalis Flows for Study Years 2011 – 2014 with release groups.

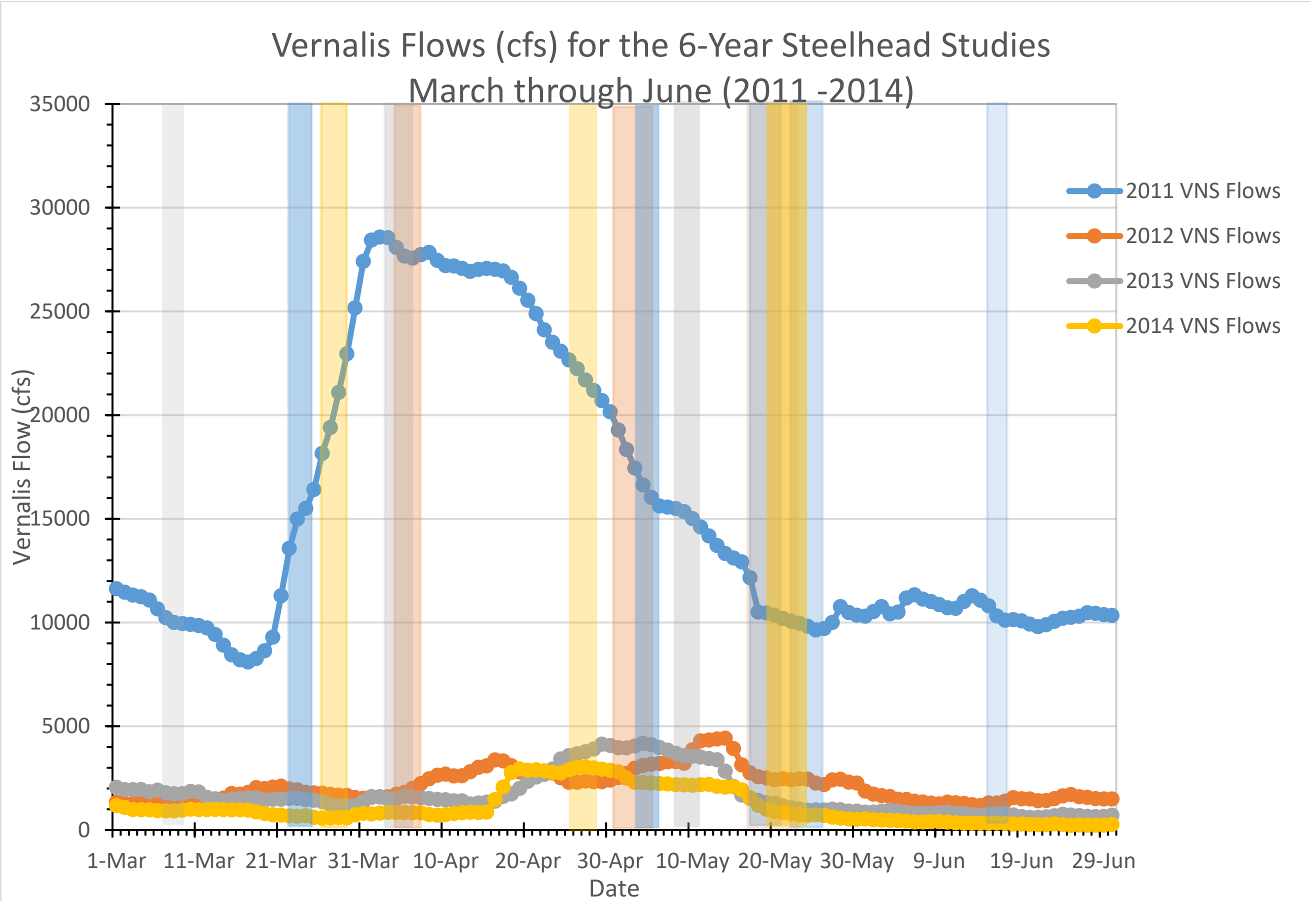
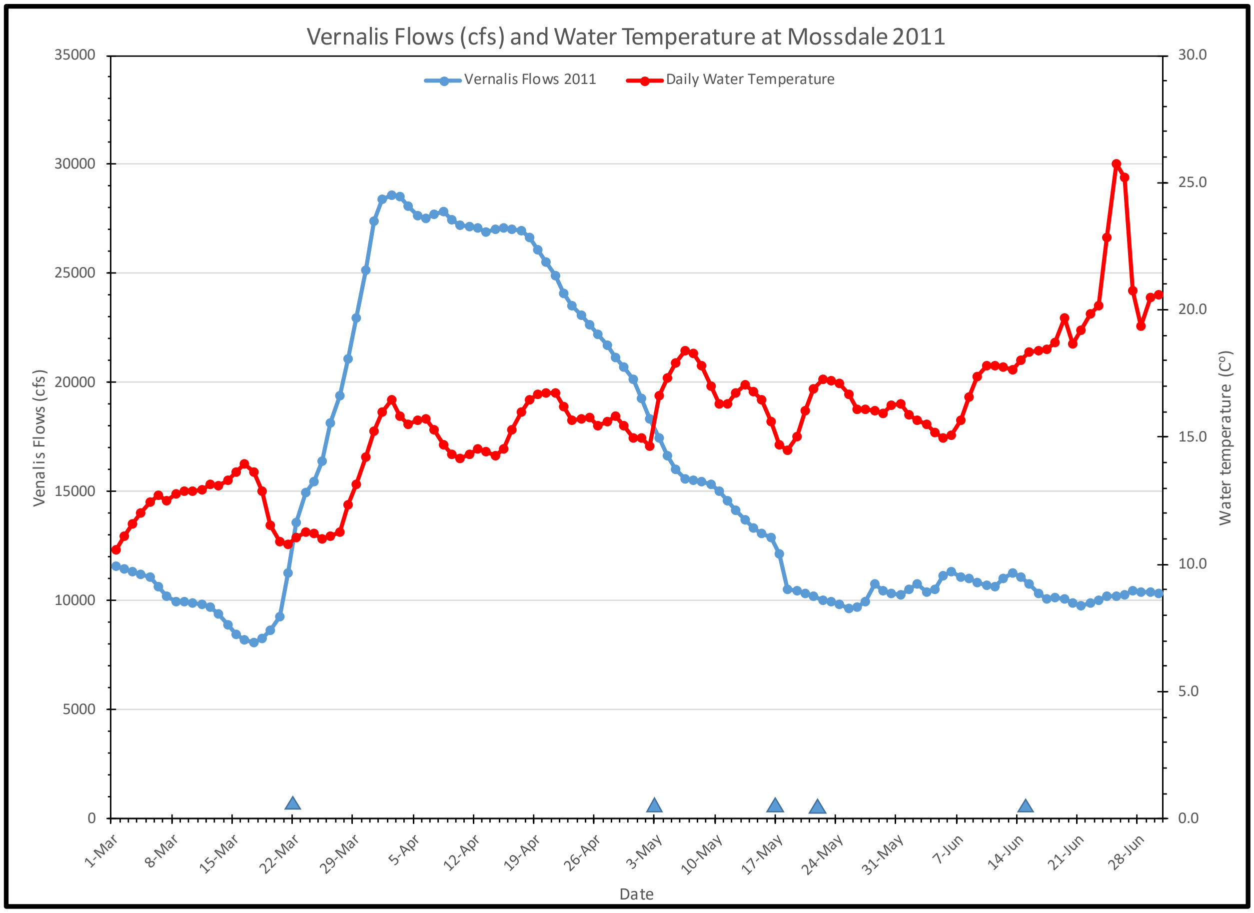
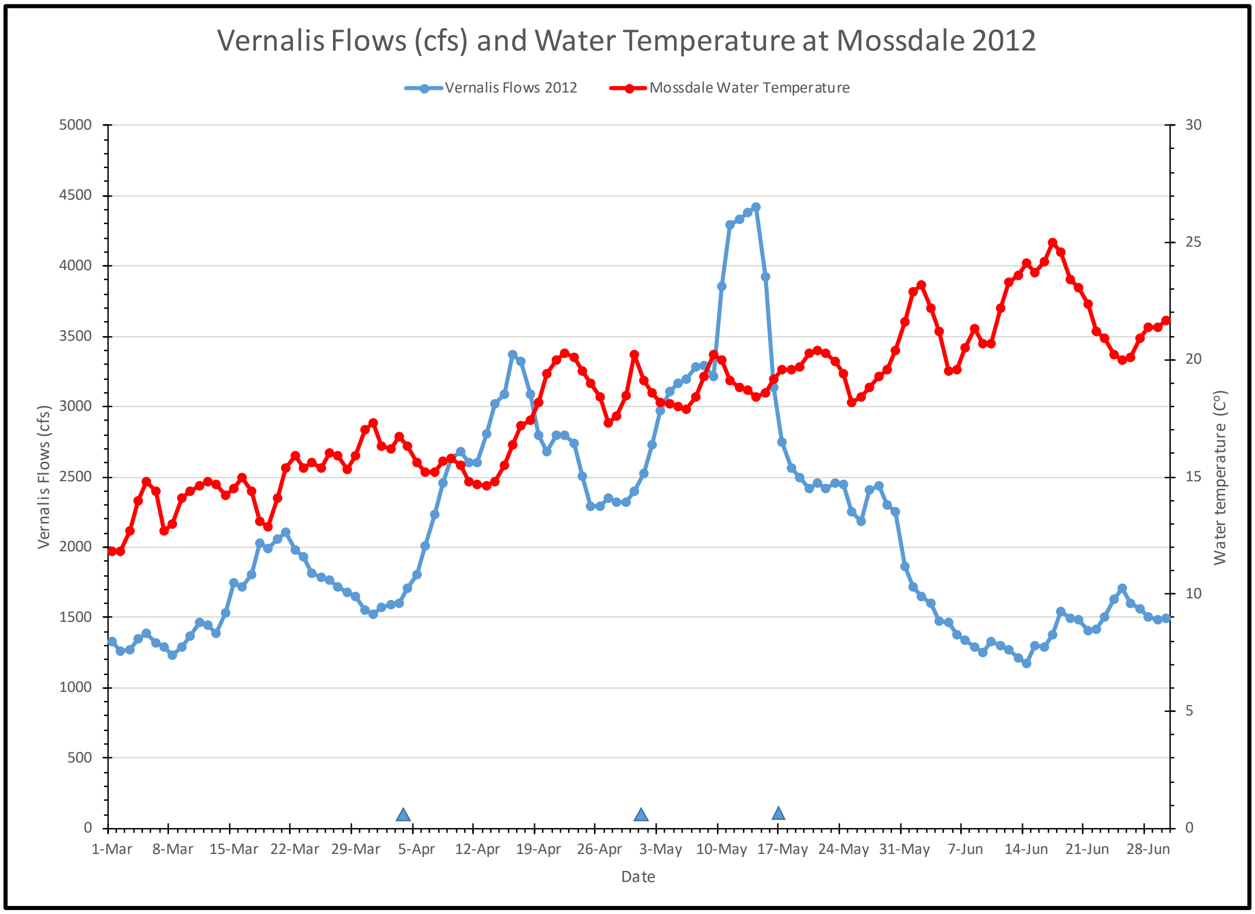


Figure 3:Vernalis Flows and Mossdale Water Temperatures March through June 2011



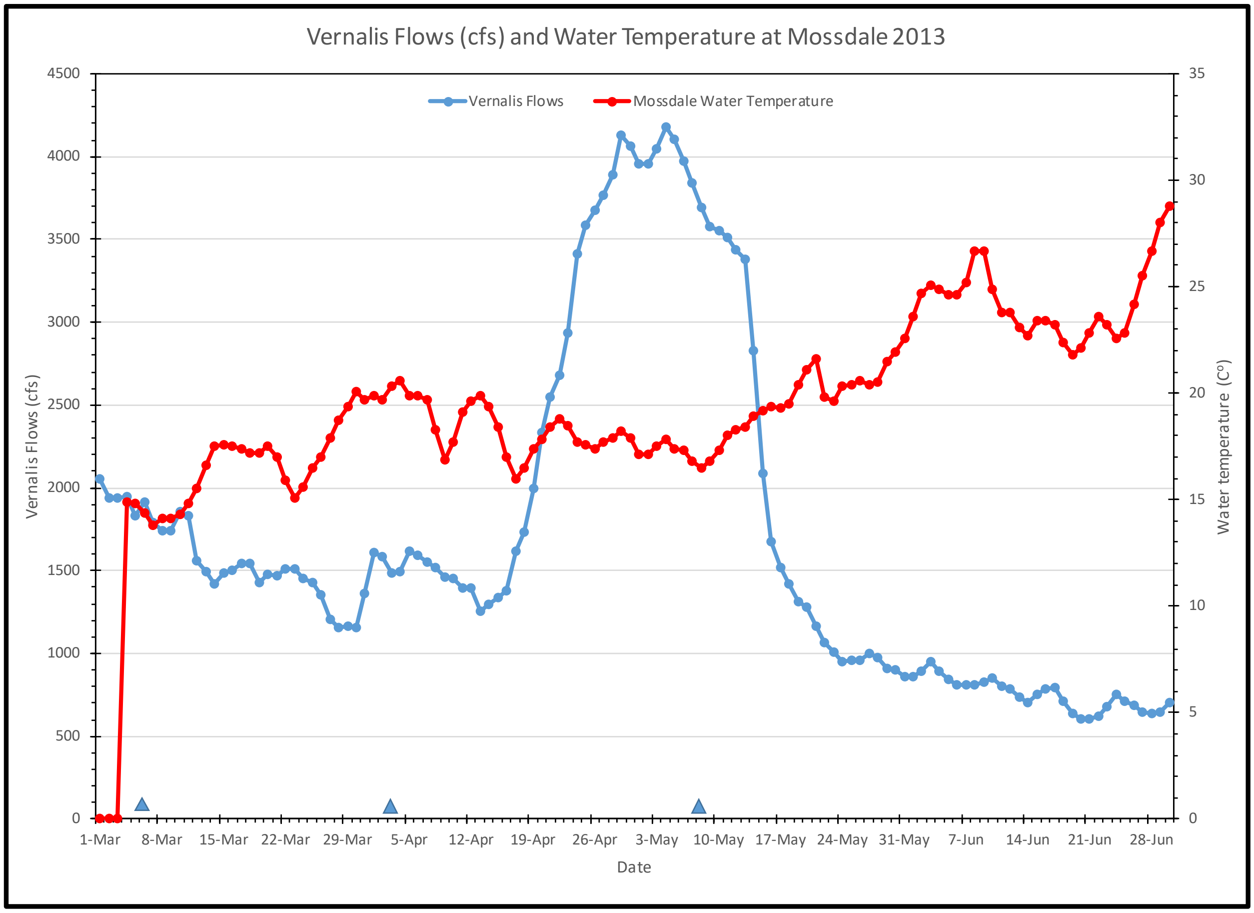

Triangles depict the initial date of releases for each release groups

Figure 4: Vernalis Flows and Mossdale Water Temperatures March through June 2012



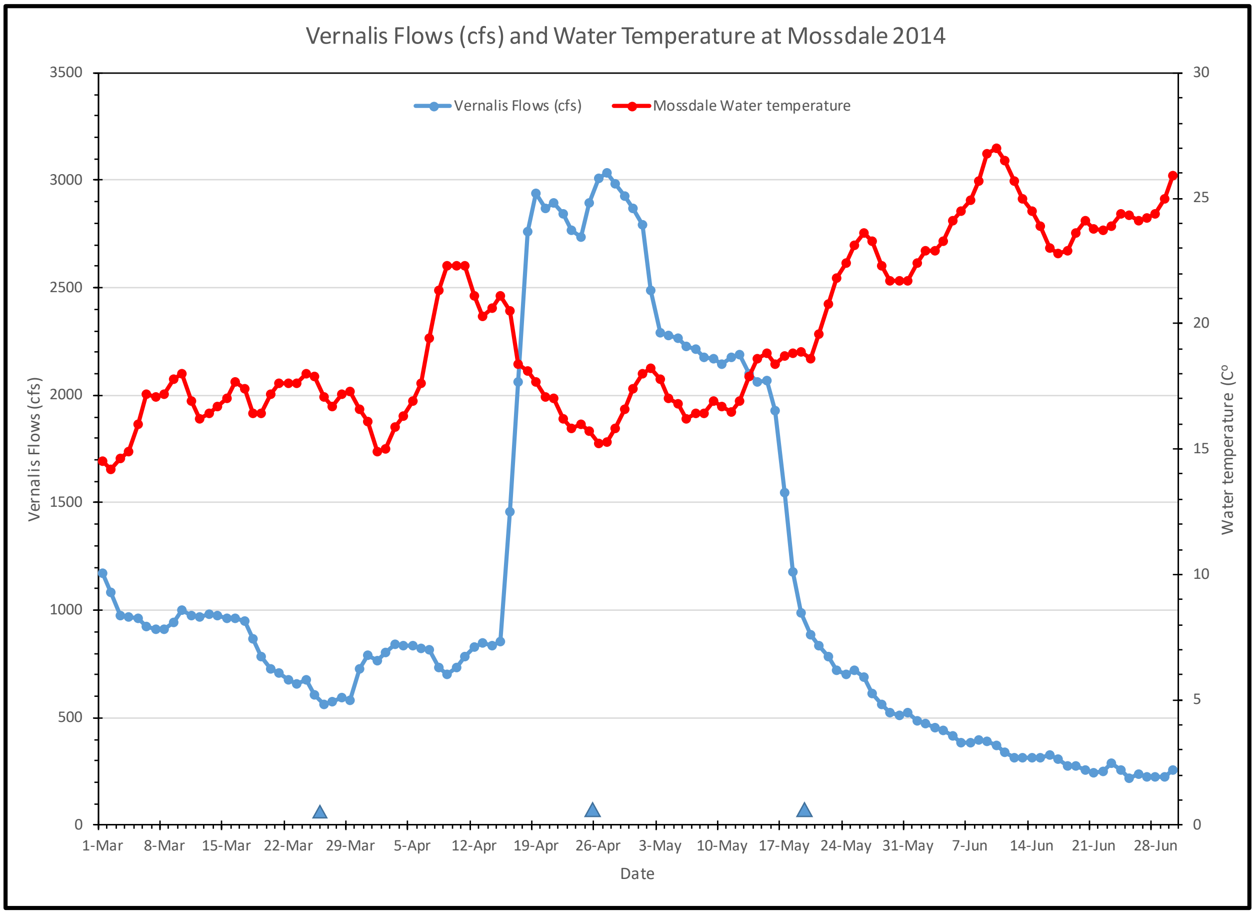

Triangles depict the initial date of releases for each release groups

Figure 5: Vernalis Flows and Mossdale Water Temperatures March through June 2013




Triangles depict the initial date of releases for each release groups

Figure 6: Vernalis Flows and Mossdale Water Temperatures March through June 2014




Triangles depict the initial date of releases for each release groups

**Figure 7**: Cumulative survival from releases at Durham Ferry to various points along the San Joaquin River route to Chipps Island by surgeon (2012 study). Error bars are 95% confidence intervals.

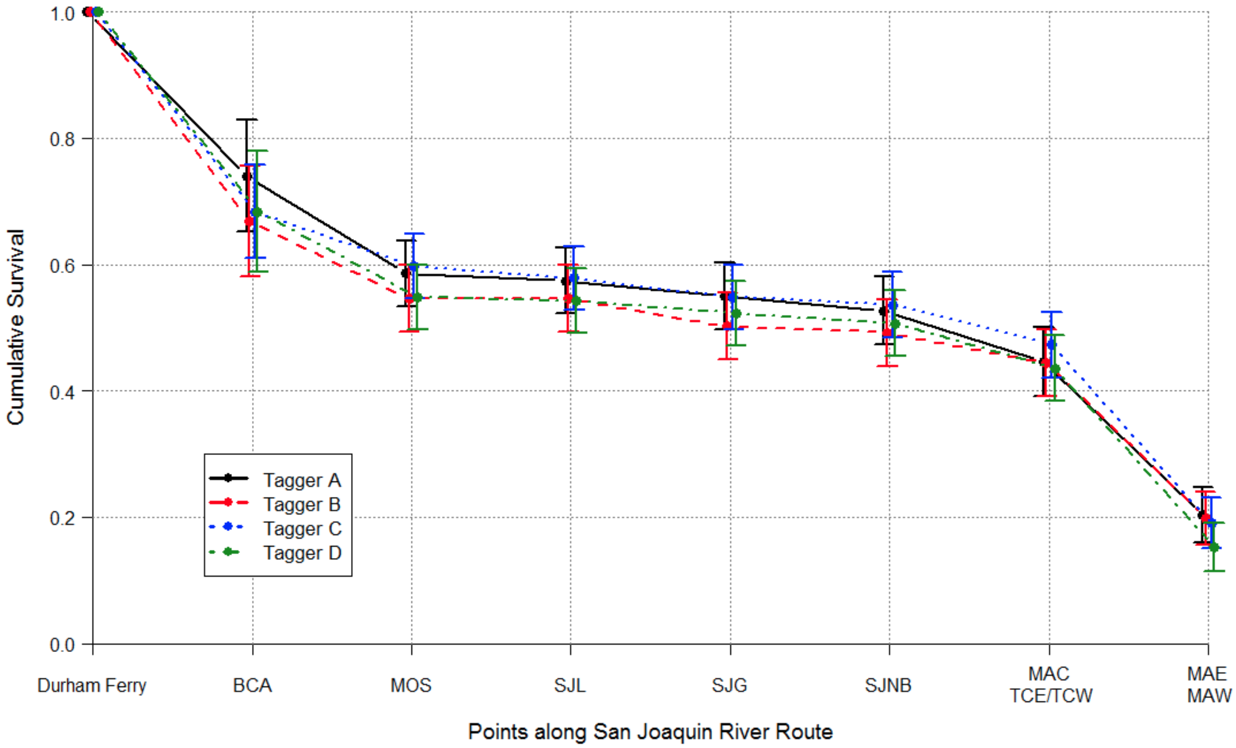


**Figure 8**: Cumulative survival from releases at Durham Ferry to various points along the Old River route to Chipps Island by surgeon (2012 study). Error bars are 95% confidence intervals.

