Appendix I

Delta Passage Model (DPM) Description

Interactive Object-Oriented Simulation (IOS) Description

SALMOD Model Description

DPM, IOS, and SALMOD Model descriptions extracted from CWF 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.

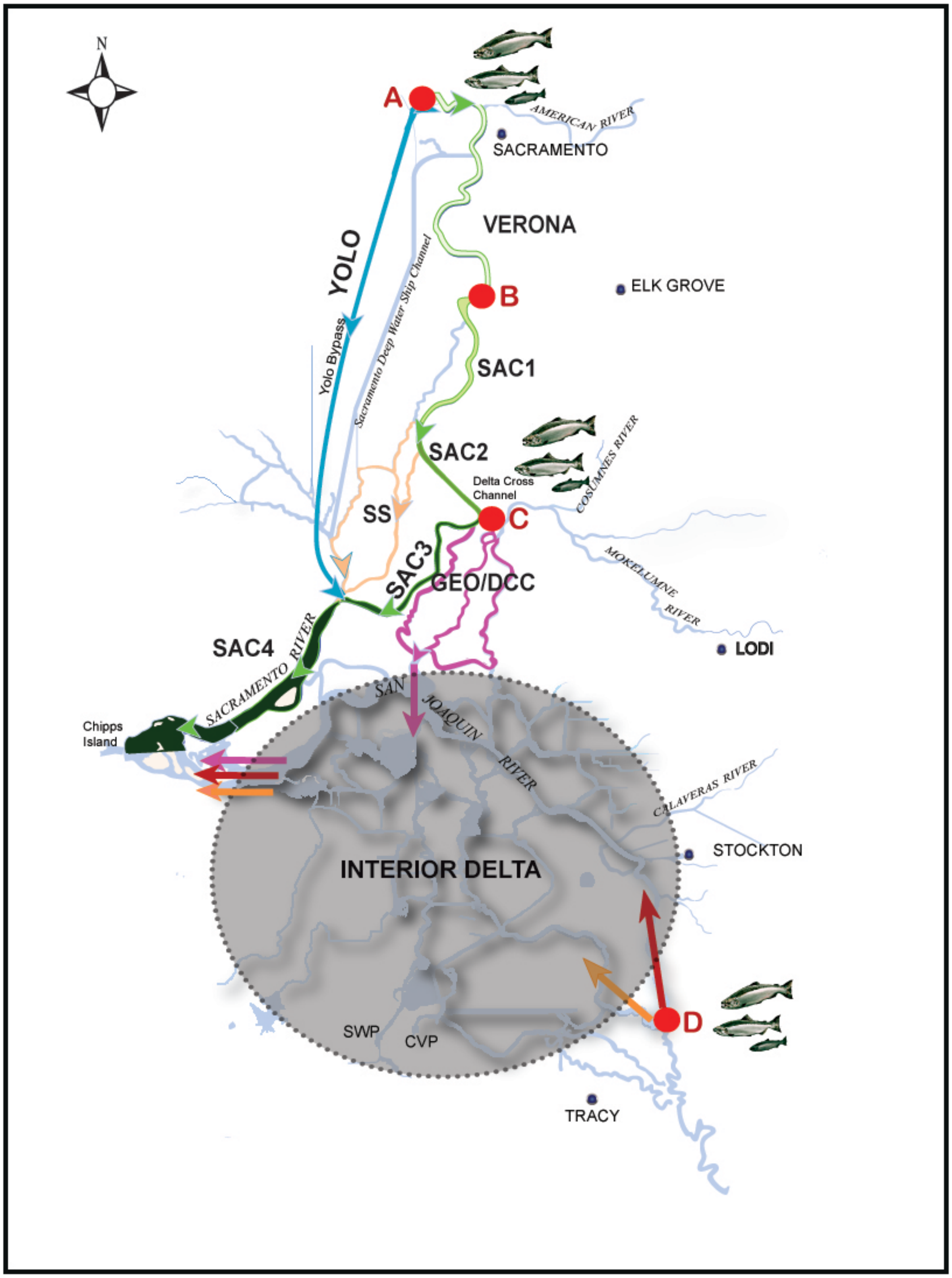
Table 5.D-35. Description of Modeled Reaches and Junctions in the Delta Passage Model

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

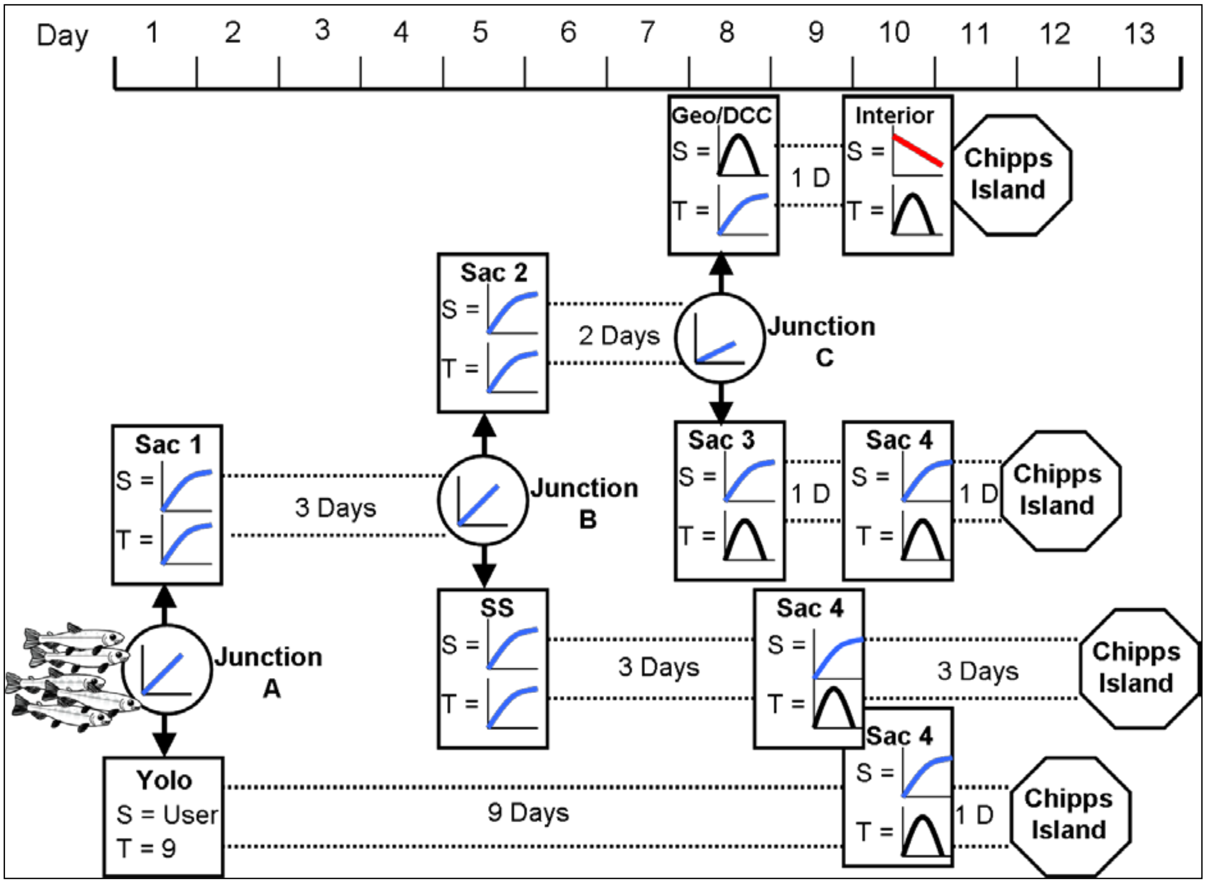
where flows into Sac1 are represented by DSM2 outputs from RSAC155 (Freeport) and flows at bottom of Sac1 are represented by DSM2 outputs from 418_mid (Sacramento River upstream of Sutter/Steamboat Sloughs and downstream of the north Delta intakes).

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 95th percentile of the range of salmon fork lengths visually identified as smolts by the USFWS in Sacramento trawls was used to determine the lower length cutoff for smolts. A lower fork length cutoff of 70 mm for smolts was applied, and all catch data of fish smaller than 70 mm were eliminated. To isolate wild production, all fish identified as having an adipose-fin clip (hatchery production) were eliminated, recognizing that most of the fall-run hatchery fish released upstream of Sacramento are not marked. Daily catch data for each brood year were divided by total annual catch to determine the daily proportion of smolts entering the Delta for each brood year. Sampling was not conducted daily at most stations and catch was not expanded for fish caught but not measured. Finally, the daily proportions for all brood years were plotted for each race, and a normal distribution was visually approximated to obtain the daily proportion of smolts entering the DPM for each run (Figure 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.

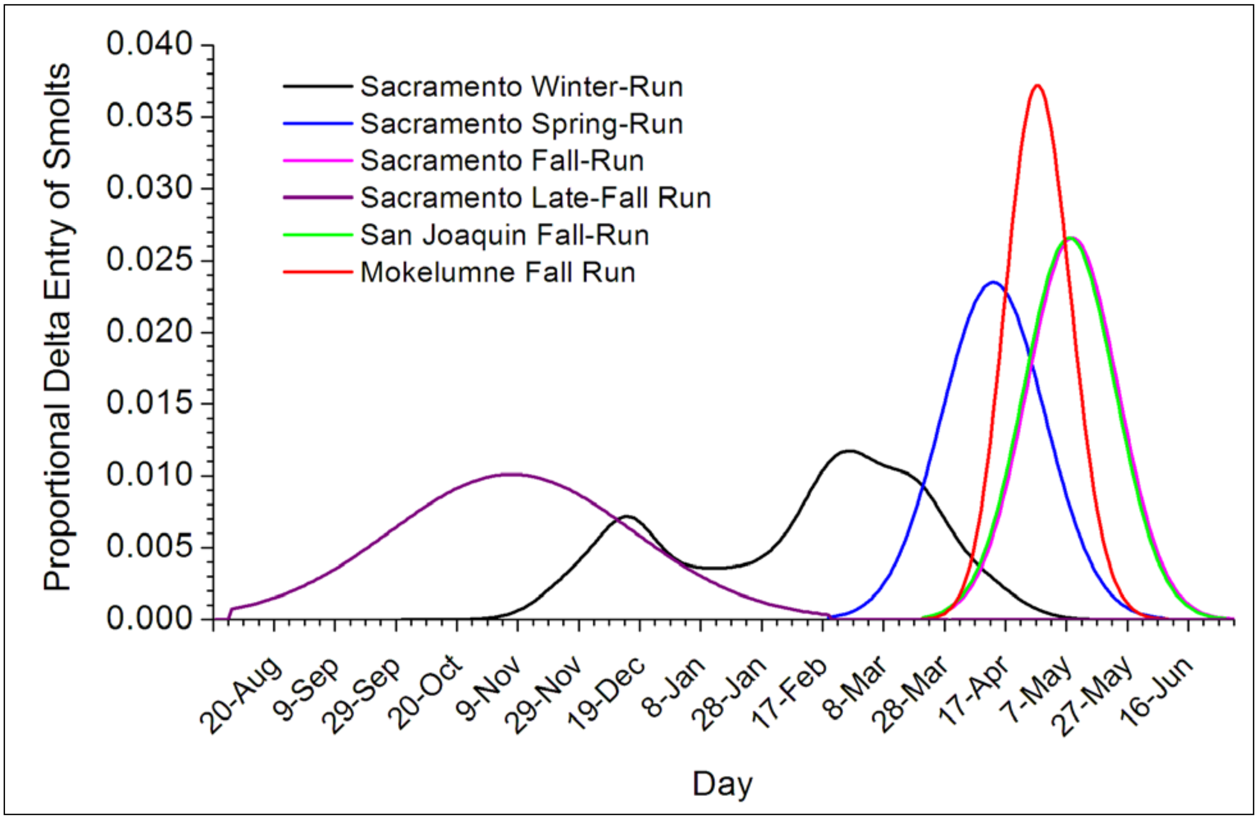


Figure 5.D-42. Delta Entry Distributions for Chinook Salmon Smolts Applied in the Delta Passage Model for Sacramento River Winter-Run, Sacramento River Spring-Run, Sacramento River Fall-Run, Sacramento River Late Fall–Run, San Joaquin River Fall-Run, and Mokelumne River Fall-Run Chinook Salmon

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 β_0 is the slope parameter and β_1 is the intercept.

Individual smolt reach-specific travel times were calculated from detection histories of releases of acoustically tagged smolts conducted in December and January for three consecutive winters (2006/2007, 2007/2008, and 2008/2009) (Perry 2010). Reach-specific migration speed (km/day) for each smolt was calculated by dividing reach length by travel days (Table 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)

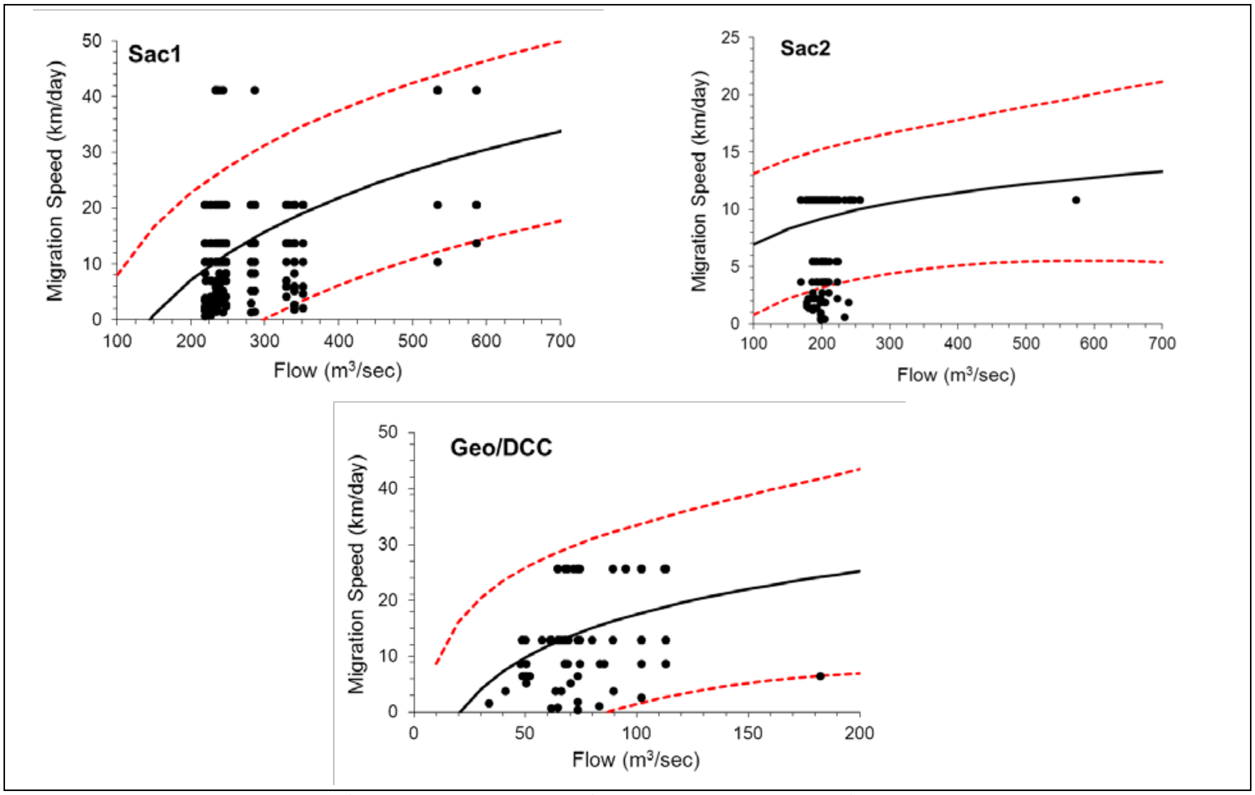
Reach	Gauging Station ID	Release Dates	Sample Size	Speed (km/day)			
				Avg	Min	Max	SD
Sac1	FPT	12/05/06–12/06/06, 1/17/07–1/18/07, 12/04/07–12/07/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	452	13.32	0.54	41.04	9.29
Sac2	SDC	1/17/07–1/18/07, 1/15/08–1/18/08, 11/30/08–12/06/08, 1/13/09–1/19/09	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 (β_0) and Intercept (β_1) Parameter Estimates with Associated Standard Error (in Parenthesis) for the Relationship between Migration Speed and Flow for Reaches Sac1, Sac2, and Geo/DCC

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



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

Figure 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.

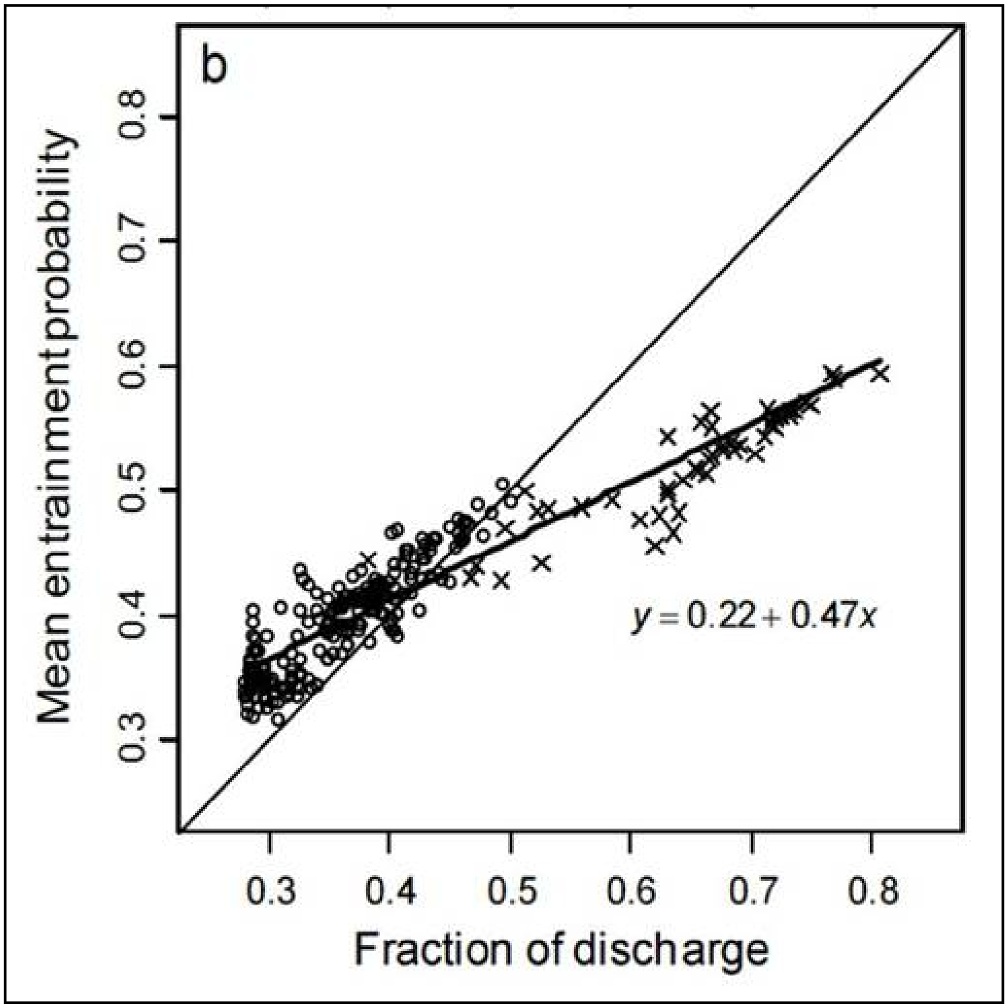
[6] As with Sutter/Steamboat Sloughs, the proportion of fish entering the junction may be somewhat less than the proportion of flow, based on the analysis by Cavallo et al. (2015).

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*):

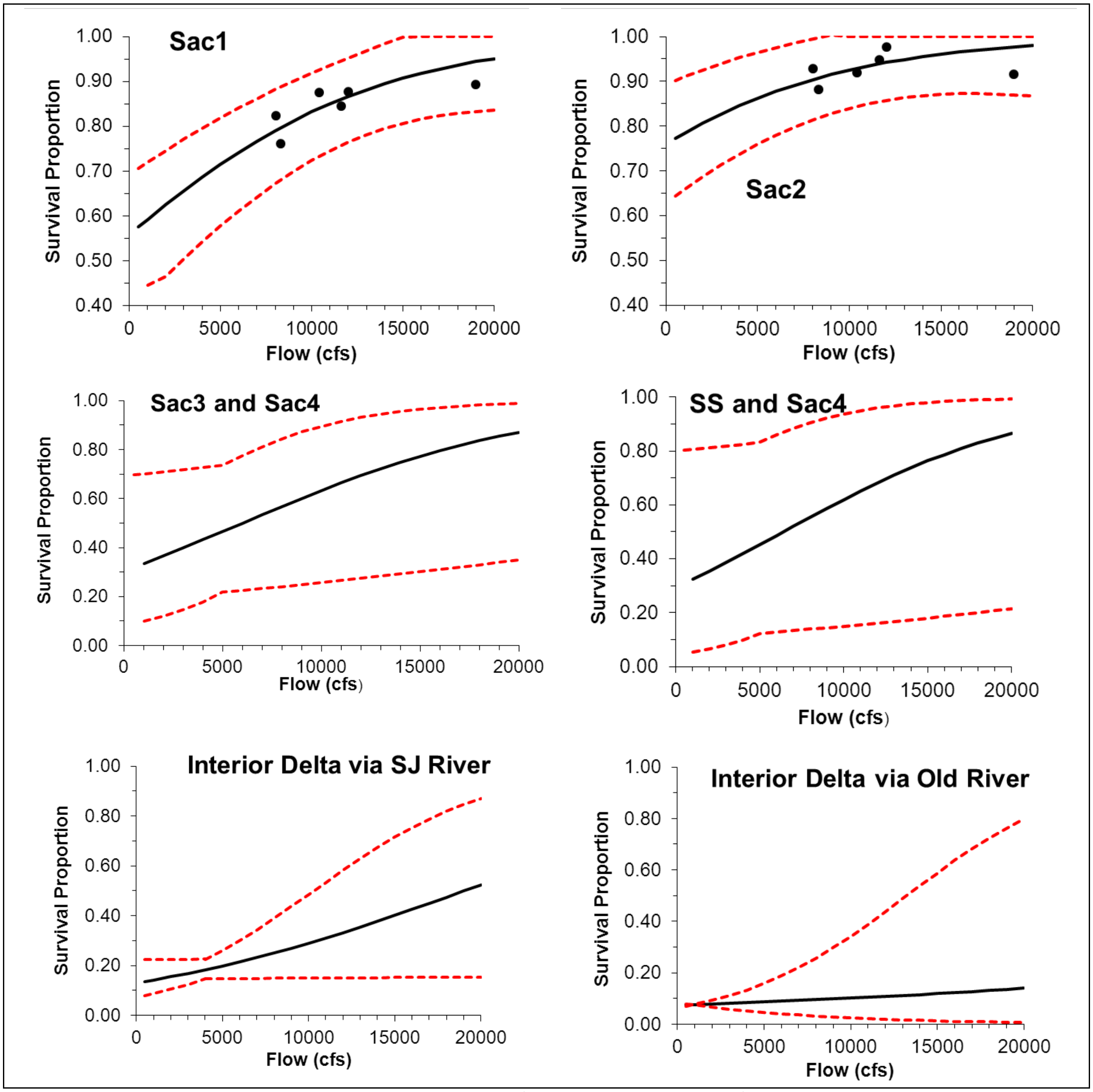
$$S = \frac{e^{(\beta_0 + \beta_1 flow)}}{1 + e^{(\beta_0 + \beta_1 flow)}}$$

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

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

With a flow-survival relationship appearing evident for group survival data of acoustically-tagged smolts in reaches Sac1 and Sac2, Perry's (2010) relationship was applied to Sac1 and Sac2 while adjusting for the mean reach-specific survivals for Sac1 and Sac2 observed during the acoustic-tagging studies[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)