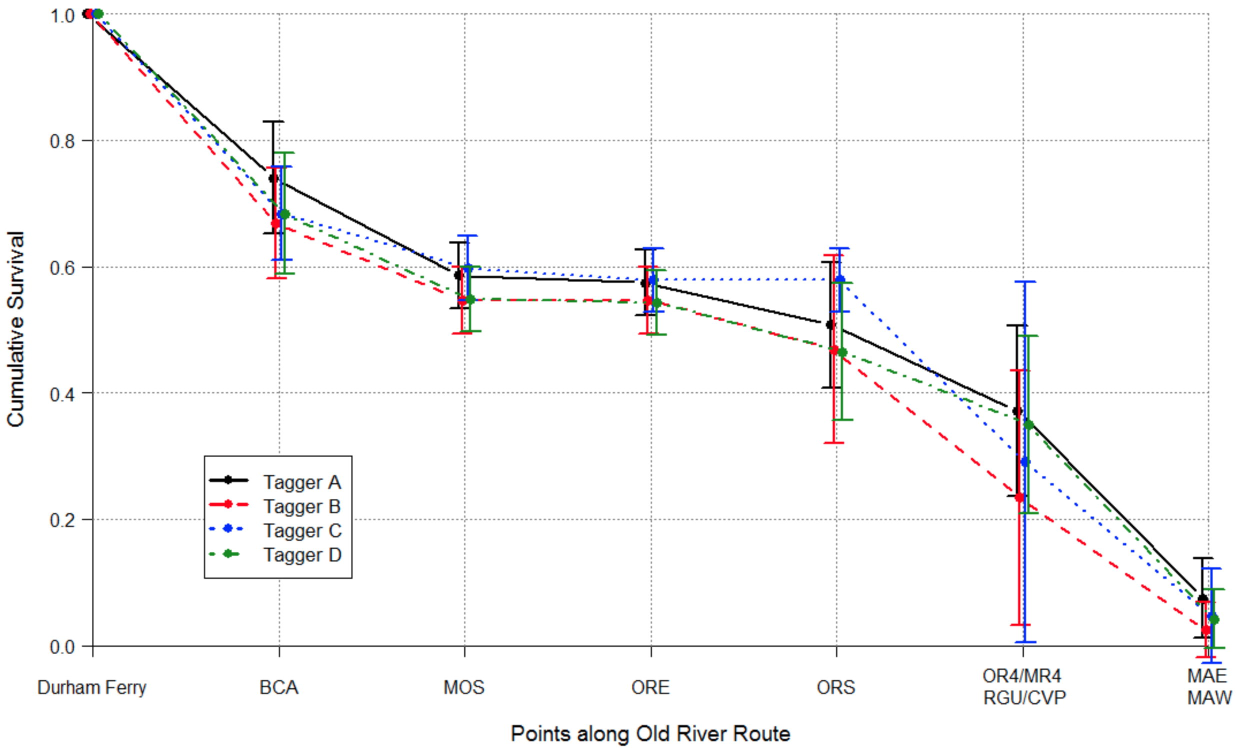


**Figure 9**: Cumulative survival from releases at Durham Ferry to various points along the San Joaquin River route to Chipps Island by surgeon (2013 study). Error bars are 95% confidence intervals.

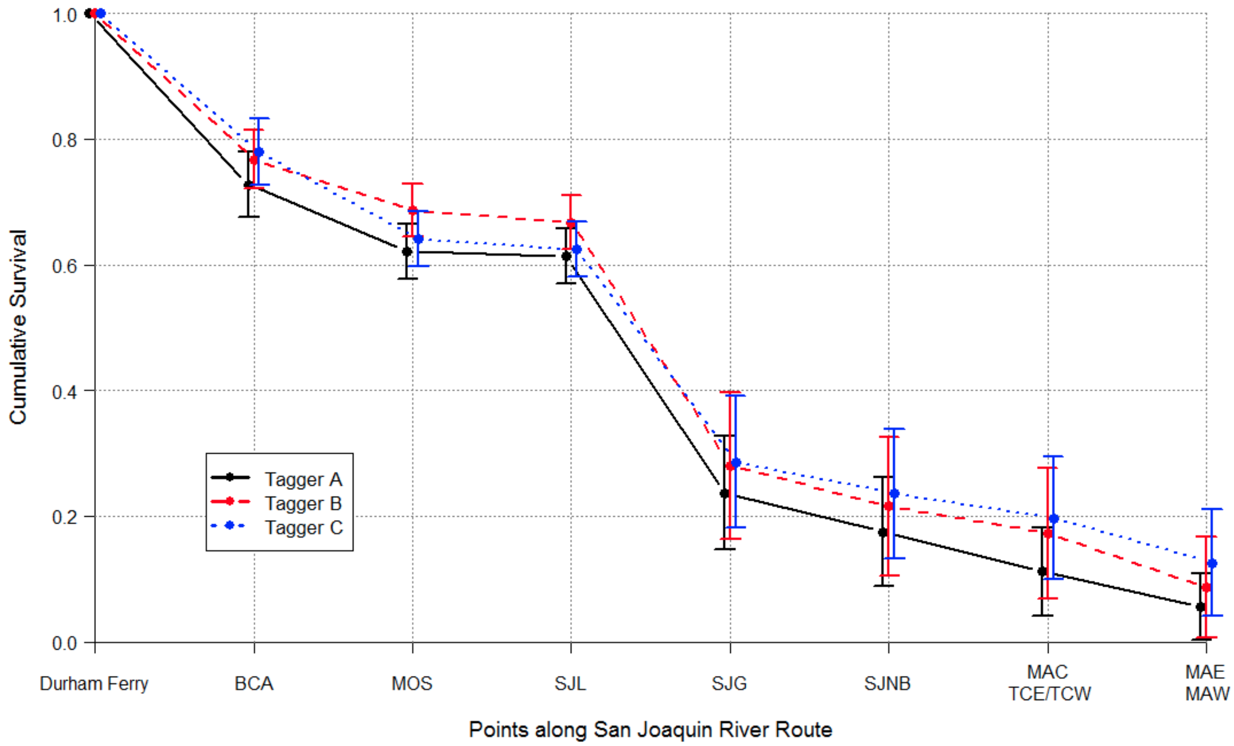


**Figure 10**: Cumulative survival from releases at Durham Ferry to various points along the Old River route to Chipps Island by surgeon (2013 study). Error bars are 95% confidence intervals.

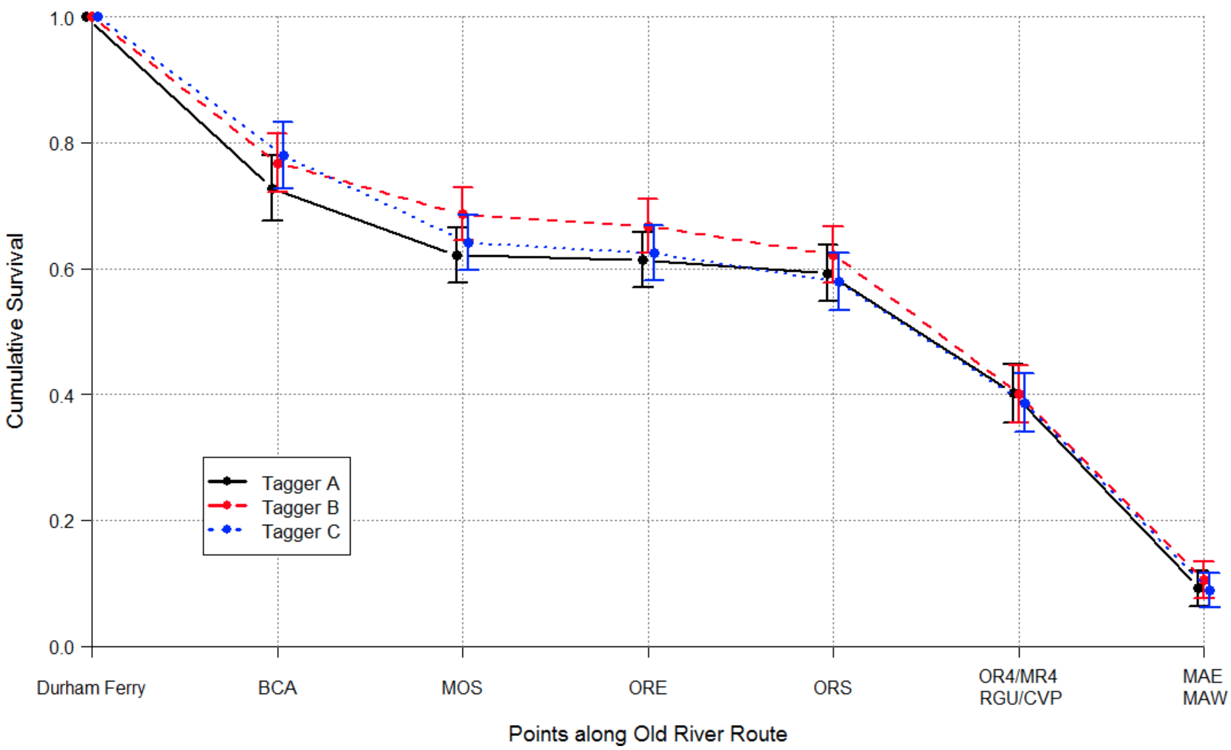


**Figure 11**: Cumulative survival from releases at Durham Ferry to various points along the San Joaquin River route to Chipps Island by surgeon (2014 study). Error bars are 95% confidence intervals. Estimates are of joint fish-tag survival.

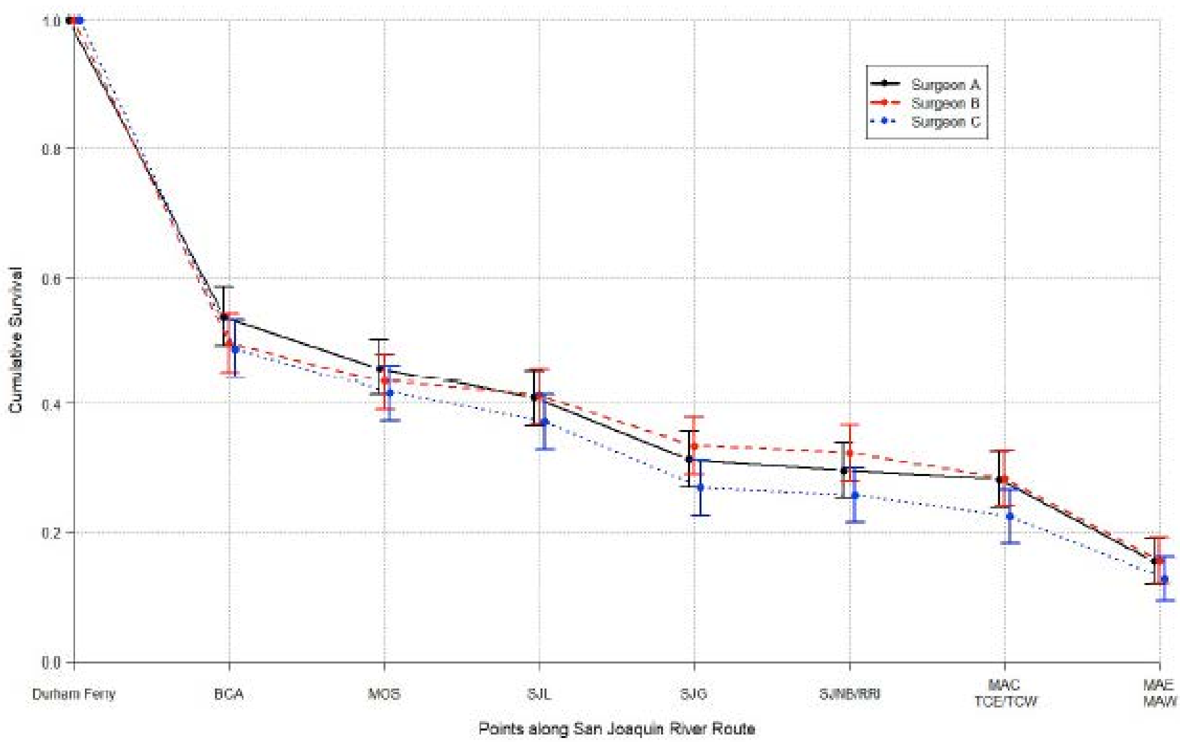
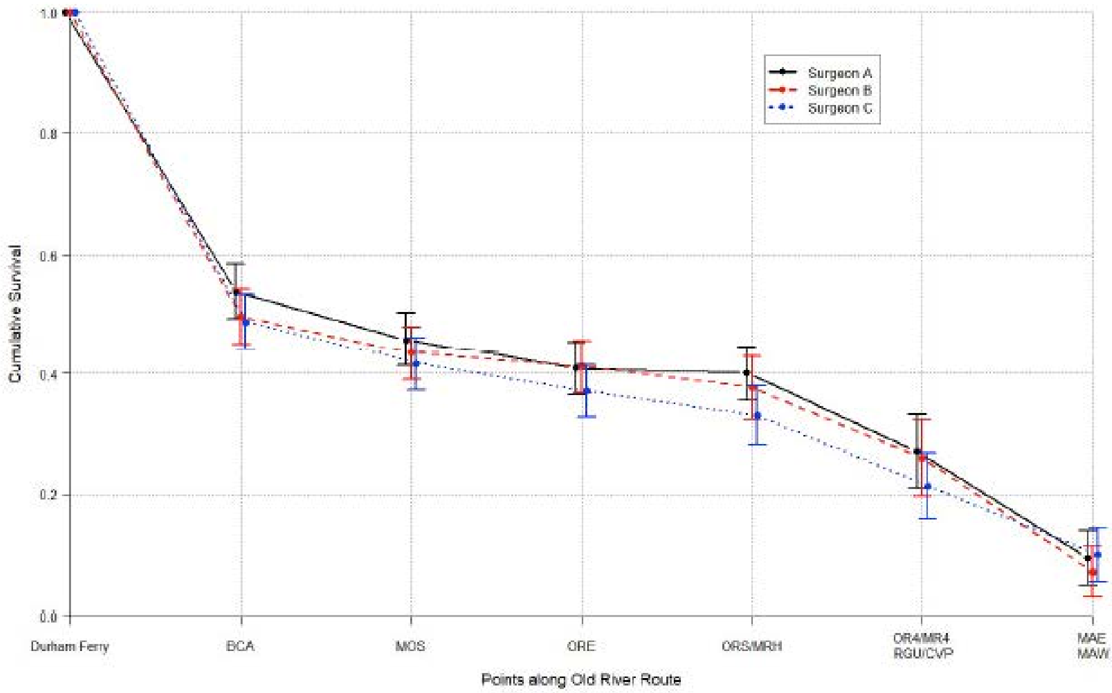


**Figure 12**: Cumulative survival from releases at Durham Ferry to various points along the Old River route to Chipps Island by surgeon (2014 study). Error bars are 95% confidence intervals. Estimates are of joint fish-tag survival.



**Summary of SWFSC report to USBR on analysis on subset of Steelhead "6-year Study" acoustic telemetry data**

**Background:** The SWFSC (Dr. Andrew Hein) used a subset of six-year study steelhead acoustic telemetry data at five hydrophone arrays in the Delta to understand the relationship between the instantaneous migration rate and environmental variables using a novel point process statistical model framework. The instantaneous migration rate refers to the minute-by-minute fish movements into the zone within range of detection by a hydrophone array, rather than the long-term movements of fish throughout the system.

**Methods (refer to Fig. 1):** Acoustically tagged fish were released at Durham Ferry (release location) and subset for analysis purposes to include mostly 2011 data. The environmental variables of interest were turbidity, conductivity, temperature, diel phase, discharge, and the rate of discharge over time. These data were subjected to a symbolic regression (point process model) aimed at generating a variety of models to predict the instantaneous movement behavior in response to different environmental variables, specifically the expected arrival of fish at location x and time t.

**Results (refer to Fig. 2):** Discharge, conductivity and turbidity were the variables that most often had the strongest relationship with the arrival rate of steelhead at the subset of hydrophone arrays investigated. The conditional effects of each environmental variable (varying one variable at a time while holding all others at their mean value) for each hydrophone array location are described below:

- At **BCA** (near release site), arrivals of fish were negatively related to discharge, and positively related with warmer and more turbid water conditions.
- At **SJL,** turbidity and temperature exerted dominant effects on arrival rates with a slightly less pronounced effect of water conductivity, however discharge did not have a strong influence. The conductivity effect was stronger than at other arrays higher in the river.
- At **Turner Cut (C18/16),** a more tidally influenced region, the fish moved most with high conductivity, discharge, temperature and turbidity – with discharge and conductivity having the strongest positive relationship with arrivals. (More tidal region)
- At **Jersey Point (JPT)** arrival rates were positively correlated with conductivity with less influence to no relationship with other variables. (More tidal region)
- At the **Old River (ORN)** hydrophone array, there was a different pattern in arrivals in relation to environmental variables than at other arrays investigated here. Specifically, predicted fish arrival rates increased with strong negative flows and with positive flows (a non-linear relationship) with also a small net positive effect of turbidity.

**Caveats:** The analysis in this report was done as a proof of concept for the modelling framework, not to answer specific management related questions. Only one full year of data was used (2011) and as such results only provide a partial understanding of conditions that might affect steelhead movement during dry years. Further, models assume that detection probability for a given hydrophone array are constant but there is likely different detection probabilities through time for each array. The models also do not necessarily use the most representative (closest) gauge data for environmental data to model with arrival detections. Other gauges or hydrological models might be appropriate to use here to couple environmental conditions with arrival detections at hydrophone locations.

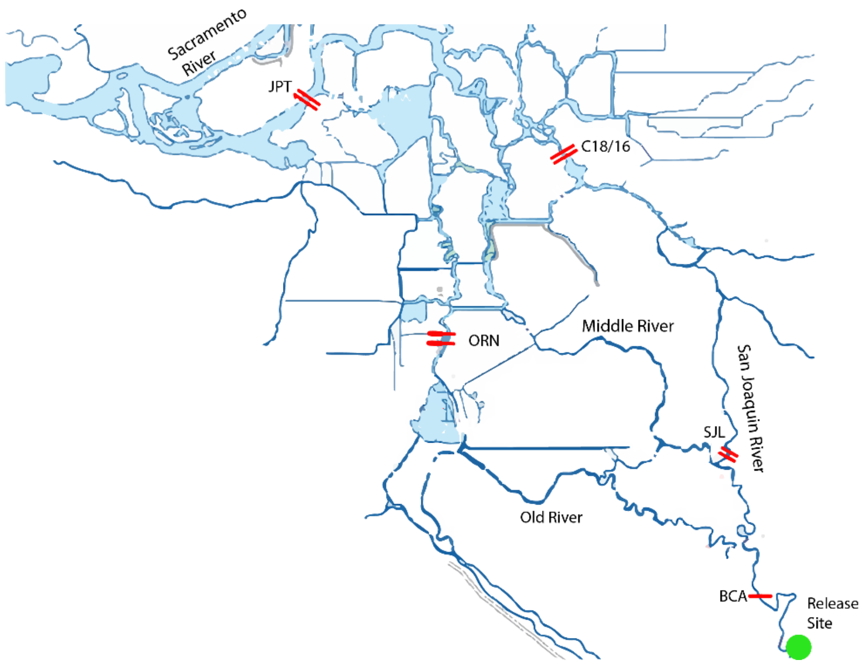



Fig. 1) Map of the Sacramento/San-Joaquin Delta with locations of single or dual hydrophone arrays (represented by one and two red bars, respectively) used in the analysis.