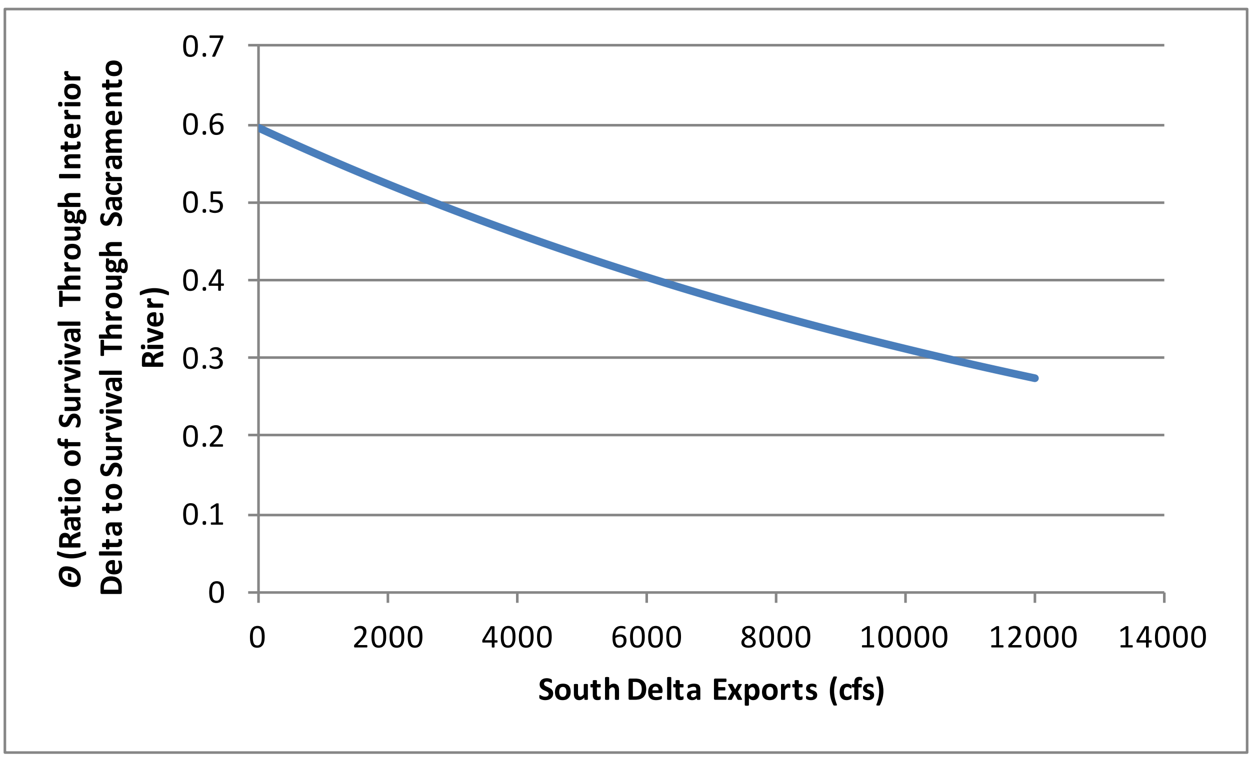
5.D.1.2.2.2.5.6 Export-Dependent Survival

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

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

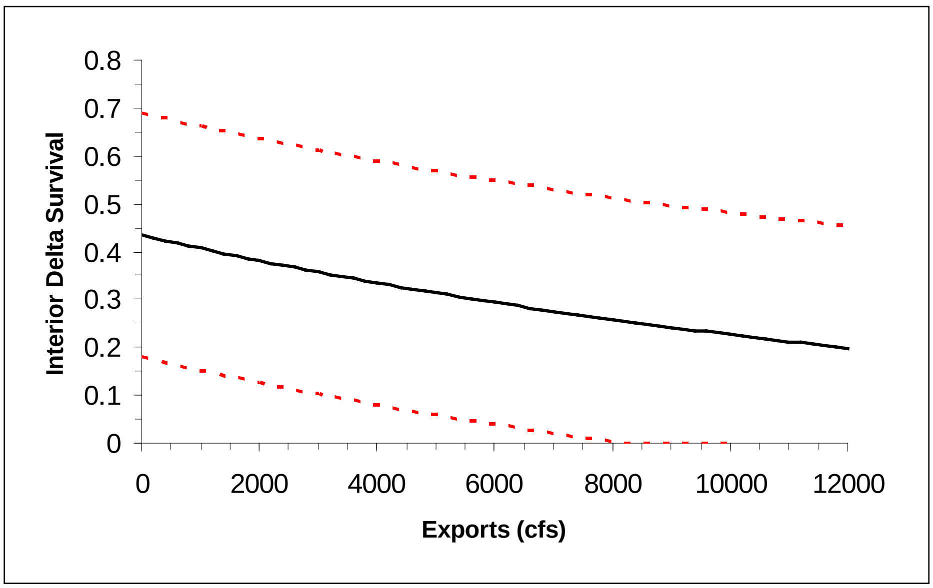
θ was converted from a ratio into a value of survival through the Interior Delta using the equation:

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

where S_{ID} is survival through the Interior Delta, θ is the ratio of survival between Georgiana Slough and Sacramento River smolt releases, $S_{Geo/DCC}$ is the survival of smolts in the Georgiana Slough/Delta Cross Channel reach, $S_{Sac3} * S_{Sac4}$ is the combined survival in reaches Sac 3 and Sac 4 (Figure 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 90th percentile values in each water year-type. To demonstrate flow effects, exports were held at the 50th percentile value and 100 iterations of the model were run at each flow percentile from the 10th to the 90th. Similarly, for the export effect demonstration, flow values in each reach were held at the 50th percentile value while 100 iterations of the model were run at each percentile of exports from the 10th to the 90th.

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.

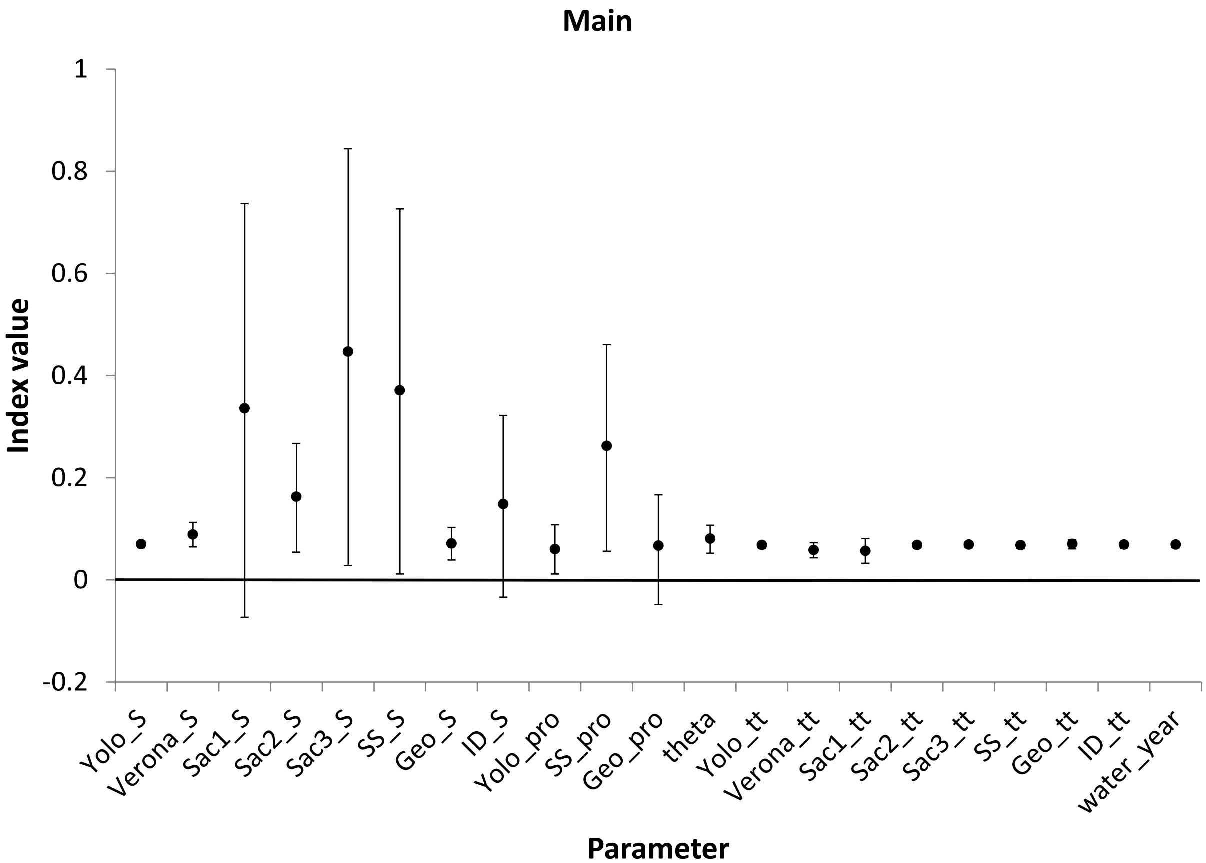


Figure 5.D-48. DPM Sensitivity Analysis Parameter Uncertainty: Main index values from Sobol' sensitivity indices. Confidence intervals that cross zero indicate that parameter did not have a disproportionate effect of model output.

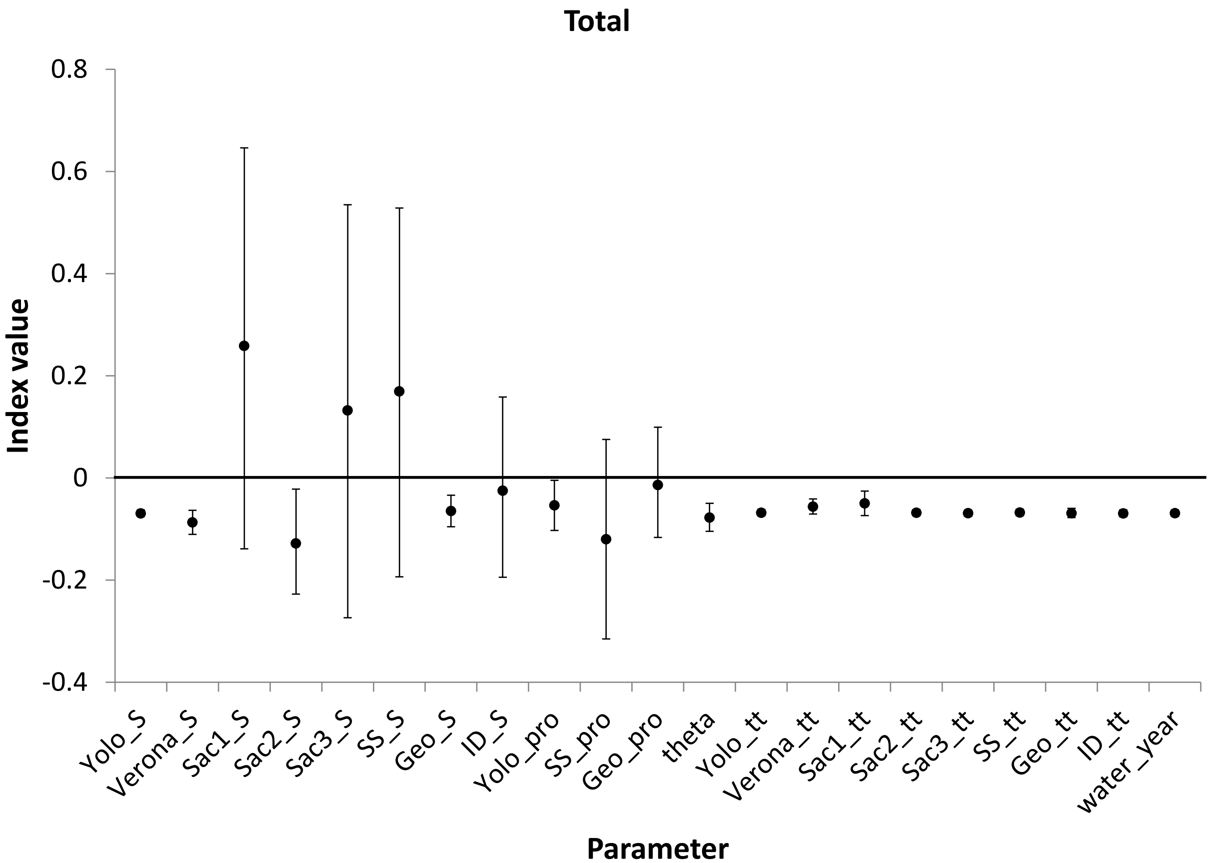


Figure 5.D-49. DPM Sensitivity Analysis Parameter Uncertainty: Total index values from Sobol' sensitivity indices. Confidence intervals that cross zero indicate that parameter did not have a disproportionate effect of model output.

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 90th 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 10th and 20th percentile values. The increase in survival from the 10th to 20th percentile flow was greater than the increase between the 10th and 30th 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.

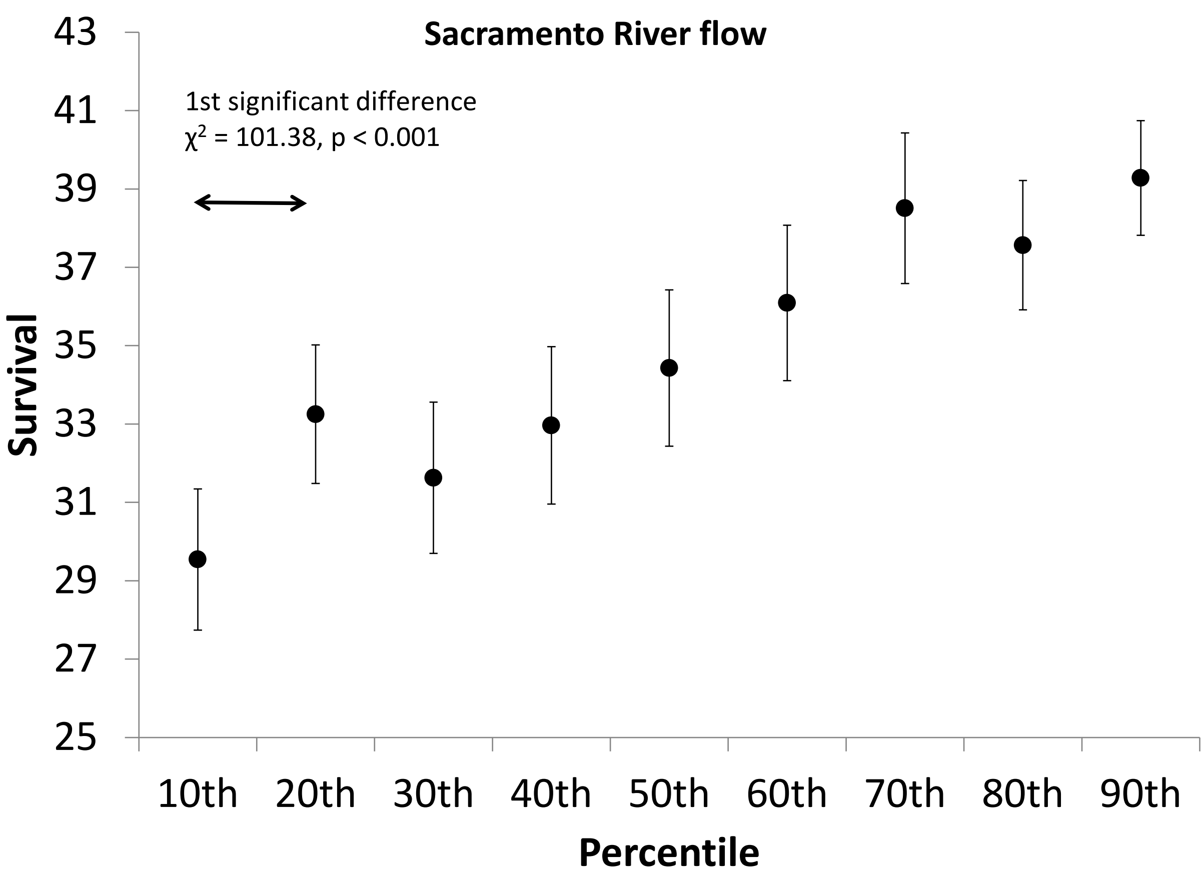


Figure 5.D-50. Means and standard errors of total through-Delta survival for winter run Chinook salmon at 10th – 90th percentile flow values in each reach with exports held at the 50th percentile values.

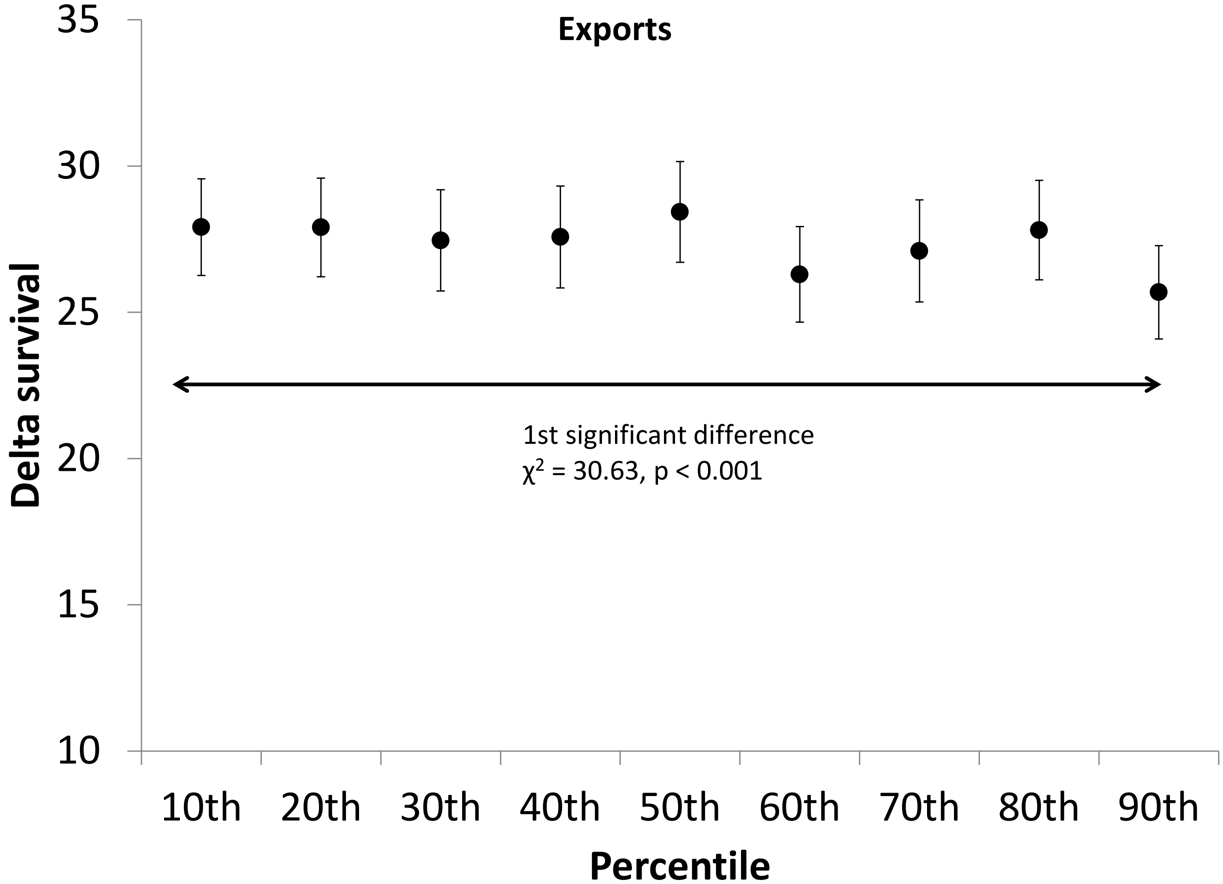


Figure 5.D-51. Means and standard errors of total through-Delta survival for winter run Chinook salmon at 10^{th} – 90^{th} percentile export values in each reach with flows held at the 50^{th} percentile values.

To examine the flow and export ranges used in the sensitivity analyses, the 10^{th} – 90^{th} 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 10^{th} and 90^{th} 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.

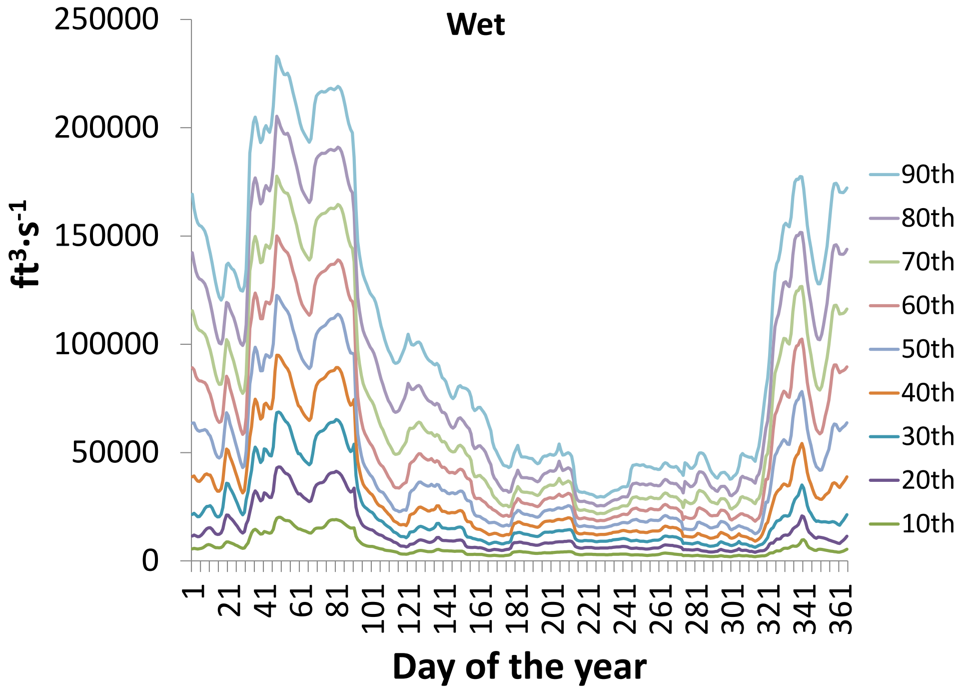


Figure 5.D-52. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Wet Years, Used in the Sensitivity Analysis's Model Demonstration.

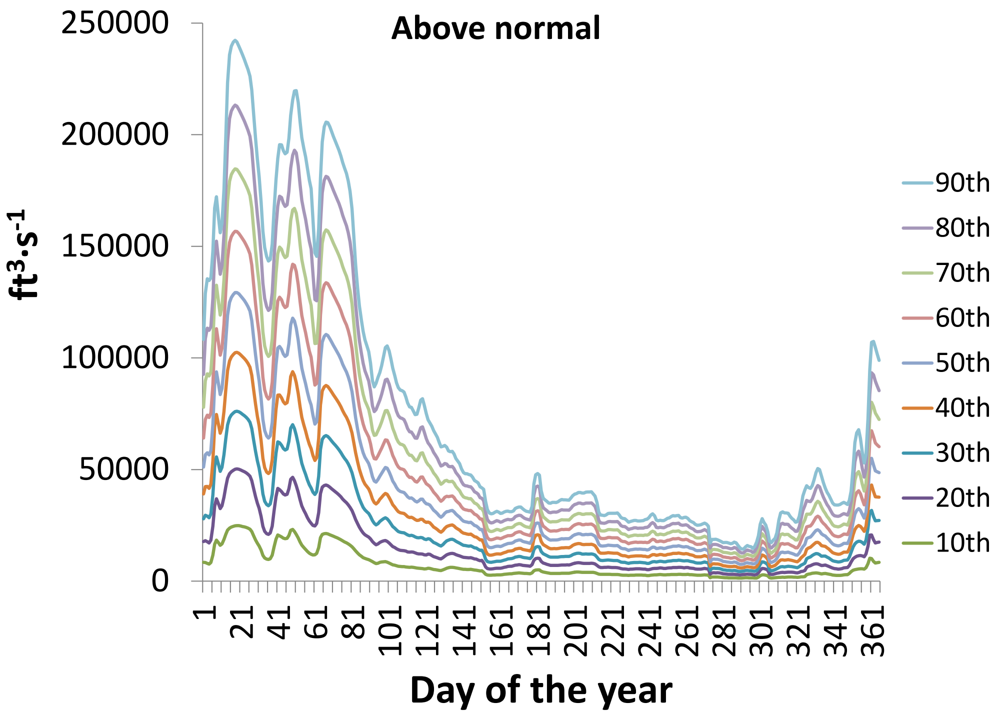


Figure 5.D-53. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Above Normal Years, Used in the Sensitivity Analysis's Model Demonstration.