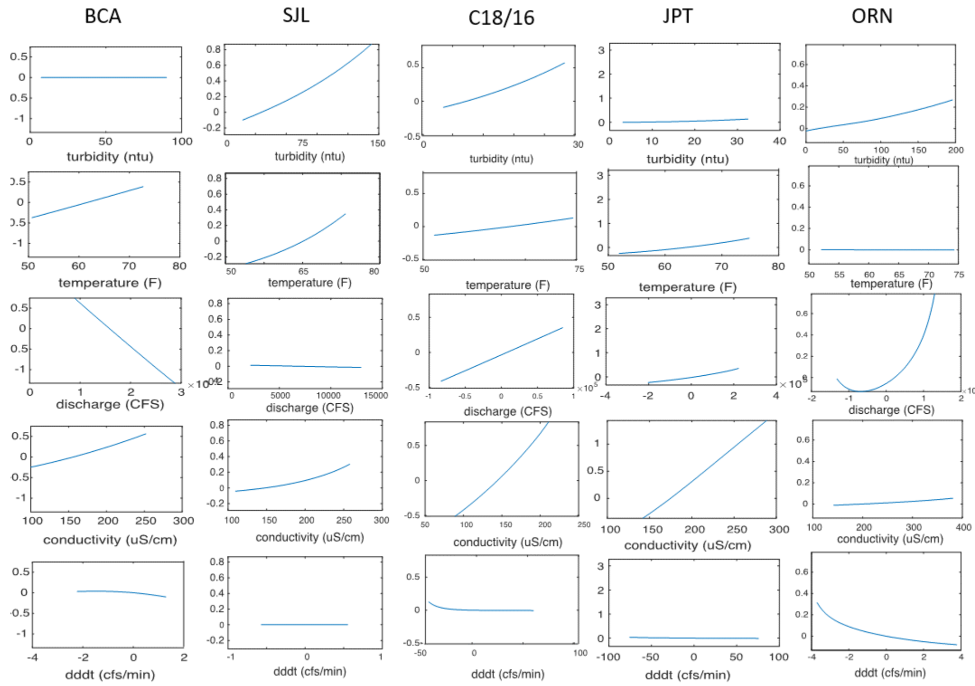



Fig. 2) Model averaged conditional effect of each environmental variable (holding others constant at mean values) on arrival rates for each hydrophone array within the Delta. Column names (BCA, SJL, C18/16, JPT, ORN) refer to individual hydrophone arrays within the Delta identified in Fig 1.

## Chinook survival results

Results from:

Brandes et al. 2017, Multivariate San Joaquin River Chnook Salmon Survival Investigation, 2012-2013. USFWS report. 6 October 2017.

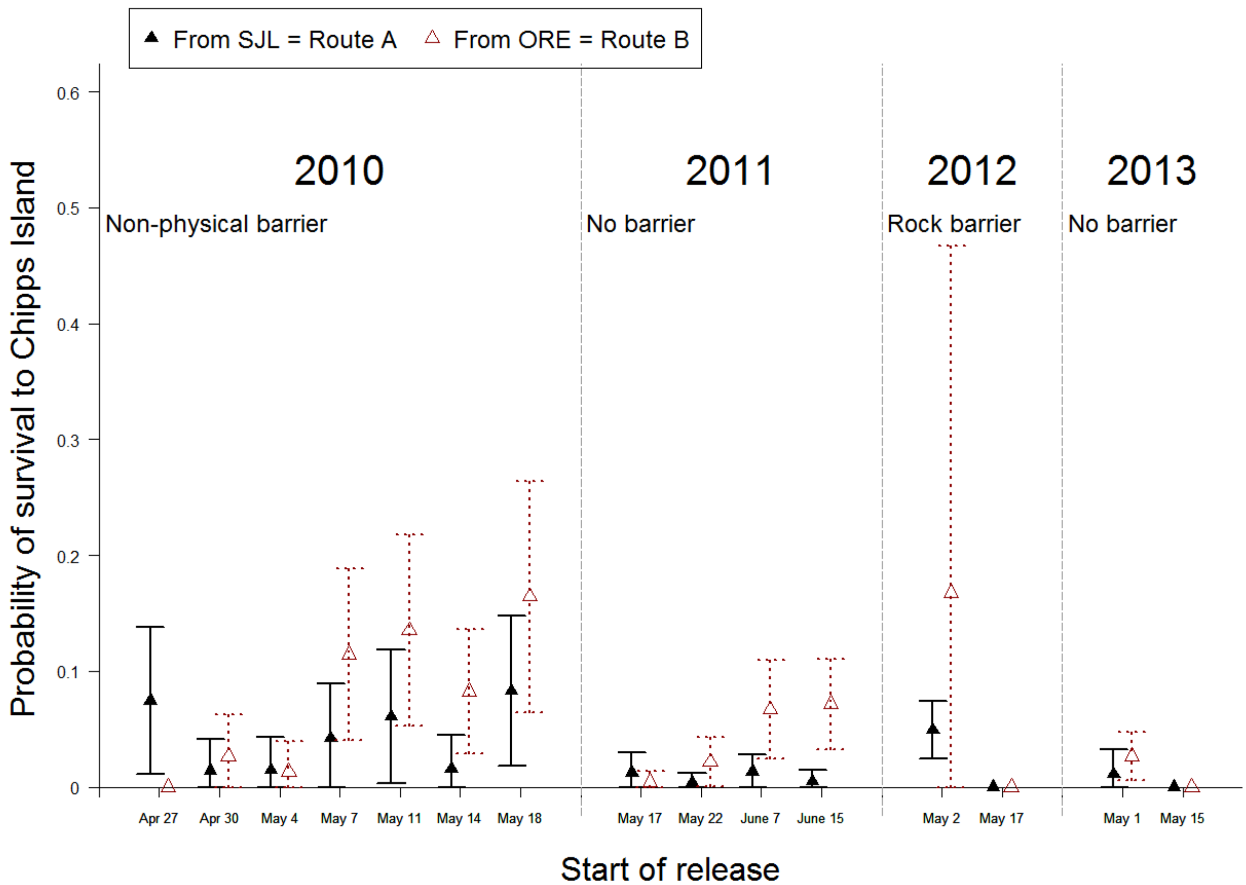



**Figure 1. Estimated probabilities of surviving from the head of Old River (SJL or ORE receivers) to Chipps Island for the San Joaquin River route (Route A) and the Old River route (Route B), for each study year and release group; bars indicate asymptotic 95% confidence intervals. Route is determined at the head of Old River; salmon in the San Joaquin River route may enter the interior Delta further downstream.**

# Appendix I

**Delta Performance Metrics:**
**Cumulative and Annual Loss Thresholds**

## I. Delta Performance Objectives in June 14, 2019 PA

The Delta Performance Objectives, included as an element of "Additional Real-Time OMR Restrictions and Performance Objectives" in the June 14, 2019 PA, are excerpted below:

- Cumulative Loss Threshold:
  - Reclamation and DWR propose to avoid exceeding cumulative loss thresholds over the duration of the Biological Opinions for wild Winter-Run Chinook Salmon, hatchery Winter-Run Chinook Salmon, wild Central Valley Steelhead from December through March, and wild Central Valley Steelhead from April 1 through June 15th. Wild Central Valley Steelhead are separated into two time periods to protect San Joaquin Origin fish that historically appear in the Mossdale trawls later than Sacramento origin fish. The loss threshold and loss tracking for hatchery Winter-Run Chinook Salmon does not include releases into Battle Creek. Loss (for development of thresholds and ongoing tracking) for Chinook salmon are based on length-at-date criteria.
  - The cumulative loss thresholds shall be based on cumulative historical loss from 2010 through 2018. Reclamation's and DWR's performance objectives will set a trajectory such that this cumulative loss threshold (measured as the 2010-2018 average cumulative loss multiplied by 10 years) will not be exceeded by 2030.
  - If, at any time prior to 2024, , Reclamation and DWR exceed 50% of the cumulative loss threshold, Reclamation and DWR will convene an independent panel to review the actions contributing to this loss trajectory and make recommendations on modifications or additional actions to stay within the cumulative loss threshold, if any.
  - In the year 2024, Reclamation and DWR will convene an independent panel to review the first five years of actions and determine whether continuing these actions are likely to reliably maintain the trajectory associated with this performance objective for the duration of the period.
  - If, during real-time operations, Reclamation and DWR exceed the cumulative loss threshold, Reclamation and DWR would immediately seek technical assistance from USFWS and NMFS, as appropriate, on the coordinated operation of the CVP and SWP for the remainder of the OMR management period. In addition, Reclamation and DWR shall, prior to the next OMR management season, charter an independent panel to review the OMR Management Action consistent with "Chartering of Independent Panels" under the "Governance" section of this Proposed Action. The purpose of the independent review shall be to evaluate the efficacy of actions to reduce the adverse effects on listed species under OMR management and the non-flow measures to improve survival in the south Delta and for San Joaquin origin fish.

- Single-Year Loss Threshold:
  - In each year, Reclamation and DWR propose to avoid exceeding an annual loss threshold equal to 90% of the greatest annual loss that occurred in the historical record from 2010 through 2018 for each of wild Winter-Run Chinook Salmon, hatchery Winter-Run Chinook Salmon, wild Central Valley Steelhead from December through March, and wild Central Valley Steelhead from April through

June 15. Wild Central Valley Steelhead are separated into two time periods to protect San Joaquin Origin fish that historically appear in the Mossdale trawls later than Sacramento origin fish. The loss threshold and loss tracking for hatchery Winter-Run Chinook Salmon does not include releases into Battle Creek. Loss (for development of thresholds and ongoing tracking) for Chinook salmon are based on length-at-date criteria.

- During the year, if Reclamation and DWR exceed the average annual loss from 2010 through 2018, Reclamation and DWR will review recent fish distribution information and operations with the fisheries agencies at WOMT and seek technical assistance on future planned operations. Any agency may elevate from WOMT to a Directors discussion, as appropriate.
- During the year, if Reclamation and DWR exceed 50% of the annual loss threshold, Reclamation and DWR will restrict OMR to a 14-day moving average OMR index of no more negative than -3,500 cfs, unless Reclamation and DWR determine that further OMR restrictions are not required to benefit fish movement because a risk assessment shows that the risk is no longer present based on real-time information.
- The -3500 OMR operational criteria adjusted and informed by this risk assessment will remain in effect for the rest of the season. Reclamation and DWR will seek NMFS technical assistance on the risk assessment and real-time operations.
- During the year, if Reclamation and DWR exceed 75% of the annual loss threshold, Reclamation and DWR will restrict OMR to a 14-day moving average OMR index of no more negative than -2,500 cfs, unless Reclamation and DWR determine that further OMR restrictions are not required to benefit fish movement because a risk assessment shows that the risk is no longer present based on real-time information.
- The -2500 OMR operational criteria adjusted and informed by this risk assessment will remain in effect for the rest of the season. Reclamation and DWR will seek NMFS technical assistance on the risk assessment and real-time operations.
- Risk assessment: Reclamation and DWR will determine and adjust OMR restrictions under this section by preparing a risk assessment that considers several factors including, but not limited to, real-time monitoring detects few fish in the south Delta and few fish are detected in salvage. Reclamation and DWR will share its technical analysis and supporting documentation with USFW and NMFS, seek their technical assistance, discuss the risk assessment and future operations with WOMT at its next meeting, and elevate to the Directors as appropriate.
- If, during real-time operations, Reclamation and DWR exceed the single-year loss threshold, Reclamation and DWR would immediately seek technical assistance from USFWS and NMFS, as appropriate, on the coordinated operation of the CVP and SWP for the remainder of the OMR management period. In addition, Reclamation and DWR shall, prior to the next OMR management season, charter an independent panel to review the OMR Management Action consistent with "Chartering of Independent Panels" under the "Governance" section of this

Proposed Action. The purpose of the independent review shall be to evaluate the efficacy of actions to reduce the adverse effects on listed species under OMR management and the non-flow measures to improve survival in the south Delta and for San Joaquin origin fish.

- Reclamation and DWR shall consider the historical monthly distribution of loss to avoid disproportionately salvaging fish during any single month.

NMFS provides a supplemental effects analysis for these revised loss thresholds in Section 2.5.5.11 of the opinion; this appendix simply reports the specific values for the cumulative thresholds (in Section II) and annual thresholds (in Section III).

## II. Cumulative loss thresholds

*Excerpt from the June 14, 2019, PA:* "Reclamation's and DWR's performance objectives will set a trajectory such that this cumulative loss threshold (measured as the 2010-2018 average cumulative loss multiplied by 10 years) will not be exceeded by 2030."

The cumulative loss thresholds for each population are summarized in Table 1.

*Table 1: Cumulative loss thresholds for each population for which a performance objective was included in the June 14, 2019, PA.*

| Population | 2010-2018 average [annual] cumulative loss | 2010-2018 average [annual] cumulative loss x 10 |
|---|---|---|
| Wild winter-run-sized Chinook salmon (December – March) | 0.36% of wild JPE | calculated as 0.36% of sum of WY 2020-WY2029 wild JPE estimates* |
| Hatchery winter-run Chinook salmon | 0.0252% of hatchery JPE | calculated as 0.0252% of sum of WY 2020-WY2029 wild JPE estimates* |
| Wild steelhead (December – March) | 663 | 6,630 |
| Wild steelhead (April – June 15) | 597 | 5,970 |

**Because the loss thresholds are scaled to population size, the cumulative 10-year loss threshold is calculated as the average annual loss percentage of the 10-year cumulative JPE estimate.*

Assuming the opinion goes into effect in January 2020, it makes sense to use the WY 2020 salvage season (including December 2019-March 2020) as the first year of data for wild winter-run-sized Chinook salmon and wild steelhead and to include the first ten water years of implementation (through WY 2029) in the tracking of cumulative loss, as shown in the example below for wild steelhead (December – March). Starting in WY 2030, the cumulative loss threshold can be tracked on a rolling ten water year basis.

*Table 2: Example of tracking observed loss against the ten-year cumulative loss threshold for wild steelhead (December – March). Assuming the opinion goes into effect in January 2020, the observed cumulative loss through WY 2029 (a+b+c+d+e+f+g+h+i+j) should not exceed 6,630 wild steelhead.*

| Water Year | Observed loss of wild steelhead (December – March) | 2010-2018 average [annual] cumulative loss for wild steelhead (December - March |
|---|---|---|
| 2020 | a | 663 |
| 2021 | b | 663 |
| 2022 | c | 663 |
| 2023 | d | 663 |
| 2024 | e | 663 |
| 2025 | f | 663 |
| 2026 | g | 663 |
| 2027 | h | 663 |
| 2028 | i | 663 |
| 2029 | j | 663 |
| Ten year cumulative loss: | a+b+c+d+e+f+g+h+i+j | 6,630 |

## III. Annual loss thresholds

The June 14, 2019, PA specifies that "In each year, Reclamation and DWR propose to avoid exceeding an annual loss threshold equal to 90% of the greatest annual loss that occurred in the historical record from 2010 through 2018…". Various action responses (see details in the PA language excerpted in full in Section I of this appendix) are required if observed loss exceeds the following interim thresholds:

- average annual loss from 2010 through 2018
- 50% of the annual loss threshold
- 75% of the annual loss threshold

The annual loss values for WY 2010 through WY 2018 and the annual and interim loss thresholds are provided below for wild winter-run-sized Chinook salmon (Figure 1 and Table 3), hatchery winter-run Chinook salmon (Figure 2 and Table 4), and wild Central Valley Steelhead (Figure 3, Figure 4, and Table 5).

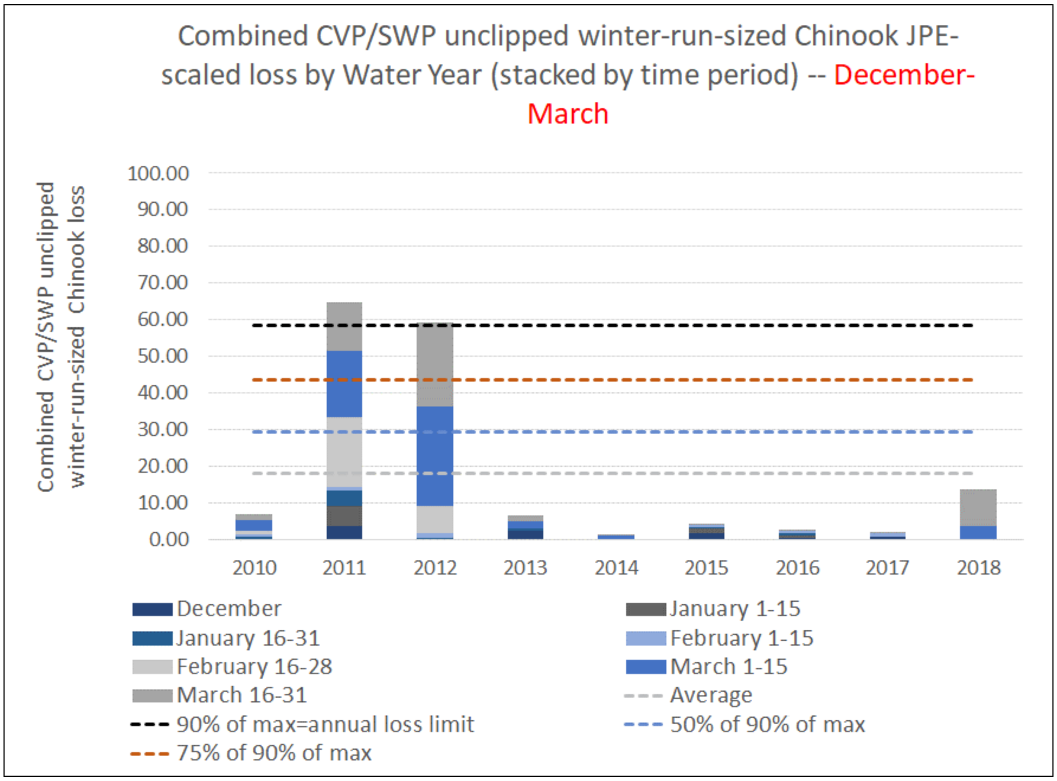



*Figure 1. Combined CVP/SWP unclipped winter-run-sized Chinook loss, as a percentage of the winter-run Juvenile Production Estimate (JPE), for WY 2010 through WY 2018. Bars represent cumulative loss from December through March, stacked by month. Horizontal reference lines indicate the loss thresholds relevant for OMR management.*

*Table 3. Wild winter-run loss for the period of December through March (Loss expressed both as percentage of 2 percent of JPE and as a percentage of the JPE). Yellow-highlighted row indicates annual loss threshold.*

| WATER YEAR | CUMULATIVE LOSS OF UNCLIPPED WR-SIZED CHINOOK as % of 2% of WR JPE | |
|---|---|---|
| 2010 | 6.8 | |
| 2011 | 64.8 | |
| 2012 | 59.3 | |
| 2013 | 6.7 | |
| 2014 | 1.3 | |
| 2015 | 4.3 | |
| 2016 | 2.8 | |
| 2017 | 2.0 | |
| 2018 | 13.8 | |
| | % of 2% of WR JPE | % of WR JPE |
| *Average Dec-March cumulative loss* | 18.0 | 0.36 |
| *Maximum Dec-March cumulative loss* | 64.8 | 1.30 |
| *90% of maximum historical loss* | 58.3 | 1.17 |
| *50% of 90% of maximum historical loss* | 29.2 | 0.58 |
| *75% of 90% of maximum historical loss* | 43.7 | 0.87 |