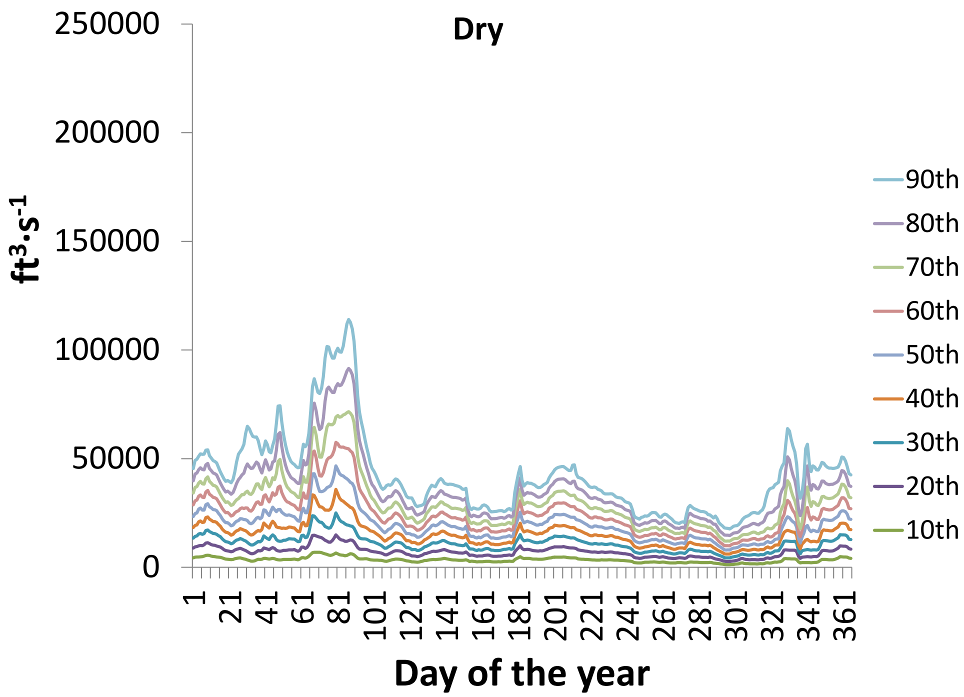


Figure 5.D-54. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Dry Years, Used in the Sensitivity Analysis's Model Demonstration.

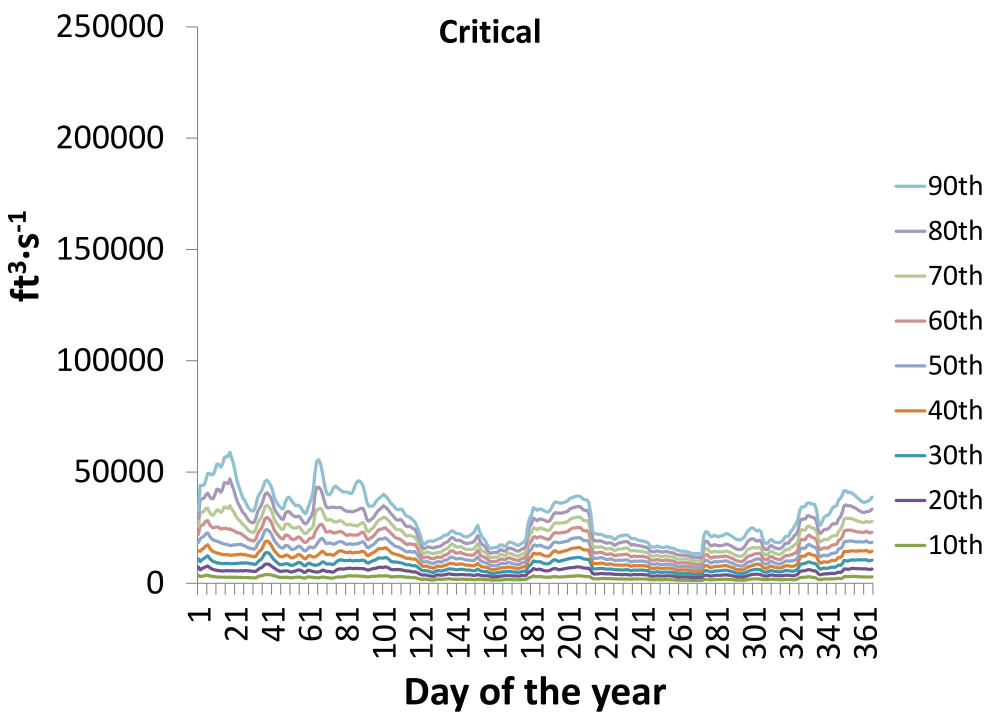


Figure 5.D-55. Ranges of Daily Flows in the Sacramento River below Georgiana Slough (DPM Reach Sac 3) in Critical Years, Used in the Sensitivity Analysis's Model Demonstration.

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.

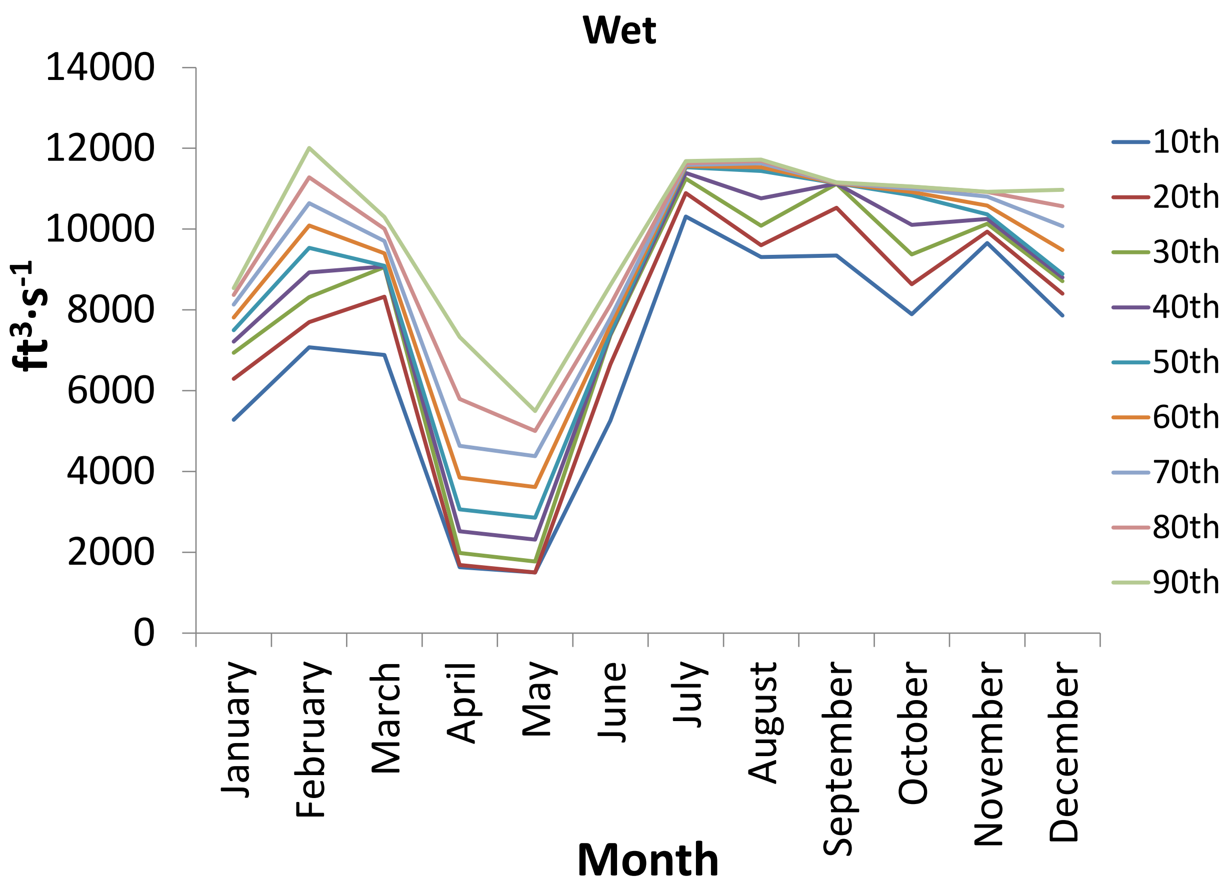


Figure 5.D-56. Ranges of Daily South Delta Exports in Wet Years, Used in the Sensitivity Analysis's Model Demonstration.

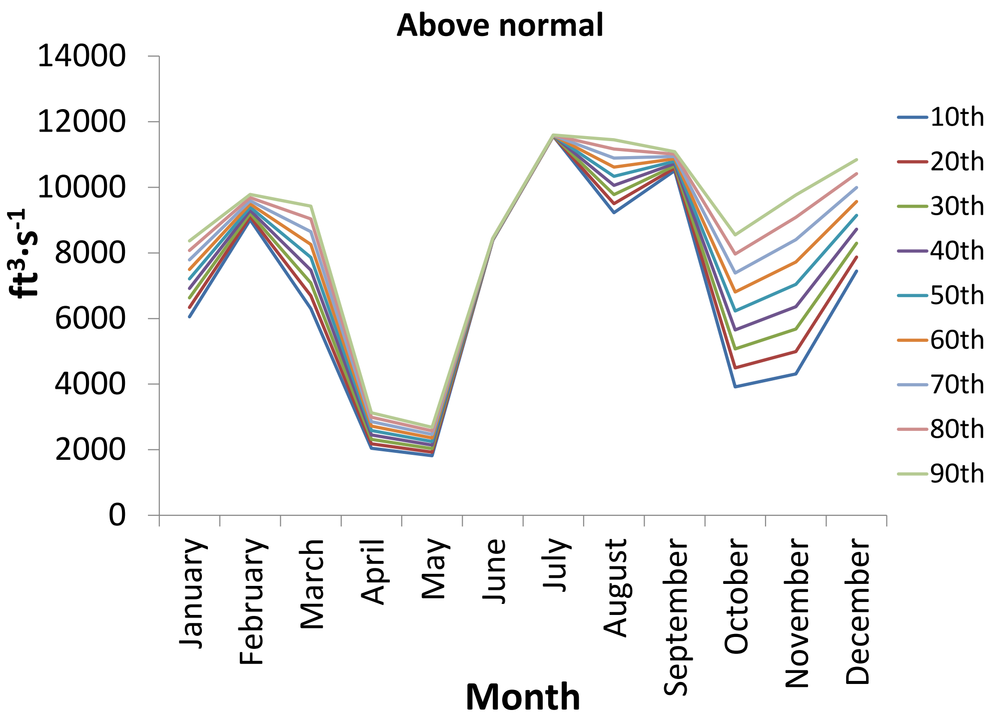


Figure 5.D-57. Ranges of Daily South Delta Exports in Above Normal Years, Used in the Sensitivity Analysis's Model Demonstration.