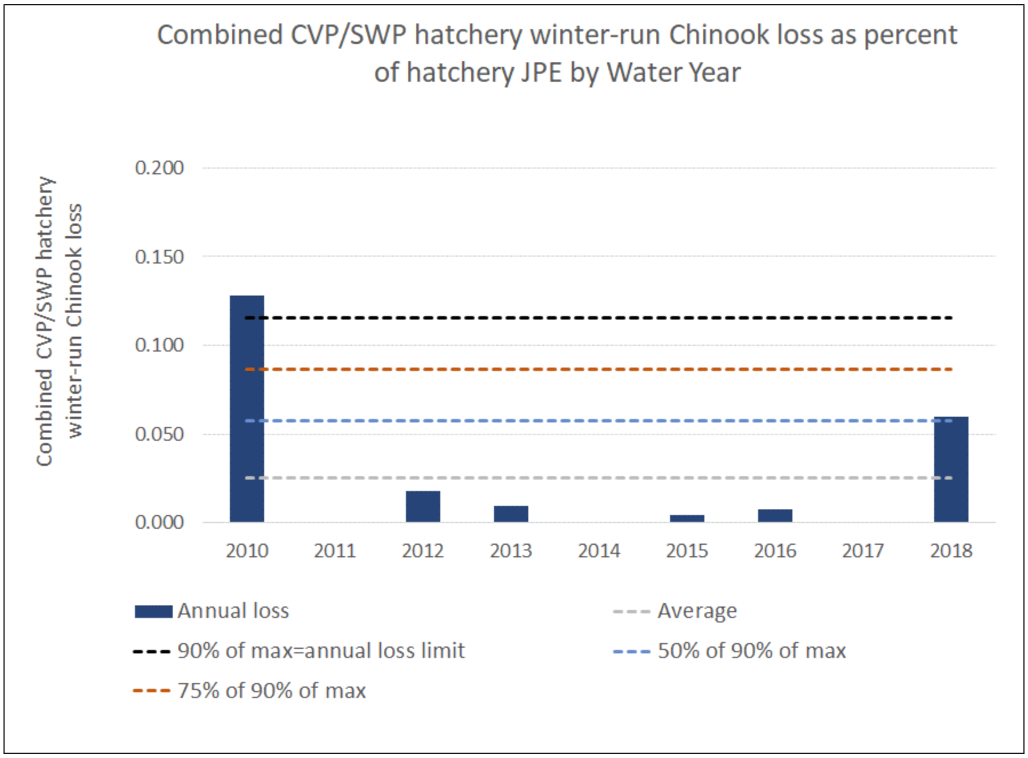



*Figure 2. Combined CVP/SWP hatchery winter-run Chinook loss for WY 2010 through WY 2018, as a percent of the number released into the Sacramento River. Bars represent cumulative loss observed within the water year of release. Horizontal reference lines indicate the loss thresholds relevant for OMR management.*

*Table 4. Hatchery winter-run loss for fish released into the Sacramento River (loss expressed as a percentage of the hatchery JPE). Yellow-highlighted row indicates annual loss threshold.*

| Water Year | Number of hatchery WR released into the Sacramento River | Hatchery WR JPE | Loss of Hatchery WR | Loss of Hatchery WR as % of hatchery WR JPE |
|---|---|---|---|---|
| 2010 | 198582 | 108725 | 140 | 0.1284 |
| 2011 | 123870 | 66734 | 0 | 0.0000 |
| 2012 | 185281 | 96525 | 17 | 0.0176 |
| 2013 | 181778 | 96525 | 9 | 0.0093 |
| 2014 | 190905 | 30880 | 0 | 0.0000 |
| 2015 | 612056 | 185600 | 8 | 0.0045 |
| 2016 | 420000 | 148000 | 11 | 0.0076 |
| 2017 | 141388 | 58188 | 0 | 0.0000 |
| 2018 | 212270 | 92904 | 55 | 0.0596 |
| | | | | |
| *Average cumulative loss* | | | | 0.0252 |
| *Maximum cumulative loss* | | | | 0.1284 |
| *90% of maximum historical loss* | | | | 0.1155 |
| *50% of 90% of maximum historical loss* | | | | 0.0578 |
| *75% of 90% of maximum historical loss* | | | | 0.0867 |

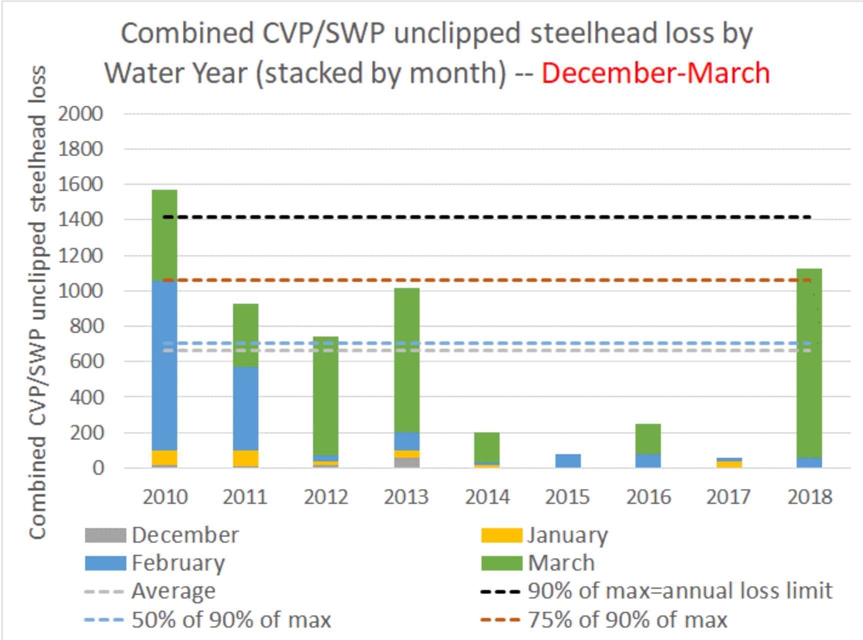



*Figure 3. Combined CVP/SWP wild steelhead loss for WY 2010 through WY 2018. Bars represent cumulative loss from December through March, stacked by month. Horizontal reference lines indicate the loss thresholds relevant for OMR management.*

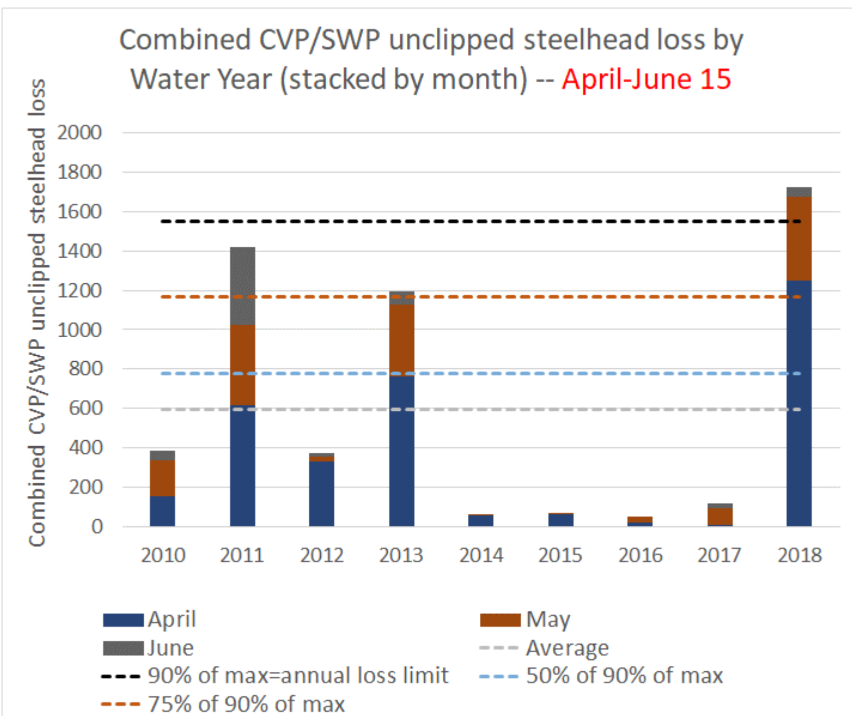



*Figure 4. Combined CVP/SWP wild steelhead loss for WY 2010 through WY 2018. Bars represent cumulative loss from April through June 15, stacked by month. Horizontal reference lines indicate the loss thresholds relevant for OMR management.*

*Table 5. Wild steelhead loss for the period of December through March, and April through June 15. Yellow-highlighted row indicates annual loss threshold for each period.*

| | Cumulative loss of unclipped steelhead | |
|---|---|---|
| **Water Year** | **Dec-Mar** | **Apr-Jun 15** |
| 2010 | 1571.15 | 382 |
| 2011 | 929.7 | 1419.13 |
| 2012 | 740.56 | 371.81 |
| 2013 | 1013.88 | 1197.2 |
| 2014 | 201.69 | 58.82 |
| 2015 | 77.94 | 61.73 |
| 2016 | 245.92 | 46.7 |
| 2017 | 60.12 | 113.69 |
| 2018 | 1127.01 | 1724.64 |
| | | |
| *average* | 663 | 597 |
| *max* | 1571 | 1725 |
| *90% of max* | 1414 | 1552 |
| *75% of 90% of max* | 1061 | 1164 |
| *50% of 90% of max* | 707 | 776 |

# Appendix J

## Estimate of Change in Abundance of Central Valley Chinook Salmon Available to Southern Resident Killer Whales under the Proposed Action

# 1 ESTIMATE OF CHANGE IN ABUNDANCE OF CENTRAL VALLEY CHINOOK SALMON AVAILABLE TO SOUTHERN RESIDENT KILLER WHALES UNDER THE PROPOSED ACTION

This assessment evaluates abundance of Chinook salmon produced from the Central Valley watershed of California and available as adults in the ocean as prey for Southern Resident killer whale (SRKW). The assessment assumes that age three and older Chinook salmon would be in the size range most suitable as prey so the assessment focuses on those Chinook salmon. The scenarios evaluated and compared are the Current Operations Scenario (COS) and the Proposed Action scenario (PA). Where portions of the lifestage affected by the PA have quantitative models available and compatible with the CalSimII water operations simulation those models are used (Table 1-1). Unquantified effects are described but not bundled into the evaluation of abundance. The quantified freshwater mortality sources are aggregated into an overall change in freshwater survival attributable to the water operations scenarios. Hatchery Chinook salmon releases are included in the analysis by using the average annual number of Chinook salmon released for all hatcheries and runs combined. Releases are separated by in-river and Bay releases using the general pattern of release locations for each hatchery over the past few years. In-river mortality based on acoustic tag data and the Delta Passage Model was applied to the in-river released hatchery fish and these were then added to the Bay releases for a total number of hatchery fish in the Bay. The past 18-year median ocean Chinook salmon abundance is divided by the hatchery and naturally produced Chinook salmon in the Bay to determine a baseline ocean survival value. The hatchery proportion is based on coded wire tag recovery data in 2012, 2013, and 2014 from the ocean and freshwater fisheries, escapement surveys, and hatchery returns. This is the most recent hatchery proportion data published by CDFW. The recent past ocean abundance along with changes in freshwater survival was used to calculate a range of Chinook salmon available as prey to SRKW under the current and proposed action.

**Table 1-1. Rivers and Chinook salmon runs assessed and models used in the assessment. The "Run" column refers to natural-origin (i.e., spawned in-river) fish unless stated otherwise. The proportions of Central Valley Chinook salmon is the mean 2001-2017 data in U.S. Fish and Wildlife Service (2018).**

| River | Run | Model | Proportion of Central Valley Chinook salmon |
|---|---|---|---|
| Sacramento | Fall | SALMOD | 0.097 |
| Sacramento | Late Fall | SALMOD | 0.026 |
| Sacramento | Winter | IOS | 0.014 |
| Sacramento | Spring | SALMOD | 0.0003 |

| River | Run | Model | Proportion of Central Valley Chinook salmon |
|---|---|---|---|
| Clear Creek | Fall and spring | Upstream effects not included | 0.023 |
| Feather | Spring and Fall | Upstream effects not included | 0.240 |
| American | Fall | Salmort | 0.223 |
| Stanislaus | Fall | Salmort | 0.010 |
| Delta | All Chinook salmon from Sacramento River basin | Delta Passage Model<br>Salvage Density Model results described | 0.936 |
| Delta | Fall-run Chinook salmon from San Joaquin River basin and Delta Eastside streams[a] | Unquantified<br>Salvage Density Model results described quantitatively | 0.065 |
| Hatchery instream releases | All runs | Winter-run JPE survival values and Delta Passage Model | 0.59 of hatchery releases |
| Hatchery Bay releases | All Bay releases | No project effects assumed | 0.41 of hatchery releases |

[a] "Delta Eastside streams" refers to the Cosumnes River, Mokelumne River, and Calaveras River.

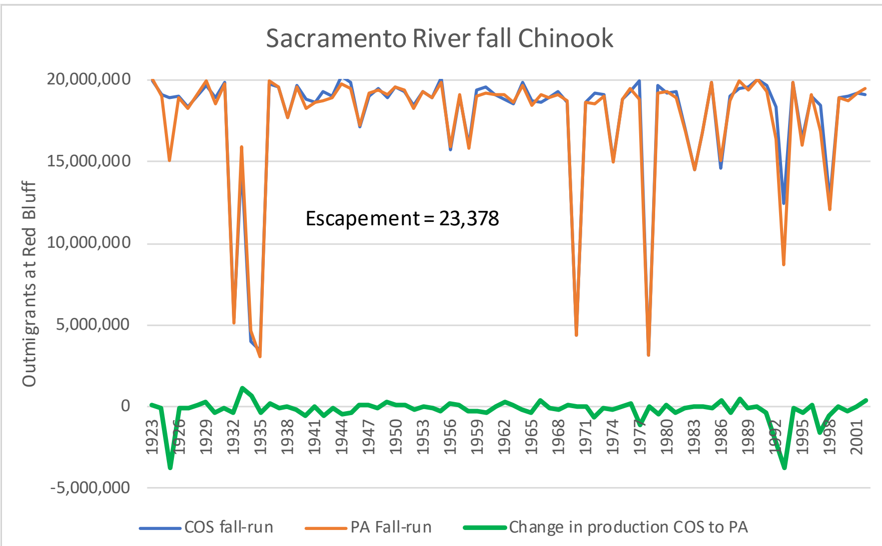
## 1.1 Changes in Chinook Salmon Survival and Production from the Upstream Areas

### 1.1.1 Sacramento River

The SALMOD model (Bartholow 2003) was used to estimate effects to fall-run, late fall-run, and spring-run Chinook salmon in the Sacramento River upstream of Red Bluff. The model calculates juvenile production emigrating downstream past Red Bluff for each run from a starting adult escapement level entering the upper Sacramento River at Red Bluff. Factors in the model affecting survival include water temperature effects on each lifestage present in the upper river (adult through emigrating juveniles), flow versus spawning habitat area relative to adult spawner distribution, flow versus rearing habitat area relative to fish distribution, and the adult escapement input to the simulation.

#### 1.1.1.1 Fall-run Chinook Salmon

Figure 1 shows the SALMOD results for Sacramento River fall-run Chinook salmon. The model results show a median reduction in production of -0.34 percent with a range of -30 percent to 17 percent change over the CalSimII simulation period. Based on examination of SALMOD results tables, factors responsible for the change in production appear to be primarily in the egg lifestage followed by the fry lifestage.

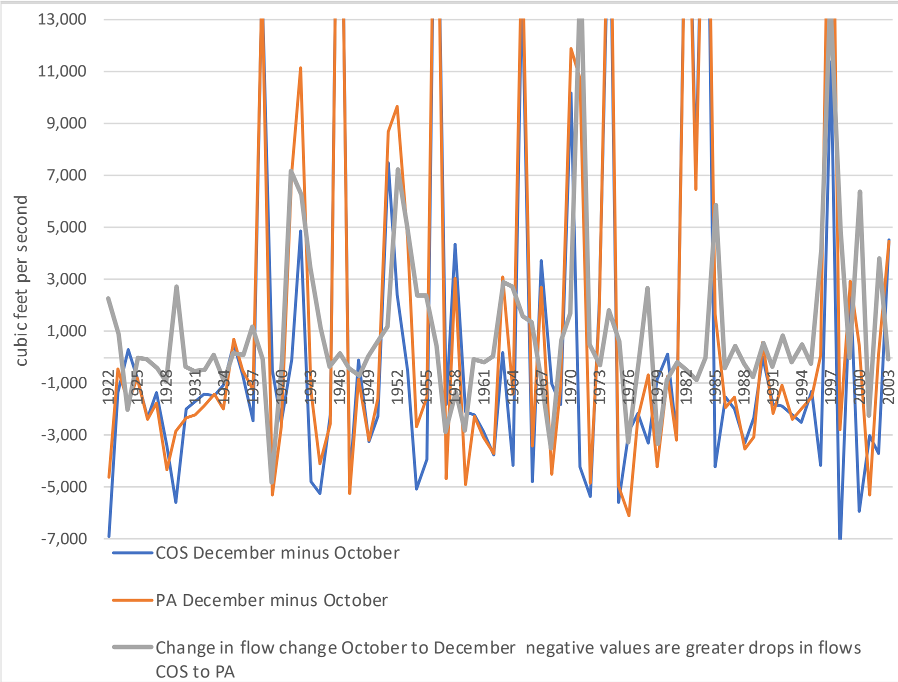



| | *% change* |
|---|---|
| | |
| Mean | -1.18907 |
| Standard Error | 0.575091 |
| Median | -0.34444 |
| Mode | #N/A |
| Standard Deviation | 5.143769 |
| Sample Variance | 26.45836 |
| Kurtosis | 16.35453 |
| Skewness | -2.57407 |
| Range | 47.61868 |
| Minimum | -30.4 |
| Maximum | 17.2187 |
| Sum | -95.1258 |
| Count | 80 |
| Largest(2) | 7.348003 |
| Smallest(2) | -20.0361 |
| Confidence Level(95.0%) | 1.14469 |

**Figure 1. Juvenile fall-run Chinook production emigrating past Red Bluff during each year of the CalSim II modeling period and change in production from COS to PA. The starting escapement value for each year is 23,378 adults. A negative value indicates fewer emigrants in the PA scenario. The chart shows descriptive statistics of the change in production used in the overall summary. SALMOD model.**

Redd dewatering is a factor not assessed in the SALMOD model and is a potentially significant stressor to fall-run Chinook salmon in particular. In general, flows on the Sacramento River are held at a level to support water delivery over the growing season and then to maintain adequate water levels for winter-run Chinook salmon egg incubation until winter-run Chinook salmon fry are estimated to have emerged from the gravel. This usually occurs in October to early November and flows are then ramped down. The fall-run Chinook salmon peak spawning period in the Sacramento River is in October. The drop in flow between October and December is often from 7,000 or 8,000 cfs down to 3,250 cfs into December if Shasta Reservoir is not close to the flood control pool level.

The flow modeling shows that in general the extent of potential fall-run Chinook salmon redd dewatering is reduced in the proposed action compared to current operations (Figure 2). Flows were modeled to drop in September in the future, prior to fall-run Chinook salmon spawning and would result in less dewatering for fall-run Chinook salmon (Figure 3). This could change the effect from fall-run Chinook salmon to winter-run Chinook salmon depending on how real time operations interact with the timing of winter-run Chinook salmon redds.




| *Change in flow change October to December negative values are greater drops in flows COS to PA* | |
|---|---|
| Mean | 981.5639 |
| Standard Error | 348.3885 |
| Median | 59.89233 |
| Mode | 0 |
| Standard Deviation | 3154.792 |
| Sample Variance | 9952713 |
| Kurtosis | 6.871418 |
| Skewness | 2.124303 |
| Range | 19790.63 |
| Minimum | -4807.95 |
| Maximum | 14982.68 |
| Sum | 80488.24 |
| Count | 82 |
| Largest(2) | 13795.65 |
| Smallest(2) | -3489.33 |
| Confidence Level(95.0%) | 693.1838 |

**Figure 2. Drop in flow at Keswick between October and December in COS and PA and difference in the drop in flow between COS and PA. The chart shows descriptive statistics on the drop in flow COS to PA.**

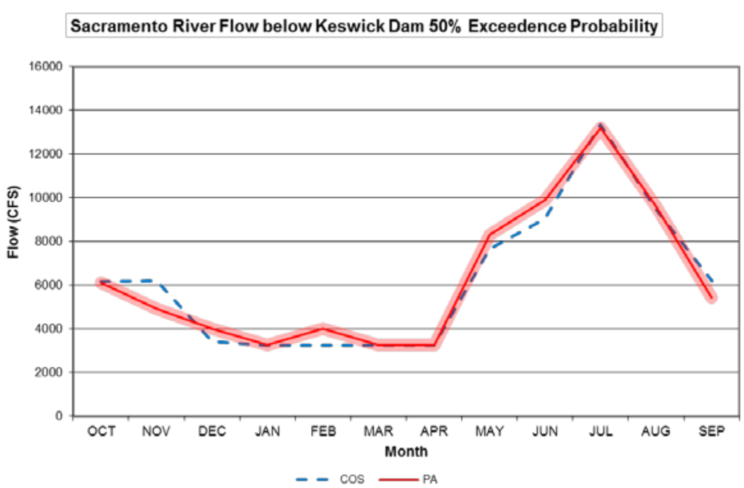
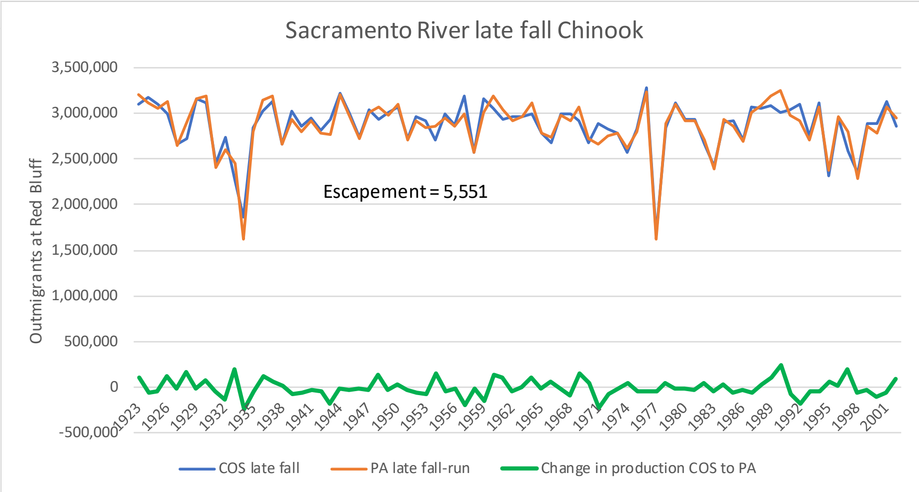



**Figure 3. Flows below Keswick Dam at 50 percent exceedance probability in the current and proposed operations.**

### 1.1.1.2 Late fall-run Chinook Salmon

SALMOD estimates that late fall-run Chinook salmon would have a median reduction in productionof -0.68 percent with a range of -12.6 percent to 8.7 percent over the CalSimII simulation period (Figure 4). Late fall-run Chinook salmon spawn when water temperatures are generally suitable for high egg survival. A main stressor for these fish is probably survival over the summer and emigration in the fall. Run size for late fall-run Chinook salmon is around 10-20 percent of that for fall-run Chinook salmon and for assessment purposes the two runs are often considered together as a single run with a spawning peak and long tail.