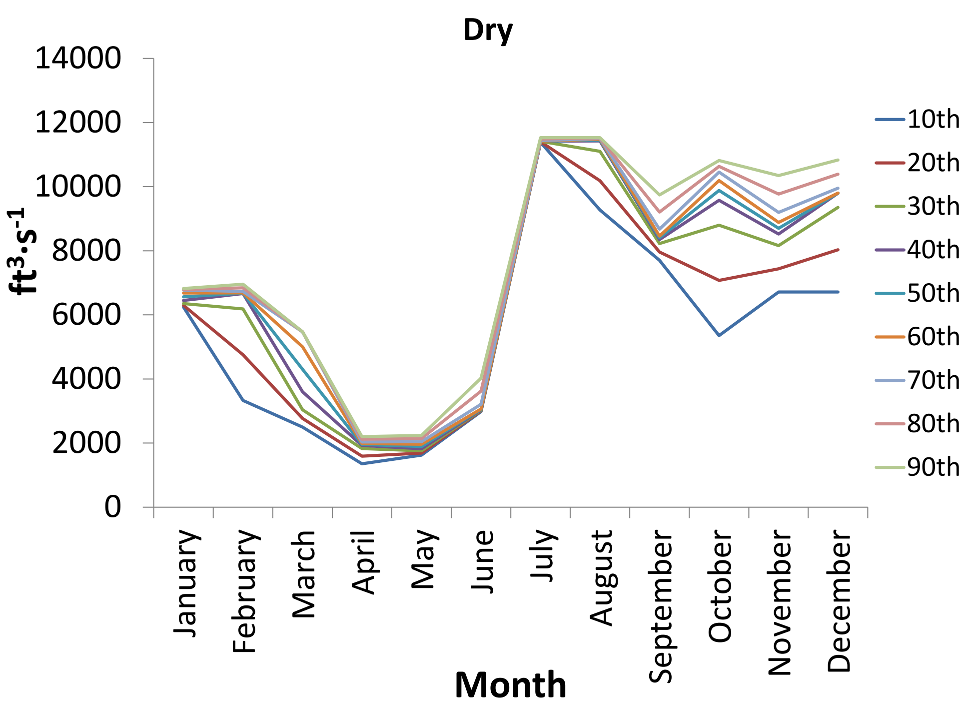


Figure 5.D-58. Ranges of Daily South Delta Exports in Dry Years, Used in the Sensitivity Analysis's Model Demonstration.

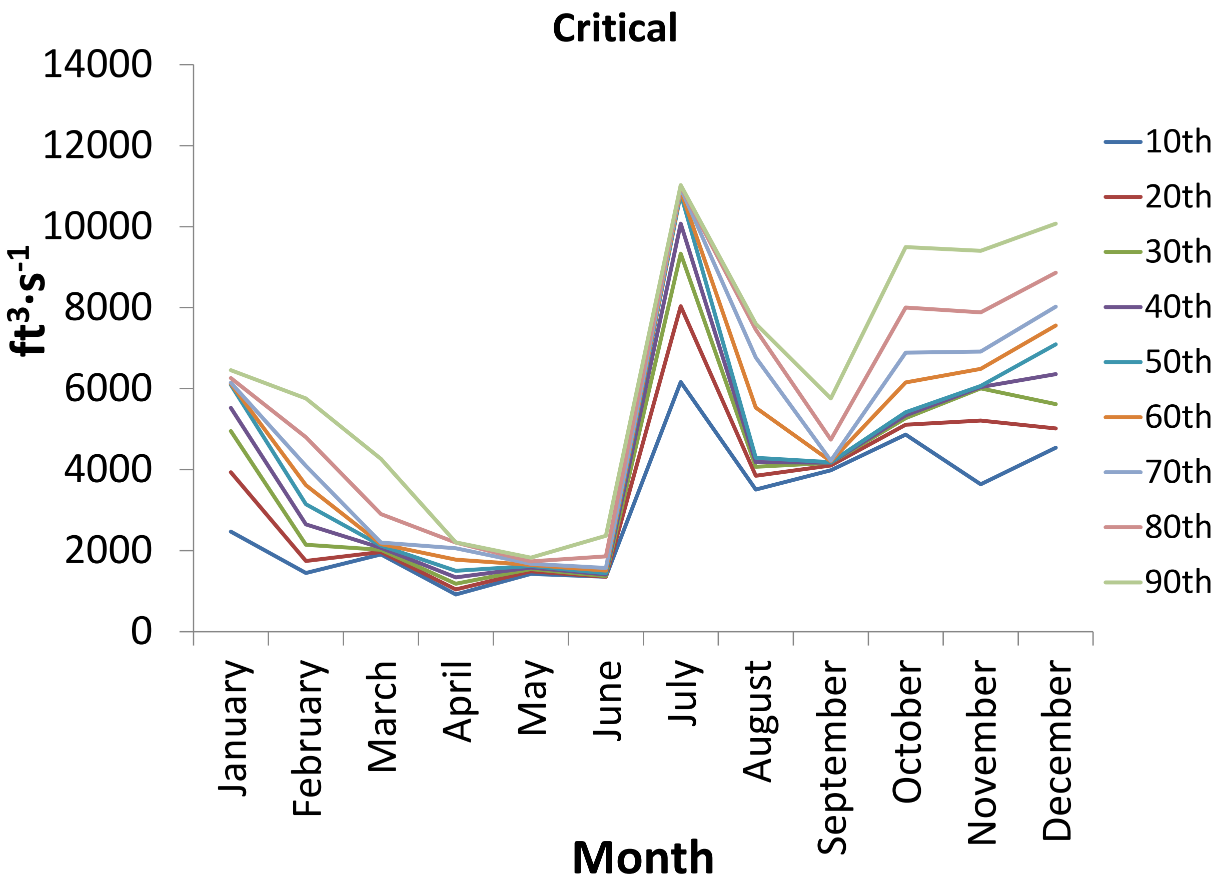


Figure 5.D-59. Ranges of Daily South Delta Exports in Critical Years, Used in the Sensitivity Analysis's Model Demonstration.

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.

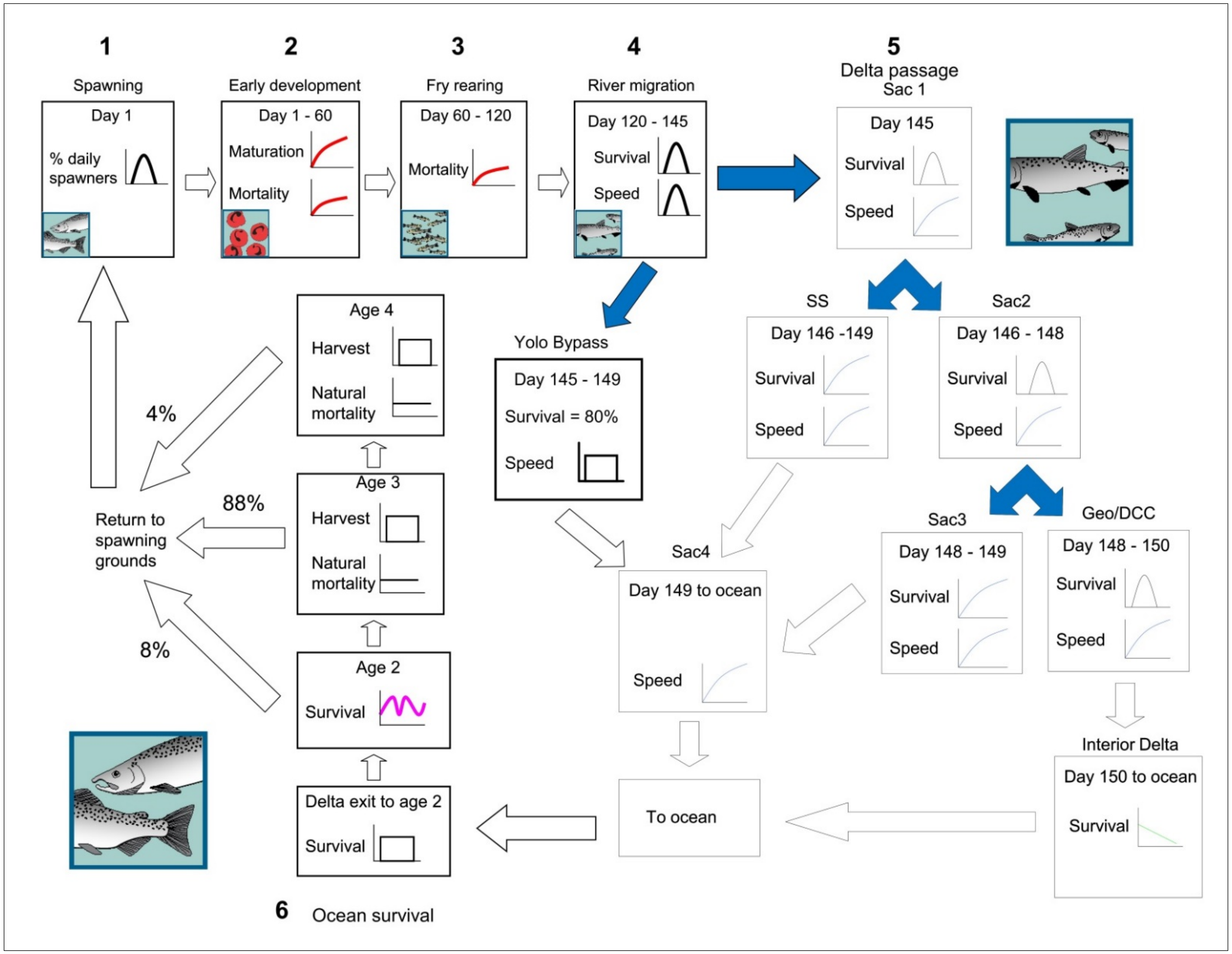
3. Fry Rearing, which models the relationship between temperature and mortality of fry during the river rearing period in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.

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 α is a parameter that describes recruitment rate, and β is a parameter that measures the level of density dependence.

The density-dependent parameter (β) 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, β 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 α 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) daily maturation rate = 0.00058*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) $\text{mortality} = 1-(1-\text{total mortality})^{(1/\text{development time})}$

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).

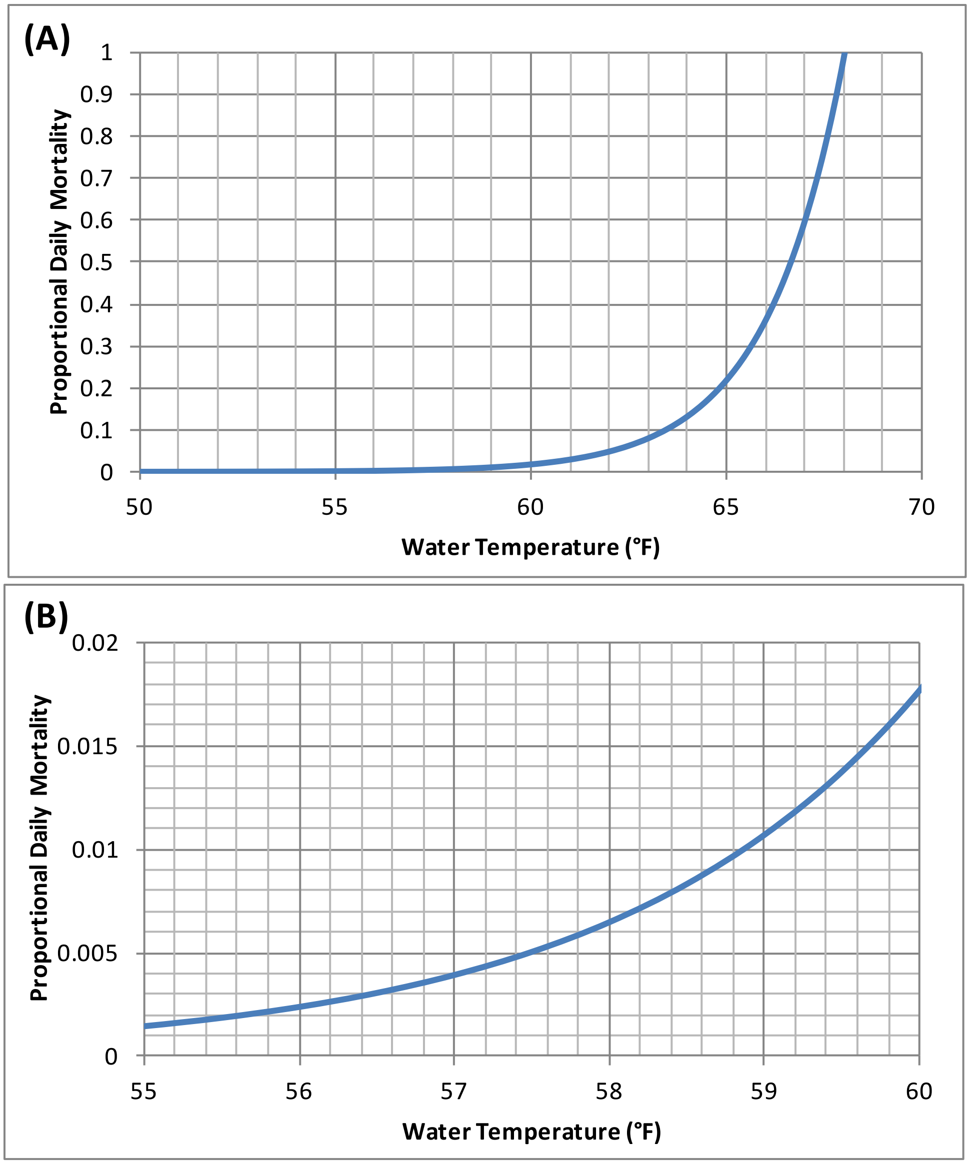


Figure 5.D-136. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Eggs and Water Temperature (Equation 7) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios

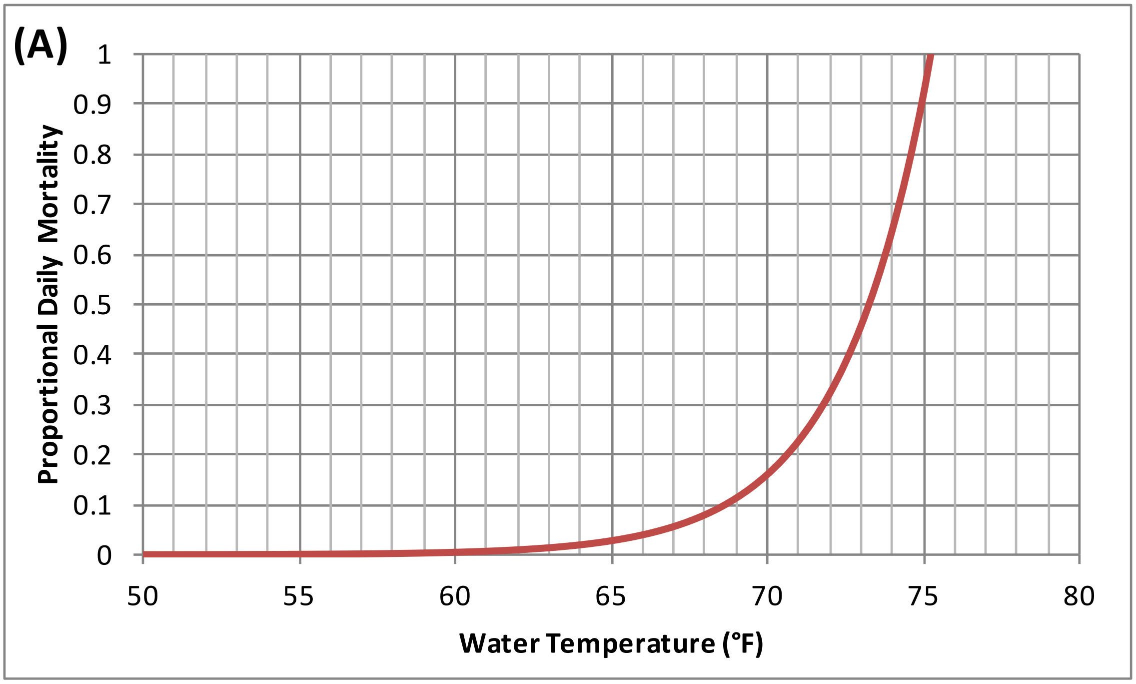
In the IOS Model, mean daily mortality rates of the incubating eggs are predicted from daily water temperatures measured at Bend Bridge on the Sacramento River using the exponential function above. The predicted mean mortality rate, along with the confidence intervals of the predicted values, is used 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.



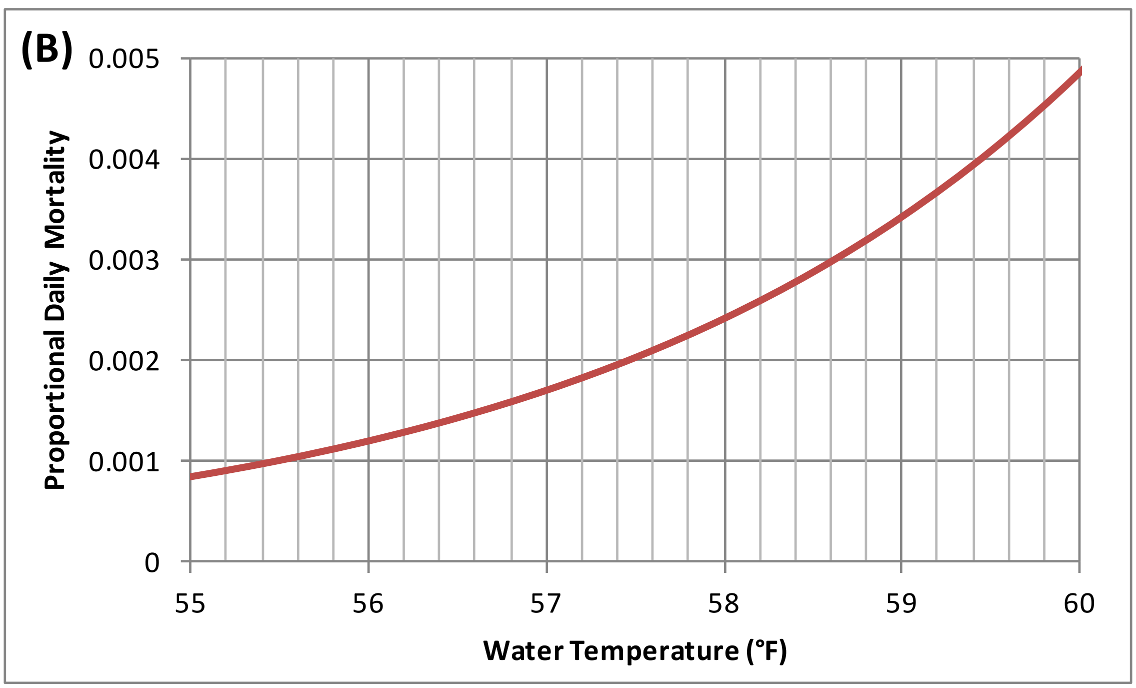


Figure 5.D-137. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Fry and Water Temperature (Equation 8) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios

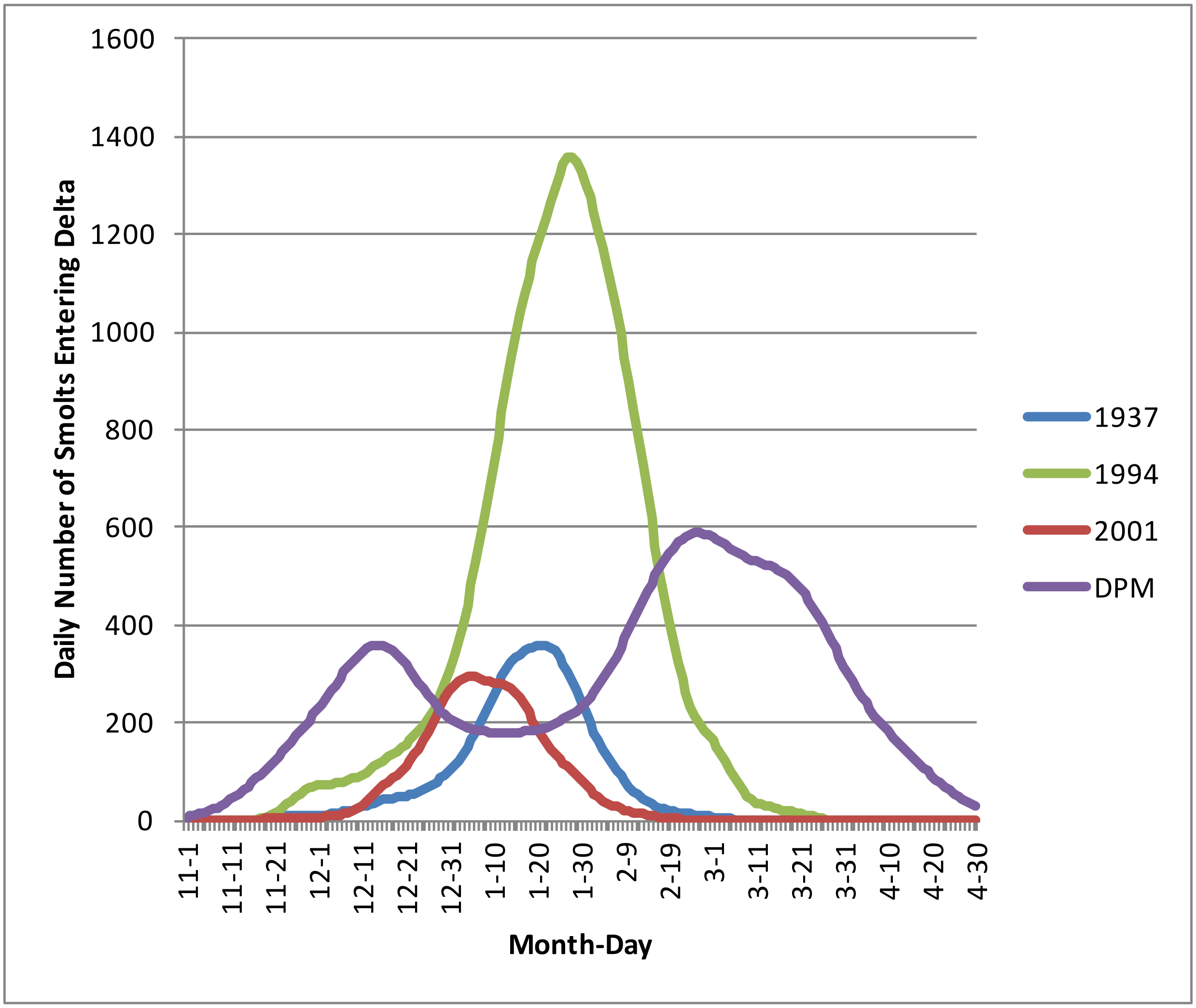
Each day the mean proportional mortality of the rearing fish is predicted from the daily water temperature using the above exponential relationship; the predicted mean mortality, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then 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).

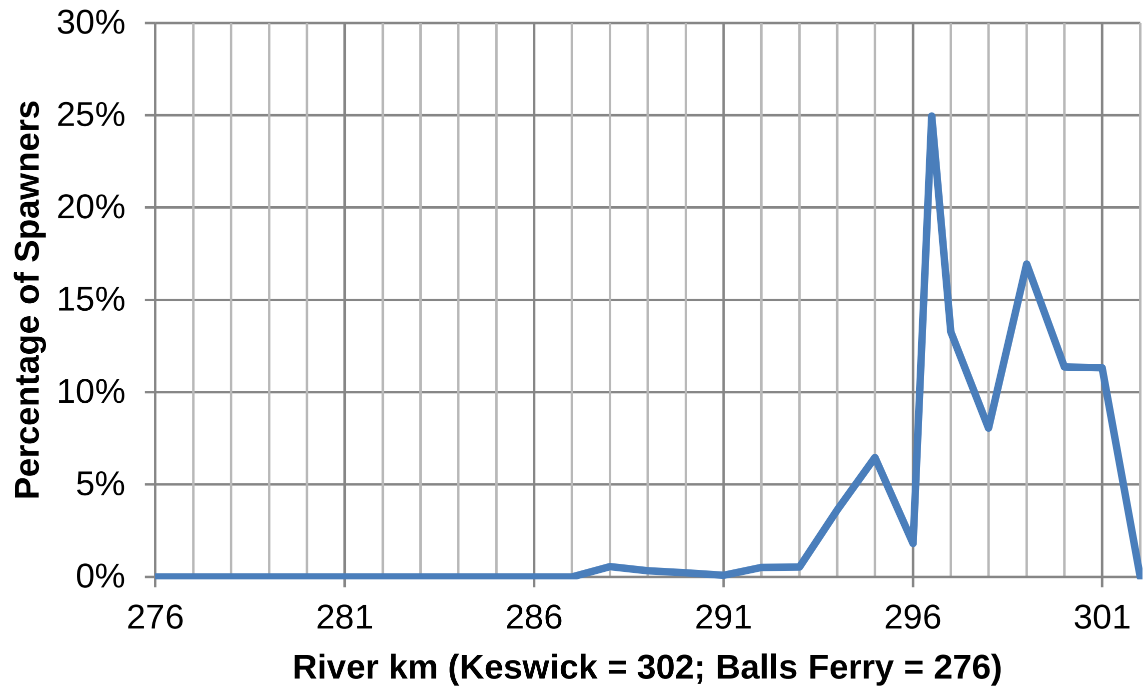


Figure 5.D-139. Mean Spawning Distribution of Winter-Run Chinook Salmon From 2010-2012 Surveys, Used to Weight SRWQM Keswick and Balls Ferry Water Temperatures Outputs for Input into IOS.