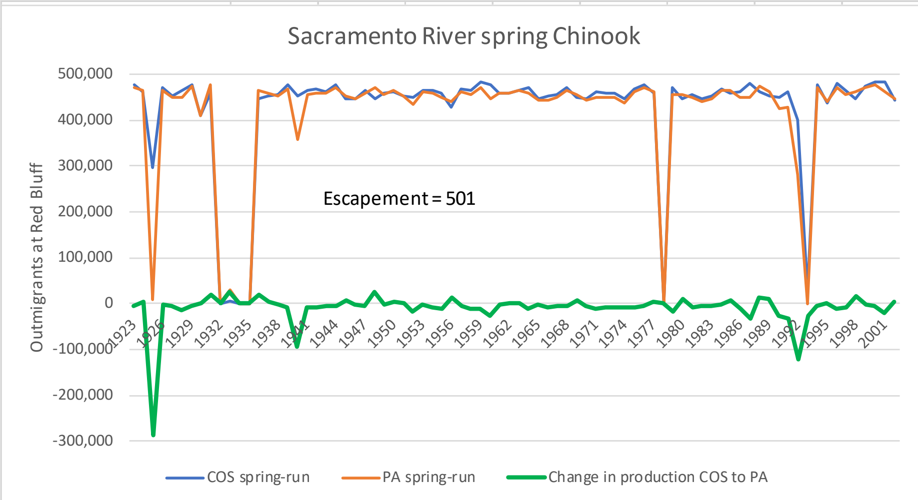



| *% change* | |
|---|---|
| | |
| Mean | -0.15428 |
| Standard Error | 0.390793 |
| Median | -0.67775 |
| Mode | #N/A |
| Standard Deviation | 3.495357 |
| Sample Variance | 12.21752 |
| Kurtosis | 1.851418 |
| Skewness | -0.11101 |
| Range | 21.3891 |
| Minimum | -12.6823 |
| Maximum | 8.706797 |
| Sum | -12.3422 |
| Count | 80 |
| Largest(2) | 8.073086 |
| Smallest(2) | -7.87089 |
| Confidence Level(95.0%) | 0.777854 |

**Figure 4. Juvenile late fall-run Chinook salmon production emigrating past Red Bluff during each year of the CalSimII modeling period and change in production from COS to PA. A negative value indicates fewer emigrants in the PA scenario. The starting escapement value for each year is 5,551 adults. The chart shows descriptive statistics of the change in production used in the overall summary. SALMOD model.**

### 1.1.1.3 Central Valley Spring-run Chinook Salmon

Populations of spring-run Chinook salmon are primarily in the cooler Sacramento River tributaries and spawning in the mainstem Sacramento River has become a rarely documented event despite regular aerial spawning surveys. Since the gates at Red Bluff Diversion Dam were permanently lifted, population estimates for spring-run Chinook salmon in the mainstem are based primarily on redds observed during September during aerial redd surveys. The temperature management focus on winter-run Chinook salmon, which generally ends by the end of October, can result in a temperature increase during the spring-run Chinook salmon incubation period in the fall which may limit the ability of spring-run to successfully reproduce in the mainstem. In many years no spawning is documented during the spring-run spawning period (considered to be September in the Sacramento River). An escapement of 501 was used for spring-run modeling in SALMOD, although actual population is lower than this, because lower populations can adversely affect the quality of model outputs in terms of capturing the effects of alternate operations scenarios. The median change indicated by SALMOD is a slight decrease in production (-1.1 percent) with a wide range of -100 percent to 601 percent (Figure 5). Sacramento River spring-run comprise less than 1 percent of natural-origin Central Valley Chinook salmon.




| *% change* | |
|---|---|
| | |
| Mean | 3.136346 |
| Standard Error | 8.19476 |
| Median | -1.08392 |
| Mode | #N/A |
| Standard Deviation | 73.29616 |
| Sample Variance | 5372.328 |
| Kurtosis | 58.01361 |
| Skewness | 7.036708 |
| Range | 701.6007 |
| Minimum | -100 |
| Maximum | 601.6007 |
| Sum | 250.9077 |
| Count | 80 |
| Largest(2) | 151.8044 |
| Smallest(2) | -99.7871 |
| Confidence Level(95.0%) | 16.31126 |

**Figure 5. Juvenile spring-run Chinook salmon production emigrating past Red Bluff during each year of the CalSim II modeling period and change in production from COS to PA. The starting escapement value for each year is 501 adults. A negative value indicates fewer emigrants in the PA scenario. The chart shows descriptive statistics of the change in production used in the overall summary. SALMOD model.**

SALMOD does not include project-related effects between Red Bluff and the Delta for Sacramento River fall-run Chinook salmon, late fall-run Chinook salmon, or spring-run Chinook salmon. This area experiences higher influence from tributary stream inflows than the areas upstream of Red Bluff, buffering some of the direct influence from Shasta operations on flows. During dry periods, flows from Keswick along with the extent of water diversions and return flows have a larger influence on conditions in this mainstem reach than the contributions from tributary inflows. Flows at Hamilton City were examined as an assessment of effects on outmigration through the middle Sacramento River. During the March – May period of fall-run and spring-run Chinook salmon outmigration, flows are generally slightly higher under the PA than under COS (Figure 6) and this would be a benefit to survival during rearing and emigration of these fish in the future.

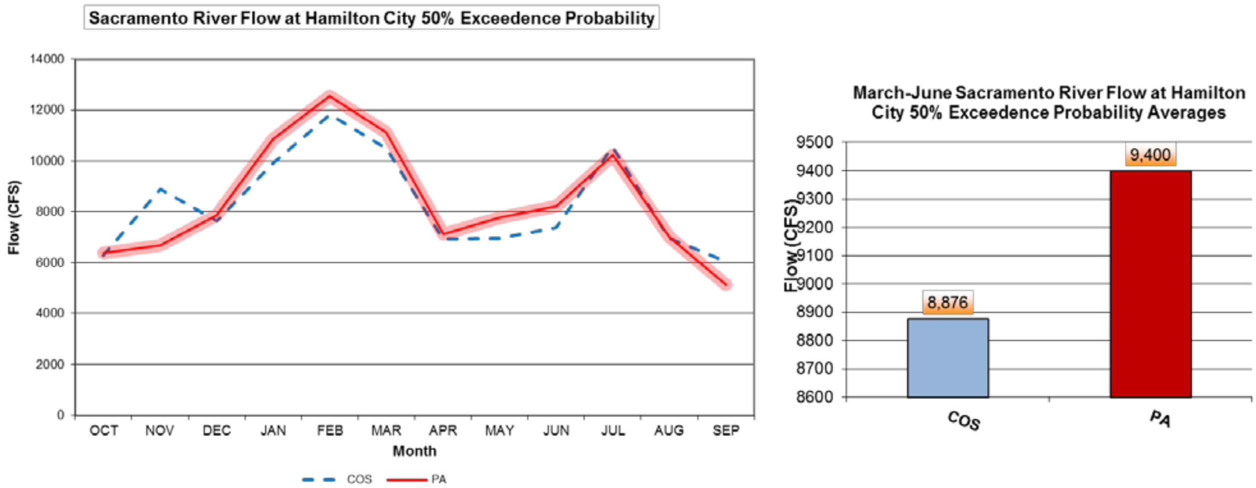
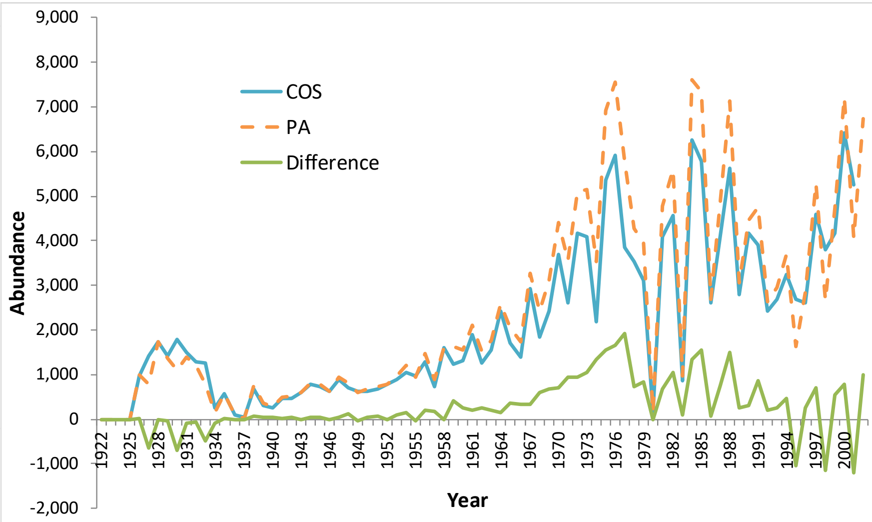



**Figure 6. Sacramento River flows at Hamilton City at the 50 percent exceedance probability level.**

### 1.1.1.4 Winter-run Chinook Salmon

Effects of the PA on winter-run Chinook salmon relative abundance throughout their lifecycle were quantified using the IOS model. IOS is a lifecycle model that provides an estimate of the change in lifestage survival and ultimate ocean abundance and escapement throughout the CalSimII simulation period. In the upper Sacramento River the model integrates the effects of temperature, flow, fish abundance, and habitat availability to arrive at production of juvenile winter Chinook salmon emigrating down the Sacramento River, through the Delta to the ocean. Ocean survival factors are included through the range of years in the ocean until the fish come back and spawn. IOS differs from the SALMOD model in that it includes the entire lifecycle with each generation seeding fish to the next. Figure 7 shows how the ocean abundance responds to the water operations and other factors over the CalSim II modeling period. The abundance displayed is that of age 3 and 4 in the ocean pre-harvest. Two year olds are not included because they are assumed to be too small to contribute significantly to killer whale prey. The change in abundance from the beginning to the end of the simulation period from a starting abundance of 5,000 escapement used to seed the model in the first four years showed a 92 percent increase in ocean abundance (age 3 and 4) for COS and a 125 percent increase for PA. The difference in median ocean abundance between the two scenarios was a 1.5 percent increase in abundance in PA compared to COS. This median change of 1.5 percent difference in median ocean abundance is the value used in the assessment along with the 2.5 percentile and 97.5 percentile change in median abundance values.




| | *COS* | *PA* | %Differer |
|---|---|---|---|
| Mean | 2,273 | 2,583 | 13.6% |
| Standard Error | 199 | 245 | |
| Median | 1,702 | 1,728 | 1.5% |
| Standard Deviation | 1,743 | 2,147 | |
| Sample Variance | 3037612 | 4607677 | |
| Kurtosis | -0.47392 | -0.28266 | |
| Skewness | 0.77329 | 0.89279 | |
| Range | 6391.121 | 7590.986 | 18.8% |
| Minimum | 31.12443 | 10.22169 | -67.2% |
| Maximum | 6422.245 | 7601.208 | 18.4% |
| Sum | 175050.1 | 198902.4 | 13.6% |
| Count | 77 | 77 | |
| Largest(2) | 6268.602 | 7565.614 | 20.7% |
| Smallest(2) | 107.5874 | 106.7359 | -0.8% |
| Confidence Level(95.0%) | 395.584 | 487.2071 | |

**Figure 7. Winter-run Chinook salmon population model results from the IOS model. The abundance displayed is that of pre-harvest adults age 3 and 4 in the ocean. The difference represents the change in abundance from COS to PA.**

### 1.1.2 Clear Creek

No appreciable difference in water temperature in Clear Creek was observed at the modeled location and there is no difference in the Whiskeytown Dam release into Clear Creek shown in the modeling (Figure 8 and Figure 9). Therefore, no modeling of change in Chinook salmon survival in Clear Creek was conducted. Clear Creek fall-run and spring-run Chinook salmon comprise about 2.3 percent of the Central Valley Chinook salmon production.

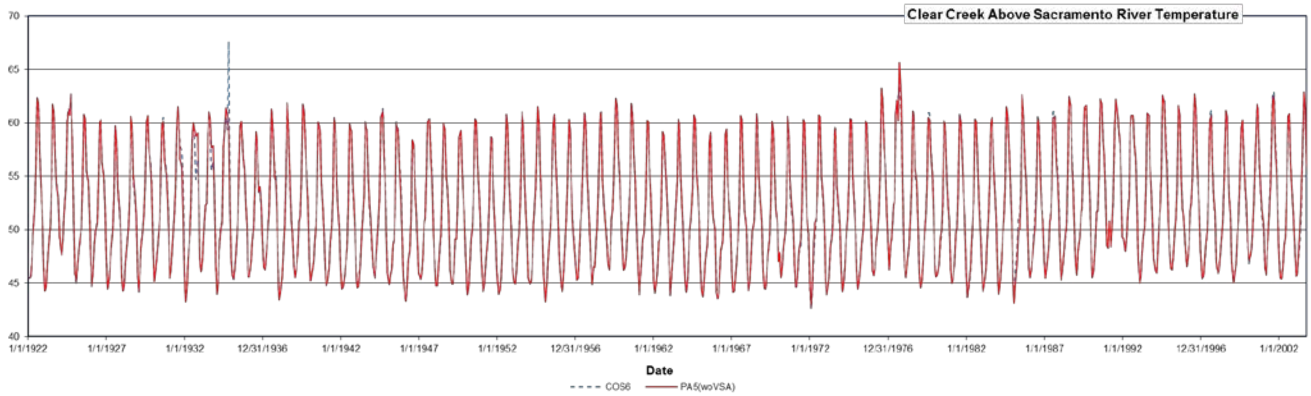



**Figure 8. Clear Creek above Sacramento River water temperature over the CalSimII modeling period under COS and PA.**

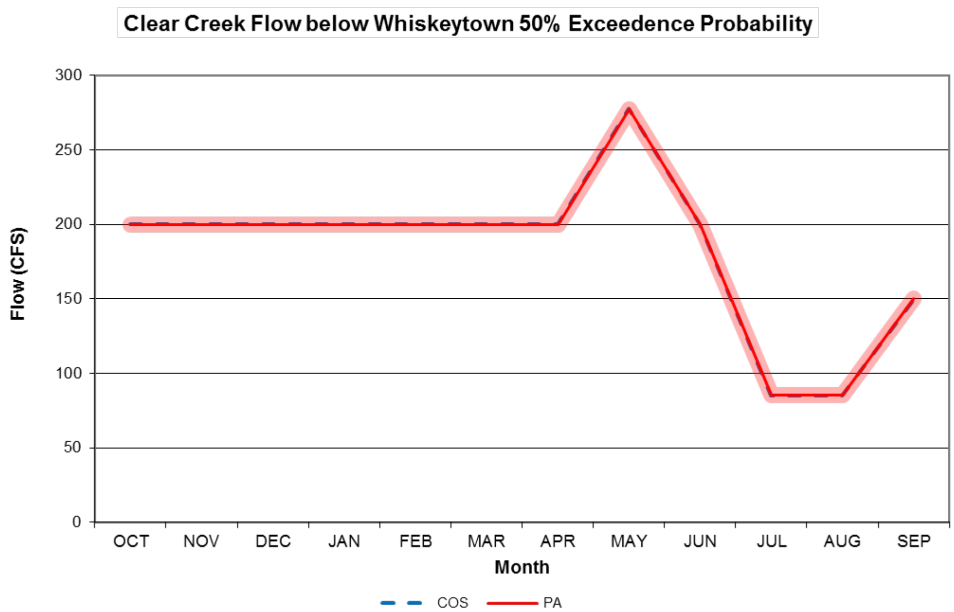
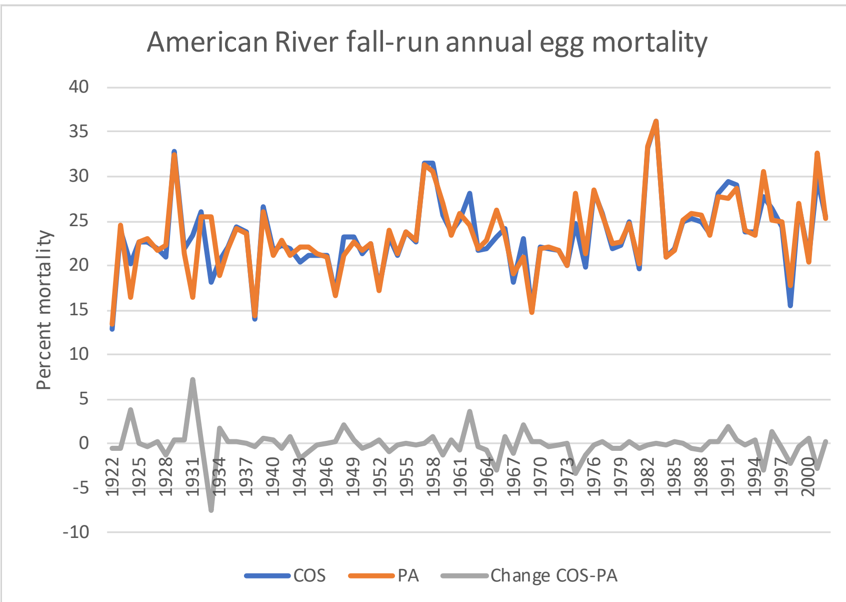



**Figure 9. Clear Creek flows below Whiskeytown Dam at the 50 percent exceedance level under current and proposed operations.**

### 1.1.3 American River

#### 1.1.3.1 Fall-run Chinook Salmon

The Salmort egg mortality model (California Department of Water Resources and U.S. Bureau of Reclamation 2016) was used to estimate the change in survival from the American River from changes in early lifestage survival attributable to water temperature. This model uses the water temperature model outputs along with Chinook salmon spawning distribution and abundance to estimate water temperature effects to pre-spawned eggs, incubating eggs, and alevins. The American River is a temperature-challenged system for salmonids and maintaining a balance in management for the CCV steelhead, fall-run Chinook salmon, and other water management needs results in tradeoffs in temperatures and flows of potentially greater magnitude for the maintenance of habitat conditions hospitable to salmonids. Survival is decreased slightly (median value of 0.012 percent reduction in survival) from COS to PA, with a range of -7.4 percent to 7.1 percent. During most years in both the COS and PA scenarios, the effect of high water temperature on egg survival is significant, ranging from around 15 percent to 35 percent mortality due to exceeding the thermal tolerances for egg and embryo viability (Figure 10).




| *AmerR Fall-Run* | |
|---|---|
| | |
| Mean | -0.05746 |
| Standard Error | 0.181045 |
| Median | -0.012 |
| Mode | #N/A |
| Standard Deviation | 1.629406 |
| Sample Variance | 2.654963 |
| Kurtosis | 9.244997 |
| Skewness | -0.01359 |
| Range | 14.548 |
| Minimum | -7.43 |
| Maximum | 7.118 |
| Sum | -4.654 |
| Count | 81 |
| Largest(2) | 3.891 |
| Smallest(2) | -3.333 |
| Confidence Level(95.0%) | 0.360291 |

**Figure 10. Annual temperature related mortality of Chinook Salmon eggs in the American River from the Salmort model and change in mortality from COS to PA. Positive change values in a year indicate an increase in survival. The chart shows descriptive statistics of change in mortality used in the summary.**

Pre-spawning mortality of fall-run Chinook salmon in the American River is the highest measured in any of the Central Valley rivers (Figure 11). This is partially depicted in the annual egg mortality estimates in Figure 10 but not fully. Water temperatures are in a stressful range for adult holding (mid 1960s) in most years and the fall-run Chinook salmon congregate near the dam or below the hatchery weir starting in summer and peaking in October to November when spawning starts. During wetter years, such as 2011, when flows are higher and water is cooler throughout the fall, the fish are distributed more evenly throughout the river and are more actively moving around and redistributing in advance of spawning in comparison with most years when the majority hold at the weir or dam. Water temperatures are relatively unchanged between scenarios so appreciable changes in the extent of pre-spawning mortality are not expected (Figure 12).

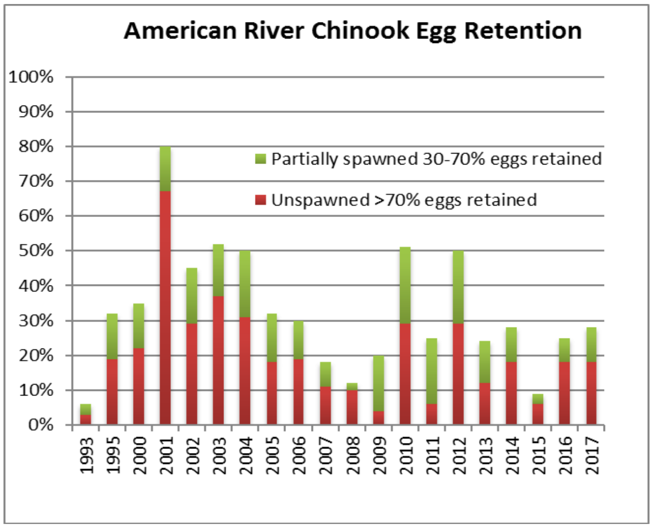



**Figure 11. Egg retention in American River Chinook salmon, 1993-2017. Note, no data for 1996-1999. Data compiled from annual CDFW escapement reports.**

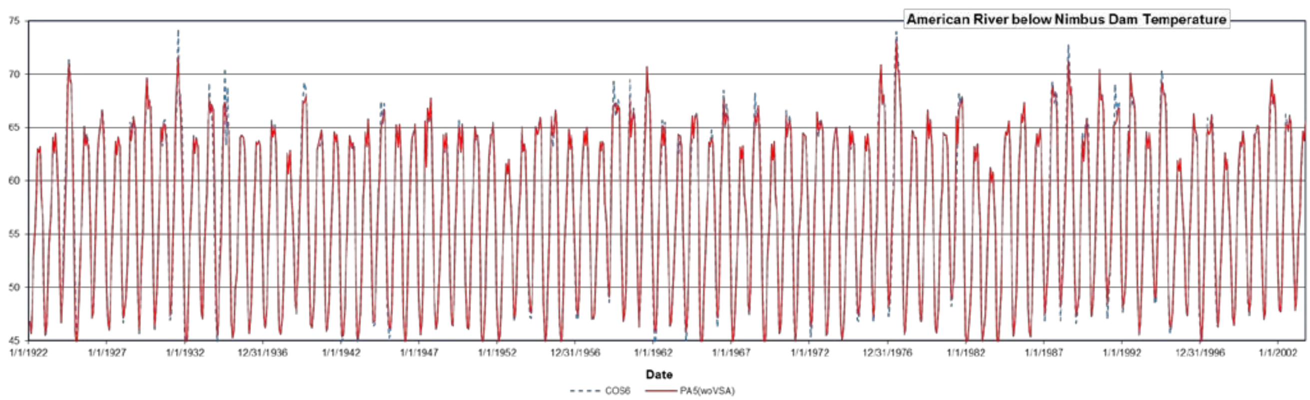



**Figure 12. American River below Nimbus Dam water temperature under current and proposed operations.**

Fish can pass the hatchery weir, likely through gaps under the pickets, such that a high proportion of the run (~50 percent) was isolated upstream of the hatchery weir in 2017 and 2018. Fishing in Nimbus Basin was closed in 2018 resulting in higher numbers of salmon and salmon carcasses remaining unharvested in that area. The 2.6 acres of spawning habitat created by the Nimbus Basin habitat project in 2014 can support about 866 redds based on CVPIA Science Integration Team values. Redd counts have been higher than 1,000 annually with high superimposition and thousands of extra fish with no place to spawn. The escapement survey has not covered Nimbus Basin until 2018 so the area has been under-represented in escapement data, with totals only accounting for salmon that float down to the hatchery weir and get counted there. Reclamation could consider removing the weir earlier in the season (mid-November) when the upstream habitat becomes saturated with redds to allow salmon trapped upstream of the weir to move downstream to un-saturated habitat, increasing the chance of them successfully reproducing. Permitting is in process to install a new fish ladder so that the weir will not be needed in the future. The effect of the fish trapped in Nimbus Basin was not fully quantified but in 2018 was around 10,000 adults, about half the in-river run, with likely 75 percent of those not successfully reproducing.

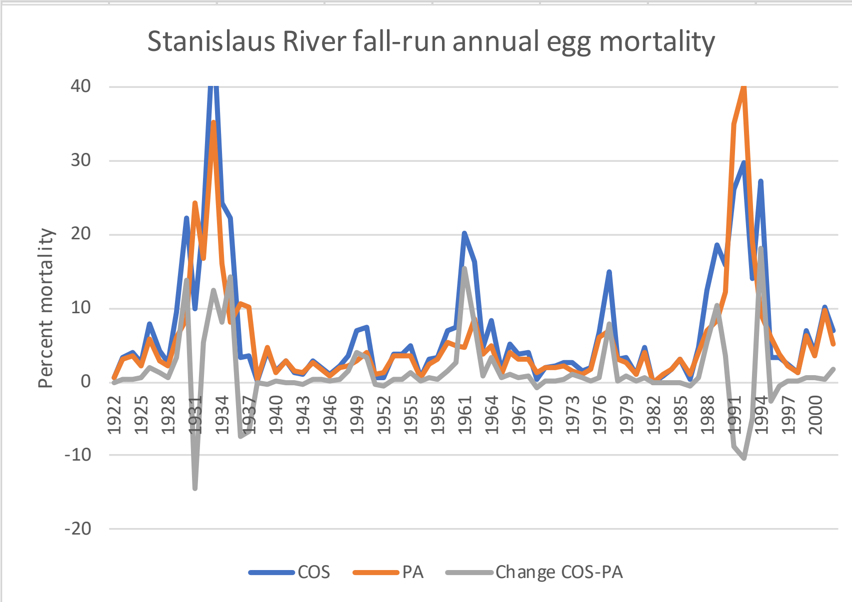
### 1.1.4 Feather River

The project area for the Feather River starts with the lower 10 miles of the Feather River to the confluence with the Sacramento River and extends downstream from there. Upstream effects were not evaluated for the Feather River because they are governed by the FERC license within that project area. Migration for Feather River salmon through the Delta is assessed with the Delta Passage Model described in the Delta section below.

### 1.1.5 Stanislaus River

#### 1.1.5.1 Fall-run Chinook salmon

The Salmort egg mortality model (California Department of Water Resources and U.S. Bureau of Reclamation 2016) was used to estimate water temperature related mortality of early life stages of fall-run Chinook salmon in the Stanislaus. During most years water temperatures are suitable for fall-run Chinook salmon spawning although in years when New Melones storage volume is low there is potentially significant temperature related mortality based on egg mortality model results (Figure 13). It sometimes takes a few years to regain storage and coldwater pool in New Melones so consecutive years of high temperatures may occur with the associated effects on salmonids. Egg mortality is decreased in the PA relative to the COS in a majority of years but in about 10 percent of years mortality is estimated to be higher in PA (Figure 13). Water temperatures during spawning are reduced on average in the PA relative to the COS and New Melones storage is maintained at a higher level in the PA. This benefits egg survival though egg survival is probably not the most limiting factor for fall-run Chinook salmon in the Stanislaus River.




| *StanR Fall-Run* | |
|---|---|
| | |
| Mean | 1.285753 |
| Standard Error | 0.549198 |
| Median | 0.373 |
| Mode | #N/A |
| Standard Deviation | 4.942786 |
| Sample Variance | 24.43113 |
| Kurtosis | 3.733201 |
| Skewness | 0.727284 |
| Range | 32.572 |
| Minimum | -14.44 |
| Maximum | 18.132 |
| Sum | 104.146 |
| Count | 81 |
| Largest(2) | 15.422 |
| Smallest(2) | -10.423 |
| Confidence Level(95.0%) | 1.09294 |

**Figure 13. Annual temperature related mortality of Chinook salmon eggs in the Stanislaus River from the Salmort model and change in mortality from COS to PA. Positive change values in a year indicate an increase in survival. The chart shows descriptive statistics of the change in mortality used in the summary.**

Through-Delta survival of juvenile Chinook salmon emigrating from the San Joaquin basin has been estimated to be less than 5 percent in recent years (Buchanan 2018). This low migratory survival is likely a key factor limiting natural populations in the Stanislaus River and other San Joaquin tributaries. March through June flows in the Stanislaus are slightly lower under the PA scenario so emigration survival could be slightly reduced (Figure 14 and Figure 15). The reduction in survival potential between current and future scenarios has not been quantified. Stanislaus River Chinook salmon production comprises about 1 percent of the Central Valley total.

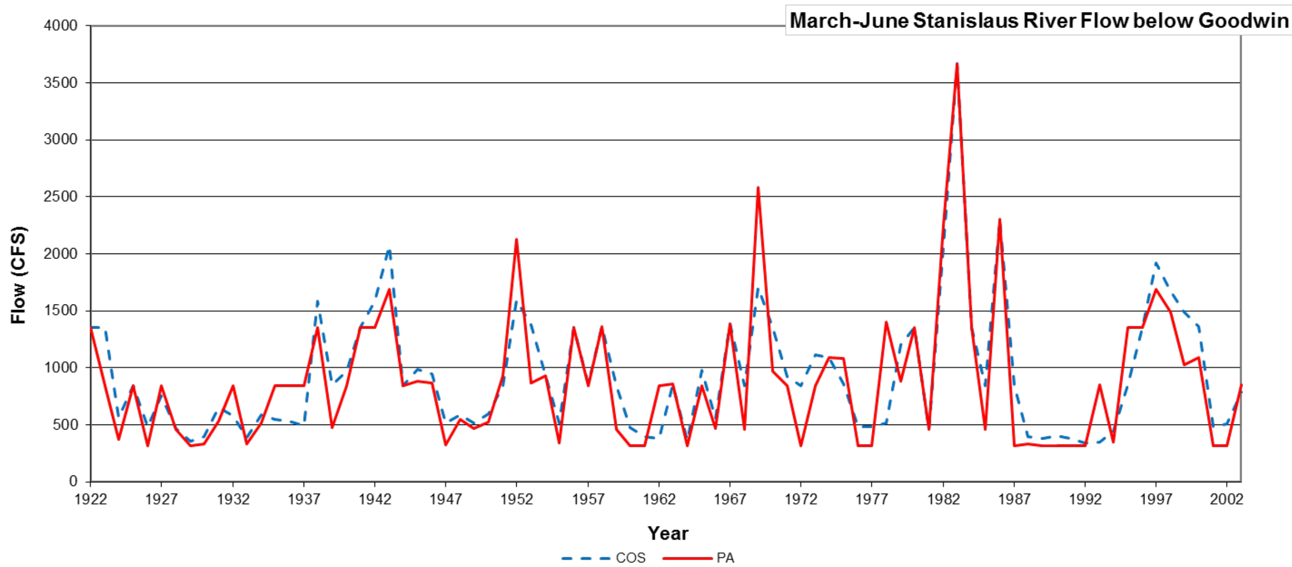



**Figure 14. March through June Stanislaus River flow below Goodwin Dam.**

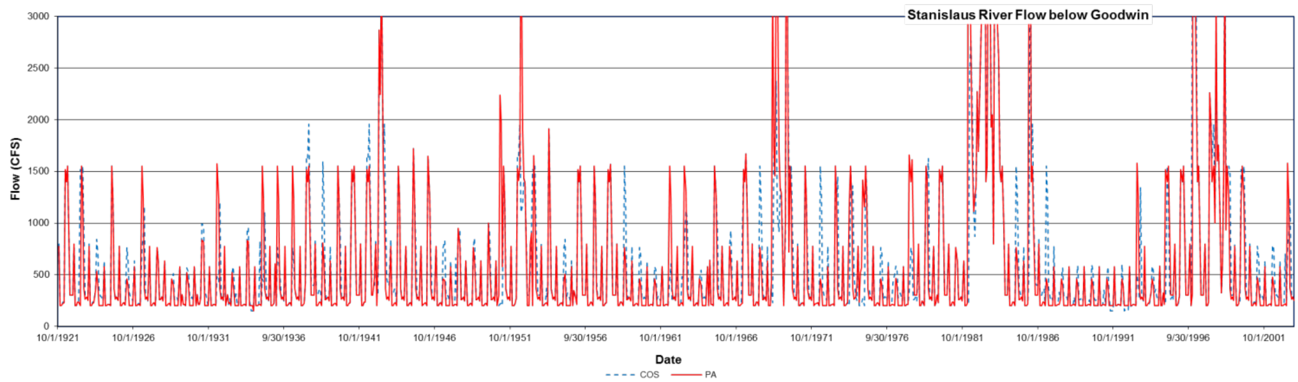



**Figure 15. Stanislaus River flow below Goodwin Dam under current and proposed operations. Flows above 3,000 cfs are not shown.**

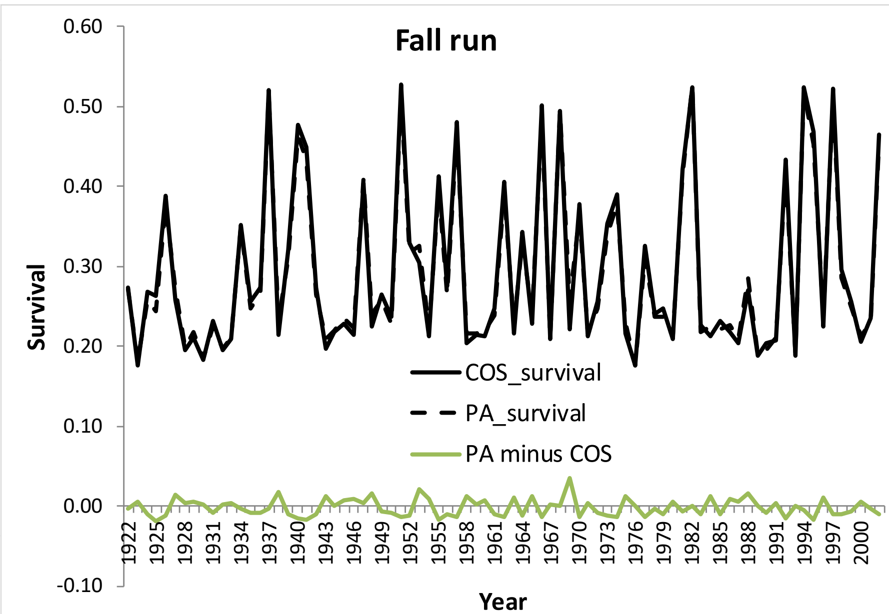
### 1.1.5.2 Spring-run Chinook salmon

Because so few spring-running Chinook salmon are expected on the Stanislaus River, no assessment of PA-related effects was conducted as part of this evaluation of Chinook salmon production for SRKW prey.

## 1.1.6 Delta

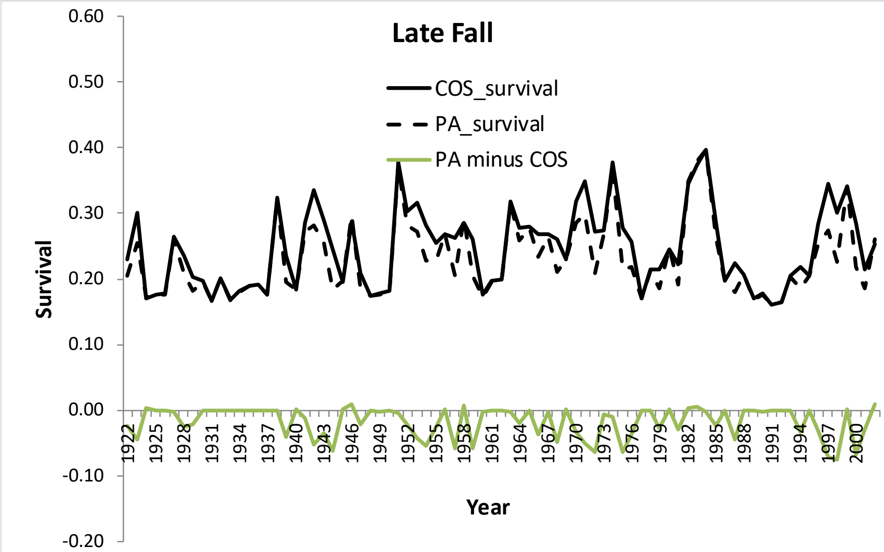
### 1.1.6.1 Sacramento River basin Chinook salmon

The Delta Passage Model (Cavallo et al. 2011) was used to estimate survival of Chinook salmon from the Sacramento River basin emigrating through the Delta. This model uses results from acoustic tagged salmon survival studies along with relationships between flow through delta channels and survival to estimate through-Delta smolt survival. Figure 16, Figure 17, and Figure 18 show Delta Passage Model results for fall-run, late fall-run, and spring-run Chinook salmon from the Sacramento River basin. Results from all three runs show less than a 1 percent median difference between COS and PA scenarios. The results for late fall-run Chinook salmon show more years with reduced survival in the PA than increased survival although the overall median reduction remains less than 1 percent.



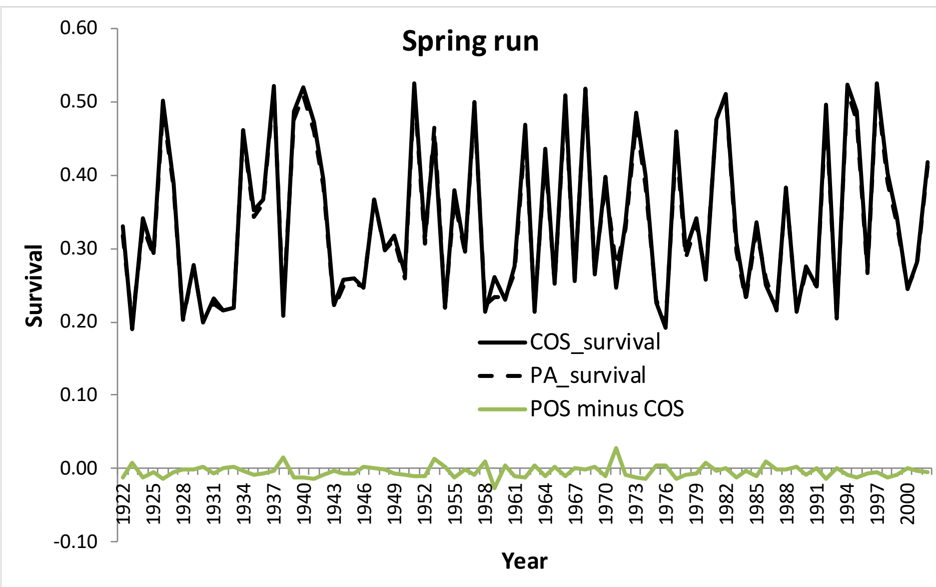

| *PA minus COS - positive numbers are increase in survival* | |
|---|---|
| Mean | -0.00163 |
| Standard Error | 0.001208 |
| Median | -0.00324 |
| Mode | #N/A |
| Standard Deviation | 0.010871 |
| Sample Variance | 0.000118 |
| Kurtosis | 0.269734 |
| Skewness | 0.693353 |
| Range | 0.054757 |
| Minimum | -0.01927 |
| Maximum | 0.035485 |
| Sum | -0.1323 |
| Count | 81 |
| Largest(2) | 0.021709 |
| Smallest(2) | -0.01697 |
| Confidence Level(95.0%) | 0.002404 |

**Figure 16. Delta Passage Model results for fall-run Chinook salmon. The table shows descriptive statistics on the difference in median survival values from COS to PA.**




| *PA minus COS - positive numbers are increase in survival* | |
|---|---|
| | |
| Mean | -0.01726 |
| Standard Error | 0.002556 |
| Median | -0.00228 |
| Mode | #N/A |
| Standard Deviation | 0.023004 |
| Sample Variance | 0.000529 |
| Kurtosis | -0.32981 |
| Skewness | -0.96227 |
| Range | 0.08562 |
| Minimum | -0.07595 |
| Maximum | 0.009665 |
| Sum | -1.39781 |
| Count | 81 |
| Largest(2) | 0.008336 |
| Smallest(2) | -0.07148 |
| Confidence Level(95.0%) | 0.005087 |

**Figure 17. Delta Passage Model results for late fall-run Chinook salmon. The table shows descriptive statistics on the difference in median survival values from COS to PA.**




| *POS minus COS - positive numbers are increase in survival* | |
|---|---|
| | |
| Mean | -0.00409 |
| Standard Error | 0.000904 |
| Median | -0.00507 |
| Mode | #N/A |
| Standard Deviation | 0.008132 |
| Sample Variance | 6.61E-05 |
| Kurtosis | 2.701652 |
| Skewness | 0.881529 |
| Range | 0.055738 |
| Minimum | -0.02716 |
| Maximum | 0.028581 |
| Sum | -0.33111 |
| Count | 81 |
| Largest(2) | 0.015145 |
| Smallest(2) | -0.01398 |
| Confidence Level(95.0%) | 0.001798 |

**Figure 18. Delta Passage Model results for spring-run Chinook salmon. The table shows descriptive statistics on the difference in median survival values from COS to PA.**

### 1.1.6.2 San Joaquin River basin and Mokelumne River Chinook Salmon

No Delta survival changes were incorporated for Chinook salmon from the San Joaquin or Mokelumne rivers. Chinook salmon from the San Joaquin tributaries comprise 2.6 percent and from Mokelumne comprise about 2.8 percent of the Central Valley total.

**Delta Export Pumping and Salvage**

Delta pumping would increase under the original proposed action (Appendix A1) in the primary outmigration season for fall-run Chinook salmon, April and May (Figure 19 and Figure 20), but these effects are decreased in the final proposed action (Appendix A3) due to revised loss thresholds for natural and hatchery winter-run Chinook salmon and natural steelhead. As supplemental information, Reclamation provided a "salvage-density" analysis conducted using historic salmonid loss densities (fish lost per amount of water pumped) at the Delta pumps assuming changes in loss occur in proportion to the change in amount of water pumped between scenarios. Pumping is close to doubled in the peak outmigration season for fall-run so based on the analysis numbers of fish salvage would also double. The salvage-density analysis is scaled to population size only for winter-run Chinook salmon. The effects of increased pumping in April and May on winter-run Chinook salmon and spring-run Chinook salmon are described in detail in Section 2.5.6.7.2.1 ("South Delta Salvage and Entrainment"); similar effects are expected for fall-run Chinook salmon during April and May. The decrease in these effects under the final PA are described in Section 2.5.5.11 ("Supplemental Analysis of June 14, 2019, Final PA") of the Delta Effects section. The projected combined loss at the CVP and SWP in the COS and PA scenarios is summarized in Table **1-2**. Except for late fall-run Chinook salmon in wet years, projected loss is higher under the PA; however, under the revised PA, April and May loss is expected to be similar in the PA compared to the COS.. The Delta Passage Model incorporates effects of Delta export pumping using the relationship between interior Delta survival and export pumping from acoustic tag studies (Figure 21). Salmon not estimated by the model to enter the interior Delta are not influenced by the survival relationship.

Delta exports more strongly affect Chinook salmon outmigrating from the San Joaquin River tributaries than those from the Sacramento River basin. Even under the final PA, the effects of pumping would most strongly affect the approximately 2.6 percent of Chinook salmon entering the Delta from the San Joaquin basin, particularly at the CVP facility. The Delta Passage Model was not adapted for use with San Joaquin River-origin salmon so there is no assessment in the difference in survival between scenarios for San Joaquin River fall-run Chinook salmon.

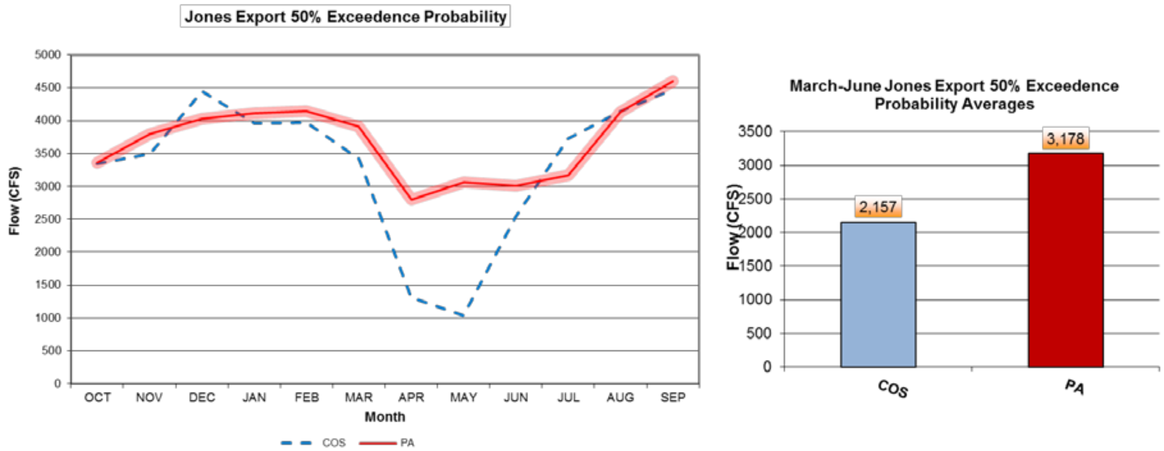



**Figure 19. CVP exports at the Jones Pumping Plant in the COS and PA scenarios at 50 percent exceedance level.**

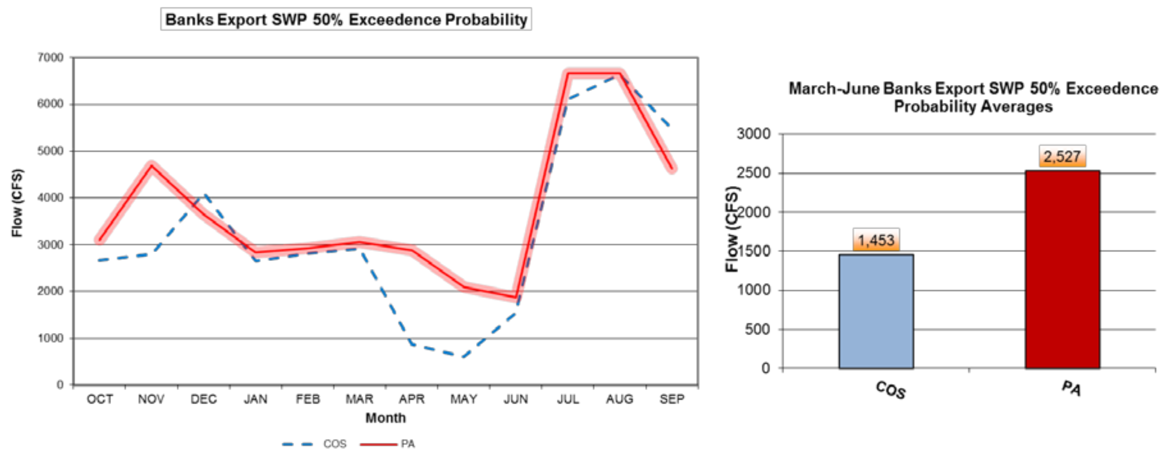



**Figure 20. SWP exports at the Banks Pumping Plant under the COS and PA scenarios at 50 percent exceedance level.**

**Table 1-2 Projected combined loss at the CVP and SWP in the COS and PA scenarios, by Chinook salmon run and water year type, based on February 5, 2019, PA. Positive values in the final two columns represent increases in projected loss in the PA relative to the COS. The decrease in these effects under the final PA are described in Section 2.5.5.11 ("Supplemental Analysis of June 14, 2019, Final PA") of the Delta Effects section.**

| Run | Yeartype (Sacramento "40-30-30" Index under ELT Q5 hydrology) | Predicted loss under COS | Predicted loss under PA | Difference in predicted loss (PA-COS) | % Change |
|---|---|---|---|---|---|
| **Fall-run** | Wet | 86,601 | 130,431 | 43,830 | 51% |
| | Above Normal | 32,188 | 60,387 | 28,198 | 88% |
| | Below Normal | 18,341 | 29,905 | 11,563 | 63% |
| | Dry | 27,353 | 51,530 | 24,177 | 88% |
| | Critical | 6,966 | 11,405 | 4,439 | 64% |
| **Late fall-run** | Wet | 357 | 351 | -6 | -2% |
| | Above Normal | 312 | 336 | 25 | 8% |
| | Below Normal | 33 | 38 | 4 | 13% |
| | Dry | 178 | 188 | 11 | 6% |
| | Critical | 45 | 50 | 4 | 9% |
| **Spring-run** | Wet | 42,532 | 86,606 | 44,074 | 104% |
| | Above Normal | 23,057 | 59,659 | 36,603 | 159% |
| | Below Normal | 5,814 | 11,679 | 5,865 | 101% |
| | Dry | 13,885 | 24,118 | 10,233 | 74% |
| | Critical | 7,628 | 12,474 | 4,845 | 64% |
| **Winter-run** | Wet | 12,417 | 13,788 | 1,371 | 11% |
| | Above Normal | 6,369 | 6,805 | 437 | 7% |
| | Below Normal | 5,830 | 6,812 | 982 | 17% |
| | Dry | 4,106 | 5,070 | 965 | 23% |
| | Critical | 1,230 | 1,702 | 472 | 38% |

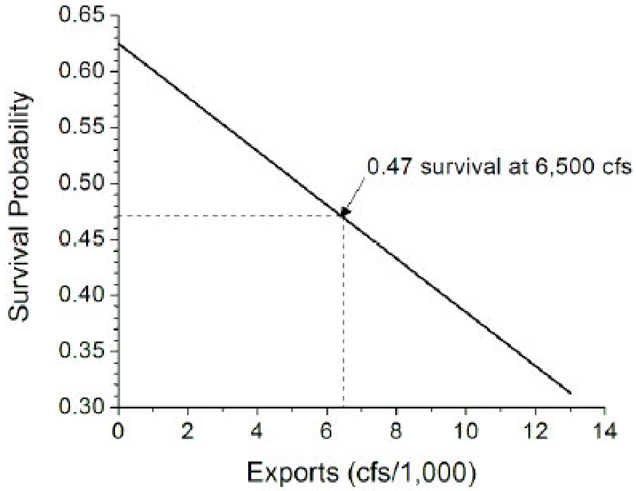



**Figure 21. Linear function used to predict mean interior Delta survival from Delta exports in the Delta Passage Model (Cavallo et al. 2011).**

## Naturally produced Chinook Salmon in San Francisco Bay

Table 3 summarizes the change in survival values for each river and model presented previously and used in the quantitative assessment. The values displayed are the median difference in annual survival, the 2.5 percentile, and 97.5 percentile from COS to PA over the CalSim II modeling period. Positive values indicate an increase in survival and negative values indicate a decrease in survival. The proportion that each river and run comprises of the Central Valley Chinook salmon abundance in the ocean over the 2001 – 2017 period (mean value) as estimated by U.S. Fish and Wildlife Service (2018) is used to scale the survival value in each watershed and run to the total Central Valley abundance.

**Table 1-3. Change in survival from COS to PA scenarios by river and model used. Note: for winter-run Chinook salmon the IOS model is applied for ocean abundance and incorporates freshwater survival factors.**

| River and run | Upstream effects - Egg Mortality Model | | | Upstream effects - Salmod juvenile production | | | Delta effects - Delta Passage Model | | | Lifecycle effects - IOS | | | Proportion of CV Abundance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | median | 97.5 %ile | 2.5 %ile | median | 97.5 %ile | 2.5 %ile | median | 97.5 %ile | 2.5 %ile | median | 97.5 %ile | 2.5 %ile | |
| Sacramento River winter-run | | | | | | | | | | 0.015 | 0.50073 | -0.4495 | 0.0141 |
| Sacramento River spring-run | | | | -0.0108 | 151.8044 | -99.787 | -0.0051 | 0.015145 | -0.014 | | | | 0.0003 |
| Sacramento River fall-run | | | | -0.0034 | 0.0734 | -0.2004 | -0.0032 | 0.021709 | -0.017 | | | | 0.0970 |
| Sacramento River late fall-run | | | | -0.0068 | 0.0807 | -0.0787 | -0.0023 | 0.008336 | -0.0715 | | | | 0.0259 |
| Clear Creek fall and spring-run | | | | | | | -0.0032 | 0.021709 | -0.017 | | | | 0.0228 |
| American River fall-run | -0.0001 | 0.0389 | -0.0333 | | | | -0.0032 | 0.021709 | -0.017 | | | | 0.2233 |
| Stanislaus River fall-run | 0.0037 | 0.1542 | -0.1042 | | | | | | | | | | 0.0099 |
| Feather River fall and spring-run | | | | | | | 0.0032 | 0.016971 | -0.0217 | | | | 0.2397 |
| Other Sac Runs (spring) | | | | | | | -0.0051 | 0.015145 | -0.014 | | | | 0.0218 |
| Other Sac Runs (fall) | | | | | | | -0.0032 | 0.021709 | -0.017 | | | | 0.2915 |
| San Joaquin Basin | not evaluated | | | | | | | | | | | | 0.0264 |
| Mokelumne | not evaluated | | | | | | | | | | | | 0.0284 |

The scaled aggregate change in survival from upstream areas was a slight reduction to 0.995 for PA compared to COS and a 97.5 percentile to 2.5 percentile range from an increase of over 6 percent to a decrease of 6 percent (Table 3)[1].

**Table 1-4. Aggregate proportional change in upstream survival from COS to PA scaled by the proportion of Central Valley production each river comprises.**

| **Upstream** | Values scaled to CV-wide | | |
|---|---|---|---|
| | **median** | **97.5 %ile** | **2.5 %ile** |
| Sacramento River winter-run | lifecycle result for ocean abundance | | |
| Sacramento River spring-run | 0.00000 | 0.04643 | -0.03052 |
| Sacramento River fall-run | -0.00033 | 0.00712 | -0.019436 |
| Sacramento River late fall-run | -0.00018 | 0.00209 | -0.002041 |
| American River fall-run | -0.00002 | 0.00869 | -0.007435 |
| Stanislaus River fall-run | 0.00004 | 0.00153 | -0.001032 |
| Feather River Fall/spring | upstream changes not quantified for these runs | | |
| Other Sac Tribs -spring | | | |
| Other Sac Tribs - fall | | | |
| Upstream survival change | -0.00050 | 0.06585 | -0.06046 |
| Upstream survival compared | 0.99950 | 1.06585 | 0.93954 |

## Hatchery Produced Chinook Salmon

Hatchery produced Chinook salmon releases are included in the analysis by using the average release of hatchery juveniles for 2007 – 2013 (Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018, 2019) as the number of hatchery produced fish released each year for all Central Valley Chinook salmon runs combined (average total of 35,059,237 and range of 30,455,664 to 38,510,728). The proportion of hatchery fish released in-river and in the Bay varies from year to year based on water year conditions and other factors. The general release goals and release locations based on recent trends (Table 4) were used to estimate an average in-river release proportion of 0.59.

[1] Example scaled survival for Sacramento River fall-run: -0.0034 change in survival from SALMOD * 0.097 proportion of CV Chinook salmon production made up of Sac fall-run = -0.00033 change in survival for Central Valley Chinook salmon in aggregate

**Table-1-5. Central Valley Chinook salmon hatchery release goals and proportion released in-river and in Bay areas.**

| Hatchery annual Chinook releases | General goal | Proportion bay | Proportion in-river | Number in-river |
|---|---|---|---|---|
| Coleman fall | 12,000,000 | 0 | 1 | 12,000,000 |
| Coleman late fall | 1,000,000 | 0 | 1 | 1,000,000 |
| LSNFH Winter | 200,000 | 0 | 1 | 200,000 |
| Feather Fall | 6,000,000 | 0.7 | 0.3 | 1,800,000 |
| Feather Spring | 2,000,000 | 0.5 | 0.5 | 1,000,000 |
| Feather enhancement | 2,000,000 | 1 | 0 | 0 |
| Nimbus | 4,000,000 | 0.33 | 0.67 | 2,680,000 |
| Mokelumne | 5,000,000 | 0.7 | 0.3 | 1,500,000 |
| Mokelumne enhancement | 2,000,000 | 1 | 0 | 0 |
| Merced | 300,000 | 0 | 1 | 300,000 |
| Total release | 34,500,000 | | | |
| In-river release | 20,480,000 | | | |
| Proportion released in-river | 0.59 | | | |

In-river mortality was applied to all the in-river released hatchery fish using a static river survival value for survival from release to the delta of 0.5. This value comes from the winter-run juvenile production estimate and is based on 2013-2018 acoustic telemetry survival studies using late fall-run Chinook salmon (National Marine Fisheries Service 2019). As for natural-origin Chinook salmon, the Delta Passage Model was used to estimate Delta survival for the COS and PA scenarios for hatchery Chinook salmon. The in-river released hatchery Chinook salmon surviving through the Delta were added to the Bay releases for a total number of hatchery fish in the Bay (Table 5).

**Table 1-6. Calculation of hatchery Chinook salmon in the Bay under COS and PA scenarios.**

| | | | |
|---|---|---|---|
| Total Hatchery Release | 35,059,237 | | |
| Proportion released in-river | 0.59 | | |
| Survival to Delta | 0.5 | Smolt survival RBDD to the delta based on JPE (2013-2018 AT studies) | |
| Hatchery fish to delta | 10,405,988 | | |
| **DPM results (fall-run)** | **median** | **97.5 percentile** | **2.5 percentile** |
| COS DPM survival | 0.248 | 0.525 | 0.176 |
| PA DPM survival | 0.245 | 0.519 | 0.182 |
| COS hatchery fish to bay | 2,583,758 | 5,462,809 | 1,834,991 |
| PA Hatchery fish to bay | 2,544,841 | 5,400,430 | 1,888,708 |
| Change in hatchery fish to bay | -38,917 | -62,378 | 53,718 |
| Hatchery Bay release | 14,247,261 | 14,247,261 | 14,247,261 |
| Hatchery total in Bay COS | 16,831,019 | 19,710,070 | 16,082,252 |
| Hatchery total in Bay PA | 16,792,102 | 19,647,691 | 16,135,970 |

## Hatchery and Natural Proportions and Ocean Abundance

The hatchery and natural proportions of Central Valley Chinook salmon were estimated based on data from from the 2012-2014 Central Valley coded wire tag recovery reports (Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018, 2019). Values included are the numbers and hatchery proportions from fish spawning in natural areas, fish entering the hatcheries, commercial landings in California, California ocean sport harvest, and Central Valley inland sport harvest. The hatchery proportion over the three years averaged 0.70 (range 0.65 – 0.75). Analysis of Chinook salmon otoliths in 1999 and 2002 found that the contribution of hatchery-produced fish made up approximately 90 percent of the ocean fishery off the central California coast from Bodega Bay to Monterey Bay (Barnett-Johnson et al. 2007) but the more recent Central Valley CWT data with the 0.70 overall Central Valley hatchery proportion was used for this analysis.

The ocean abundance, hatchery releases, and hatchery proportions are values regularly estimated with greater confidence than the abundance of naturally produced Chinook salmon entering the ocean from the Central Valley. Therefore, the median ocean abundance for the period 2001 – 2018 of 454,052 (Table 1-8) along with the hatchery proportion of 0.7 and median number of hatchery produced fish in the Bay in the current water operations scenario (16,831,019 from Table 5) was used to arrive at a smolt in the bay (~ Carquinez Strait) to adult survival rate of 0.0189[2]. Mortality sources other than that quantified in the fisheries (e.g. predation on adults by marine mammals) are not included in this estimate. Back calculating using the median ocean abundance, smolt to adult survival, and 0.7 hatchery proportion gives a baseline value for

[2] (454,052 adult Chinook in the ocean *0.7 hatchery proportion)/16,831,019 hatchery fish in the bay = 0.0188 bay smolt to ocean adult survival (not including enumerated jacks)

estimated number of naturally produced juvenile Chinook salmon in the Bay of 7,213,294 juveniles (Table 1-7).

### Delta Survival and Juvenile Abundance in the Bay

The Delta Passage Model results from Table 2 are aggregated for all rivers and runs from the Sacramento Basin passing through the delta. Results are scaled by the proportion of Central Valley production from each area to allow summing results across rivers for an aggregate delta survival/abundance change (Table 6). The median change in delta survival from COS to PA was -0.0014 with 2.5 percentile and 97.5 percentile values of -0.0181 and 0.0184, so the change in survival is less than a 2 percent change in the positive or negative directions.

Aggregate freshwater survival change from COS to PA is based on the upstream change multiplied by Delta change for a median PA value of 0.999 of the COS value with 2.5 percentile and 97.5 percentile values of 0.982 and 1.018 (Table 6). The aggregate change in freshwater survival in each scenario was applied to the median baseline naturally produced Chinook salmon in the Bay estimate to arrive at an estimated number of naturally produced juvenile Chinook salmon in the Bay. Because winter-run Chinook salmon effects were assessed using the IOS model results, which have no Delta-specific survival change, no estimate of survival change from that population is included in the overall Delta survival change, and naturally-produced winter-run Chinook salmon are not included in the estimates of natural-origin fish in the Bay in Table 7. Winter-run Chinook salmon effects and natural-origin abundance are accounted for in the calculations summarized in Table 8.

**Table 1-7. Delta survival change incorporating Delta Passage Model survival through the delta to all naturally produced Chinook salmon migrating from the Sacramento basin and calculation of naturally produced Chinook salmon abundance in the Bay.**

| River and run | median | 97.5 %ile | 2.5 %ile |
|---|---|---|---|
| Sacramento River spring-run | -0.000002 | 0.000005 | -0.000004 |
| Sacramento River fall-run | -0.000314 | 0.002105 | -0.001646 |
| Sacramento River late fall-run | -0.000059 | 0.000216 | -0.001854 |
| Sacramento River winter-run | IOS lifecycle model to ocean | | |
| Clear Creek fall and spring-run | -0.000074 | 0.000494 | -0.000386 |
| American River fall-run | -0.000724 | 0.004847 | -0.003789 |
| Feather River Fall/spring | 0.000777 | 0.004068 | -0.005203 |
| Other Sac Tribs -spring | -0.000110 | 0.000330 | -0.000304 |
| Other Sac Tribs - fall | -0.000945 | 0.006328 | -0.004947 |
| Delta Survival change | -0.001451 | 0.018393 | -0.018135 |
| Delta Survival compared to COS | 0.998549 | 1.018393 | 0.9818653 |
| Natural fish in Bay baseline (COS) | 7,213,294 | 7,345,971 | 7,212,754 |
| **Freshwater change (upstream X Delta)** | 0.99805 | 1.08546 | 0.92250 |
| Natural fish in Bay in PA | 7,199,260 | 7,829,734 | 6,654,245 |

### Ocean Abundance and Biomass of Adult (Age 3+) Chinook Salmon

The Sacramento River Index was used as the annual production of fall-run Chinook salmon from the Central Valley. This index is the sum of the annual (September 1 to August 31) Sacramento River fall-run Chinook salmon ocean harvest South of Cape Falcon (~Columbia River mouth), fall-run Chinook salmon impacts from non -retention (released fish), recreational harvest of Sacramento River fall-run Chinook salmon in the Sacramento River Basin, and the Sacramento River fall-run Chinook salmon spawner escapement (Pacific Fishery Management Council 2019a). Abundance of late fall-run, San Joaquin fall-run Chinook salmon, Sacramento River winter-run Chinook salmon, and Central Valley spring-run Chinook salmon was calculated from annual escapement estimates as presented in (Pacific Fishery Management Council 2019b) plus a calculated ocean harvest. Each year's ocean harvest rate for late fall-run and spring-run Chinook salmon was assumed to be the same as the year's rate for fall-run Chinook salmon. Winter-run Chinook salmon abundance assumed an annual harvest rate of 8.5 percent based on harvest management goals. Jacks, as enumerated in (Pacific Fishery Management Council 2019b), were excluded from the ocean abundance estimate for all runs because they were assumed to be too small to contribute significantly to SRKW prey.

The average size of adult Chinook salmon in the ocean varies from year to year and is likely a function of the prey availability and current age distribution. The seasonal average dressed weight at the time of harvest in the commercial troll fishery ranged from 10.8 to 15.1 pounds from 2001 through 2018 (Pacific Fishery Management Council 2019b). The dressed weight (assumed to be gutted, head off) was converted to live weight using a 1.33 conversion factor (National Marine Fisheries Service 1980) resulting in live weight range of 14.4 to 20.1 pounds. Abundance and biomass have varied substantially from year to year with cohort replacement rates for all runs combined ranging from 0.15 to 4 (Figure 21 and Table 1-8).

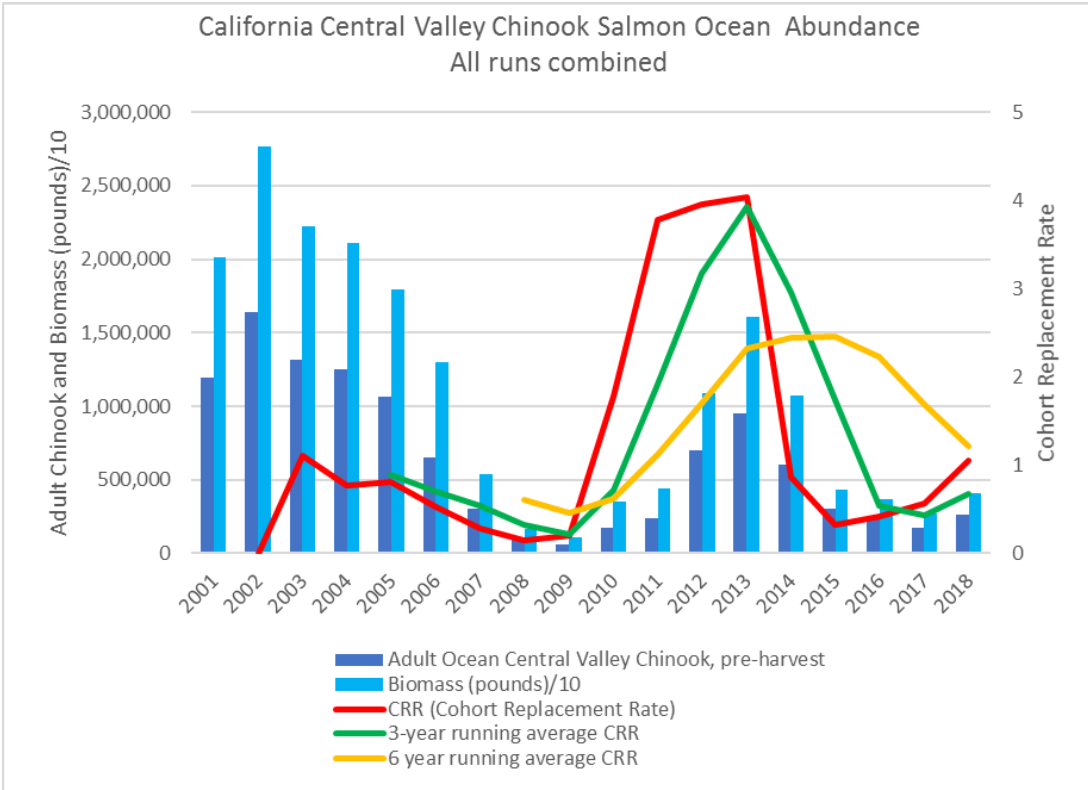



**Figure 22. Ocean abundance, biomass, and cohort replacement rates for Central Valley Chinook salmon, all runs combined. Abundance is pre-harvest in the ocean fisheries and jacks are excluded. Source: abundance calculated from data in Pacific Fishery Management Council (2019b).**

**Table 1-8. Annual Central Valley Chinook salmon ocean abundance, all rivers and runs combined pre-harvest and estimated biomass of Chinook salmon from the Central Valley. Jacks are excluded. Ocean abundance is calculated from data in (Pacific Fishery Management Council 2019b).**

| Year | Fall | Late fall | Spring | winter | Adult Ocean Central Valley Chinook, pre-harvest | CRR (Cohort Replacement Rate | | | Dressed weight statewide season | live weight* | Total biomass (pounds) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 1,114,386 | 29,684 | 38,385 | 8,076 | 1,190,531 | CRR | | | 12.7 | 16.9 | 20,109,257 |
| 2002 | 1,533,575 | 58,931 | 36,423 | 7,646 | 1,636,574 | | 6-year running average | | 12.7 | 16.9 | 27,643,378 |
| 2003 | 1,247,730 | 12,752 | 47,368 | 8,327 | 1,316,177 | 1.11 | | 3-year runn | 12.7 | 16.9 | 22,231,549 |
| 2004 | 1,191,270 | 21,802 | 29,661 | 6,278 | 1,249,010 | 0.76 | | | 12.7 | 16.9 | 21,097,033 |
| 2005 | 989,246 | 22,335 | 36,810 | 15,932 | 1,064,323 | 0.81 | | 0.89 | 12.7 | 16.9 | 17,977,482 |
| 2006 | 590,601 | 22,358 | 19,336 | 18,348 | 650,643 | 0.52 | | 0.70 | 15 | 20.0 | 12,980,320 |
| 2007 | 261,982 | 19,724 | 19,546 | 2,606 | 303,858 | 0.29 | | 0.54 | 13.4 | 17.8 | 5,415,356 |
| 2008 | 71,895 | 10,543 | 13,779 | 2,846 | 99,063 | 0.15 | 0.61 | 0.32 | 12.8 | 17.0 | 1,686,441 |
| 2009 | 43,355 | 9,610 | 4,428 | 4,864 | 62,257 | 0.20 | 0.46 | 0.21 | 12.8 | 17.0 | 1,059,870 |
| 2010 | 158,763 | 10,406 | 5,389 | 1,686 | 176,244 | 1.78 | 0.63 | 0.71 | 15.1 | 20.1 | 3,539,517 |
| 2011 | 214,150 | 10,123 | 10,477 | 691 | 235,441 | 3.78 | 1.12 | 1.92 | 14.2 | 18.9 | 4,446,535 |
| 2012 | 652,661 | 7,987 | 34,416 | 2,742 | 697,806 | 3.96 | 1.69 | 3.17 | 11.7 | 15.6 | 10,858,554 |
| 2013 | 896,306 | 12,798 | 34,814 | 6,100 | 950,018 | 4.04 | 2.32 | 3.93 | 12.7 | 16.9 | 16,046,756 |
| 2014 | 566,685 | 18,985 | 15,659 | 2,916 | 604,245 | 0.87 | 2.44 | 2.95 | 13.4 | 17.8 | 10,768,862 |
| 2015 | 277,219 | 14,370 | 6,694 | 3,669 | 301,953 | 0.32 | 2.46 | 1.74 | 10.8 | 14.4 | 4,337,258 |
| 2016 | 228,229 | 7,209 | 12,563 | 1,003 | 249,003 | 0.41 | 2.23 | 0.53 | 11.2 | 14.9 | 3,709,147 |
| 2017 | 161,906 | 7,503 | 2,305 | 532 | 172,246 | 0.57 | 1.69 | 0.43 | 11.8 | 15.7 | 2,703,224 |
| 2018 | 247,450 | 3,109 | 7,650 | 2,044 | 260,253 | 1.05 | 1.21 | 0.68 | 11.8 | 15.7 | 4,084,408 |
| **Average** | **580,412** | **16,679** | **20,872** | **5,350** | **623,314** | | | | **12.79** | **17.01** | **10,594,164** |
| **Median** | **421,952** | **12,775** | **17,497** | **3,293** | **454,052** | | | | **12.70** | **16.89** | **8,092,109** |
| | *2001 - 2005 was an average, 2008 and 2009 when no fishery occurred used 2001-2018 average | | | | | | | | | | |
| | Assumes 55% harvest for SJ fall, late fall, and CV spring-run and 8.5% for winter-run | | | | | | | | | | |

## Change in Abundance of Central Valley Chinook Salmon Available as Prey for SRKW

The estimated natural and hatchery juvenile Chinook salmon abundance in the Bay from Tables 5 and 6 were combined for a total juvenile Chinook salmon in the Bay estimate (Table 8). A static Bay smolt to adult survival rate of 0.0189 was applied to all scenarios to arrive at an estimate of age 3+ adults present in the ocean and available to SRKW. Winter-run Chinook salmon are not included in this preliminary estimate because the IOS model was able to provide an adult ocean abundance for winter-run Chinook salmon. The median winter-run Chinook salmon ocean abundance for 2001-2018 (Table 7) was used as the baseline in the COS scenario and proportional changes over the IOS modeling period were applied to that value to arrive at the winter-run Chinook salmon abundance in the ocean. The winter-run Chinook salmon abundance was then added to the abundance of the other runs to arrive at the abundance for all Chinook salmon runs ranging from 440,347 to 520,270 in the COS and from 430,615 to 532,907 in the PA using the 2.5 percentile and 97.5 percentile bounds. The median percent change in abundance is -0.21 percent with a 2.5 percentile and 97.5 percentile of -2.21 percent and 2.43 percent. Based on a median adult weight of 16.89 pounds per Chinook salmon, the median change in biomass of Chinook salmon was -16,067 (a reduction in the PA compared to the COS) with a 2.5 percentile and 97.5 percentile of -164,386 pounds and 213,435 pounds.

The year to year Chinook salmon abundance and biomass fluctuations shown in Figure 21 and Table 7 are significantly greater than the within year potential differences estimated to be attributable to changes in water operations. The hatchery proportion of 0.7, potentially a conservatively low estimate, and the higher contribution of hatchery Bay releases in comparison with instream releases and naturally produced Chinook salmon suggests that naturally-produced Chinook salmon from the Central Valley, in aggregate, are in a precarious state. Hatchery-produced Chinook salmon likely supply the bulk of the Chinook salmon available to SRKW. Given the hatchery release scenarios (i.e. Bay releases and high fish numbers) that seem to be needed to support desired harvests of Chinook salmon in the fisheries, unquantified behavioral and genetic effects to naturally produced Chinook salmon (e.g. age at return, stray rates, hatchery/wild fish spawning together) (Davison and Satterthwaite 2017)may continue to exacerbate the precarious state of naturally produced Chinook salmon with potential consequent effects on distribution and abundance of SRKW prey in the ocean. The difference in quality of the Chinook salmon, nutrition wise, by the time they reach a size usable by SRKW is likely negligible between hatchery and naturally-produced fish.

**Table 1-9. Abundance of Central Valley Chinook salmon available as prey for SRKW under the COS and PA scenarios and change in abundance between scenarios.**

| | median | 97.5 %ile | 2.5 %ile |
|---|---|---|---|
| Natural Chinook smolts in Bay baseline (COS) | 7,213,294 | 7,345,971 | 7,212,754 |
| Natural Chinook smolts in Bay in PA | 7,199,260 | 7,829,734 | 6,654,245 |
| Hatchery juvenile Chinook total in Bay COS | 16,831,019 | 19,710,070 | 16,082,252 |
| Hatchery juvenile Chinook total in Bay PA | 16,792,102 | 19,647,691 | 16,135,970 |
| Total juvenile Chinook in Bay (COS) | 24,044,313 | 27,056,041 | 23,295,006 |
| Total juvenile Chinook in Bay (PA) | 23,991,362 | 27,477,426 | 22,790,215 |
| Bay to ocean adult survival | 0.0189 | 0.0189 | 0.0189 |
| Ocean Adult Chinook Abundance (COS), not including winter-run | 454,052 | 510,925 | 439,902 |
| Ocean Adult Chinook Abundance (PA), not including winter-run | 453,052 | 518,882 | 430,369 |
| **Adjustment for winter-run from IOS model** | | | |
| Winter-run Chinook COS (IOS model) * | 3,293 | 9,345 | 446 |
| Winter-run Chinook COS to PA (proportional IOS model changes) | 0.015 | 0.501 | -0.450 |
| Winter-run Chinook PA (IOS model changes) | 3,342 | 14,024 | 245 |
| **Ocean Adult Chinook Abundance (COS)** | **457,345** | **520,270** | **440,347** |
| **Ocean Adult Chinook Abundance (PA)** | **456,393** | **532,907** | **430,615** |
| | | | |
| **Change in median number of Adult Chinook in the Ocean COS to PA** | **-951** | **12,637** | **-9,733** |
| **Percent abundance change in adult Chinook in the Ocean from COS to PA** | **-0.21%** | **2.43%** | **-2.21%** |
| **Change in Chinook Biomass (pounds) COS to PA**** | **-16,067** | **213,435** | **-164,386** |
| * The median winter-run Chinook ocean abundance for 2001-2018 was used as the baseline in COS and proportional changes over the IOS modeling period are applied to that value | | | |
| ** median adult weight of 16.89 pounds | | | |

**Habitat Restoration**

Reclamation proposed in the PA to conduct rearing habitat restoration projects in the Sacramento River, American River, and Stanislaus River through 2030. For the purposed of this analysis, it is assumed that projects would occur annually with at least one habitat improvement project completed on each of these rivers each year. Cumulative rearing habitat creation is proposed as 40-60 acres on the Sacramento River, 40 acres on the American River (based on 4.0 acres/year from among the identified sites), and 50 acres on the Stanislaus River. The CVPIA Science Integration Team (SIT) model estimates that rearing habitat is the most limiting factor on these three rivers and the SIT model estimates the potential Chinook salmon production per unit of rearing habitat. The territory estimates consistent with the SIT salmon lifecycle model inputs show that one acre of rearing habitat will support juveniles that will result in about 56 adult Chinook salmon returning to the river. Assuming a 55% harvest rate in the ocean, that is equivalent to about 102 adult Chinook salmon in the ocean. Table 10 shows the projected annual increase, attributed to rearing habitat improvements, in Chinook salmon available to SRKW. By 2030 an estimated 15,273 additional Chinook salmon could be available, which would increase by 3.3% percent the total ocean abundance of 456,693 Chinook salmon estimated under the PA in Table 8. This assumes that habitats are otherwise at carrying capacity and that any new habitat translates directly into more fish. Water operational factors are not figured into these estimates and baseline population values for these estimates are likely different than for the water operations models so these estimates are not aggregated with the prey estimates above. Regardless, the increase in habitat should help to offset impacts to populations from water operational factors and improve conditions for naturally produced Chinook salmon in California’s Central Valley.

**Table 1-10. Projected increase in Chinook salmon available to SRKW from habitat restoration in the Sacramento, American, and Stanislaus rivers, based on assumptions in SIT model.**

| River | acres new habitat by 2030 | annual new rearing habitat acres | Annual increase in escapement |
|---|---|---|---|
| Sacramento River | 60 | 6 | 336 |
| American River | 40 | 4 | 224 |
| Stanislaus River | 50 | 5 | 280 |
| Total | 150 | 15 | 840 |

| Year | new habitat acres | cumulative increase in escapement | cumulative increase in ocean abundance |
|---|---|---|---|
| 2021 | 15 | 840 | 1,527 |
| 2022 | 15 | 1,680 | 3,055 |
| 2023 | 15 | 2,520 | 4,582 |
| 2024 | 15 | 3,360 | 6,109 |
| 2025 | 15 | 4,200 | 7,636 |
| 2026 | 15 | 5,040 | 9,164 |
| 2027 | 15 | 5,880 | 10,691 |
| 2028 | 15 | 6,720 | 12,218 |
| 2029 | 15 | 7,560 | 13,745 |
| 2030 | 15 | 8,400 | 15,273 |

## REFERENCES

Barnett-Johnson, R., C. B. Grimes, C. F. Royer, and C. J. Donohoe. 2007. Identifying the Contribution of Wild and Hatchery Chinook Salmon (Oncorhynchus tshawytscha) to the Ocean Fishery Using Otolith Microstructure as Natural Tags. Canadian Journal of Fisheries and Aquatic Sciences 64(12):1683-1692.

Bartholow, J. M. 2003. Modeling Chinook Salmon with Salmod on the Sacramento River, California U.S. Geological Survey, pp. 24.

Buchanan, R. 2018. 2014 South Delta Chinook Salmon Survival Study. U.S. Fish and Wildlife Service, pp. 228.

California Department of Water Resources and U.S. Bureau of Reclamation. 2016. California WaterFix Biological Assessment, Appendix 5D Methods Attachment 5.D.1 Reclamation Salmon Mortality Model Methods. pp. 8.

Cavallo, B., H. L. Bergman, and J. Melgo. 2011. The Delta Passage Model. Cramer Fish Sciences, pp. 21.

Davison, R. J. and W. H. Satterthwaite. 2017. Life History Effects on Hatchery Contributions to Ocean Harvest and Natural-Area Spawning. Canadian Journal of Fisheries and Aquatic Sciences 74(10):1575-1587.

National Marine Fisheries Service. 1980. Conversion Factors 1980's – Gulf States Marine Fisheries Commission. Conversion Factor Documentation and Update. National Marine Fisheries Service, pp. 56.

National Marine Fisheries Service. 2019. Winter-Run Juvenile Production Estimate for Brood Year 2018, Letter to U.S. Bureau of Reclamation, February 13, 2019. National Marine Fisheries Service, pp. 20.

Pacific Fishery Management Council. 2019a. Preseason Report I. Stock Abundance Analysis and Environmental Assessment Part 1 for 2019 Ocean Salmon Fishery Regulations. Pacific Fishery Management Council, pp. 141.

Pacific Fishery Management Council. 2019b. Review of 2018 Ocean Salmon Fisheries Stock Assessment and Fishery Evaluation Document for the Pacific Coast Salmon Fishery Management Plan.

Palmer-Zwahlen, M., V. Gusman, and B. Kormos. 2018. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2013 October 2018. Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife, pp. 73.

Palmer-Zwahlen, M., V. Gusman, and B. Kormos. 2019. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2014. Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife, pp. 74.

Palmer-Zwahlen, M. and B. Kormos. 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. California Department of Fish and Wildlife, pp. 66.

U.S. Fish and Wildlife Service. 2018. Chinookprod - Chinook Salmon Production Summaries Based on CDFW Grandtab.