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 2.5th and 97.5th 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.

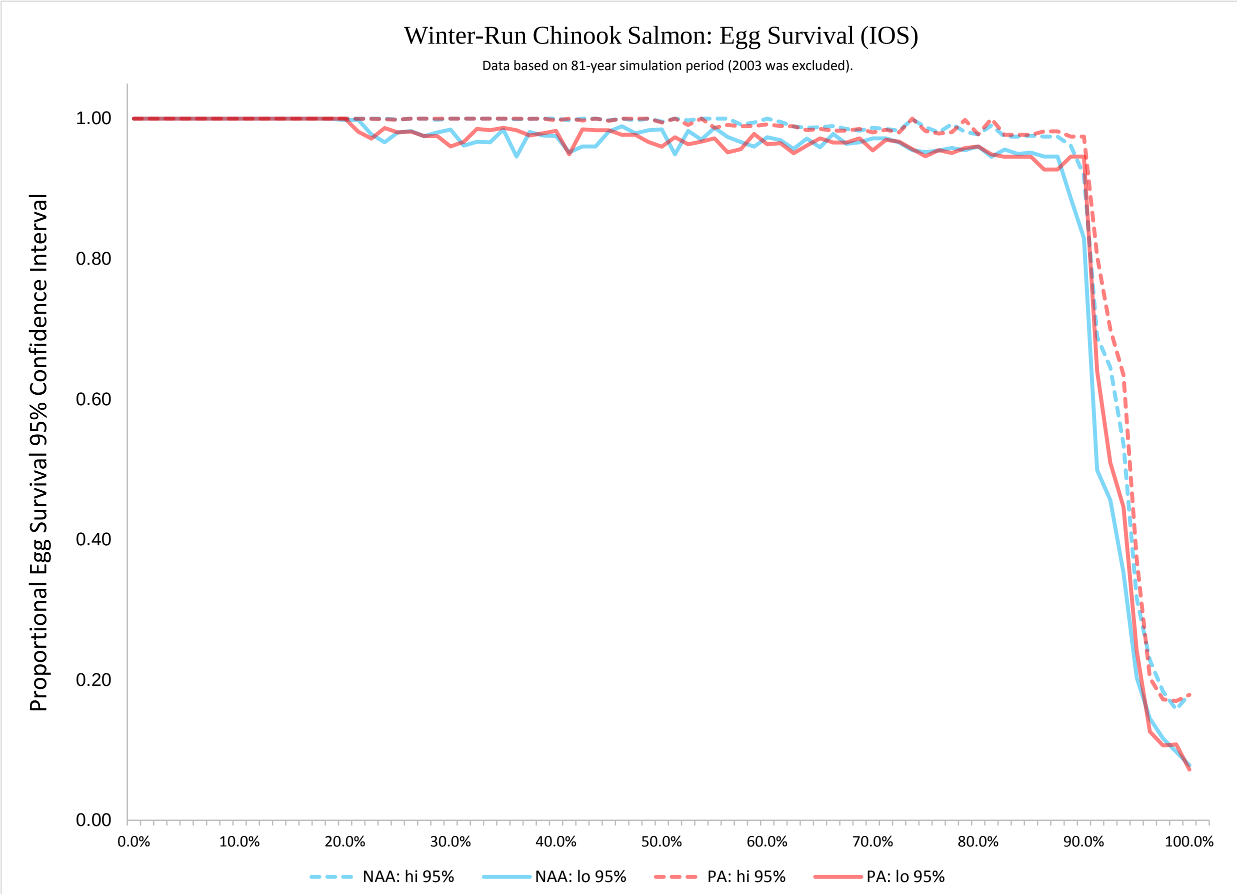
5.D.3.1.8 Results

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

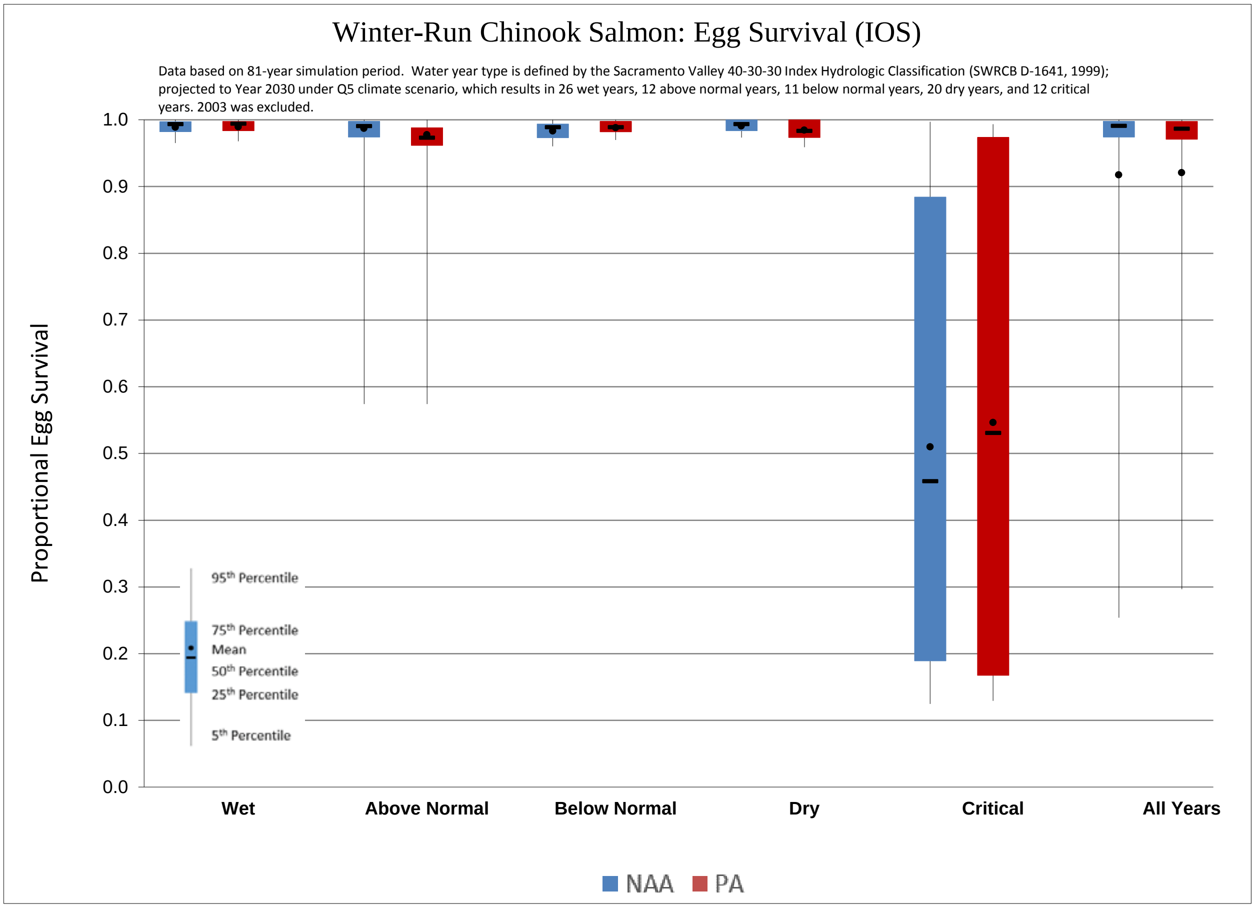
The IOS model predicted very similar egg survival for winter-Run Chinook salmon between the NAA and PA (Figure 5.D-140 and Figure 5.D-141). NAA median egg survival was 0.990 and PA median egg survival was 0.991 (Figure 5.D-140). In 12 of the 81 years simulated, the 95% confidence intervals of the annual 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).

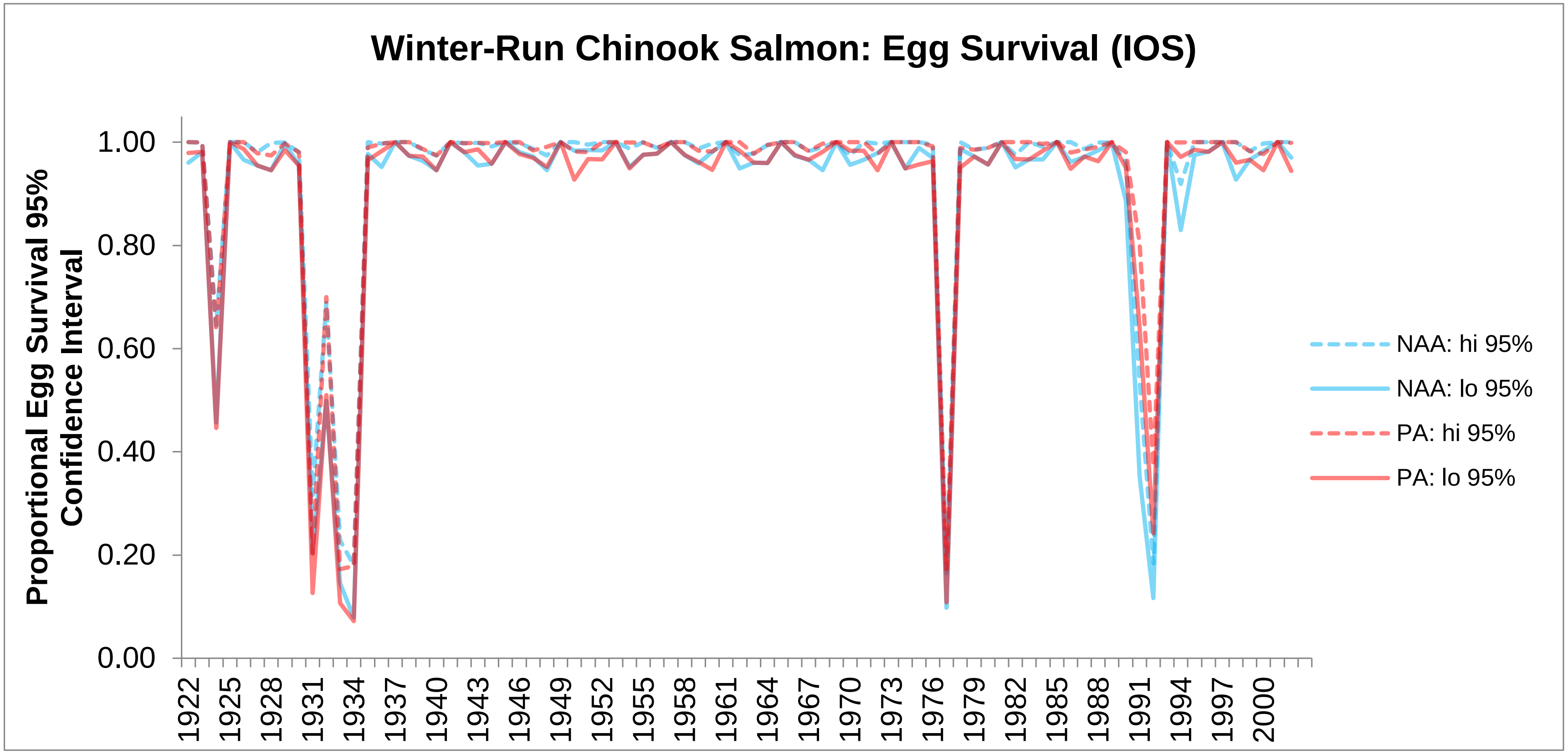
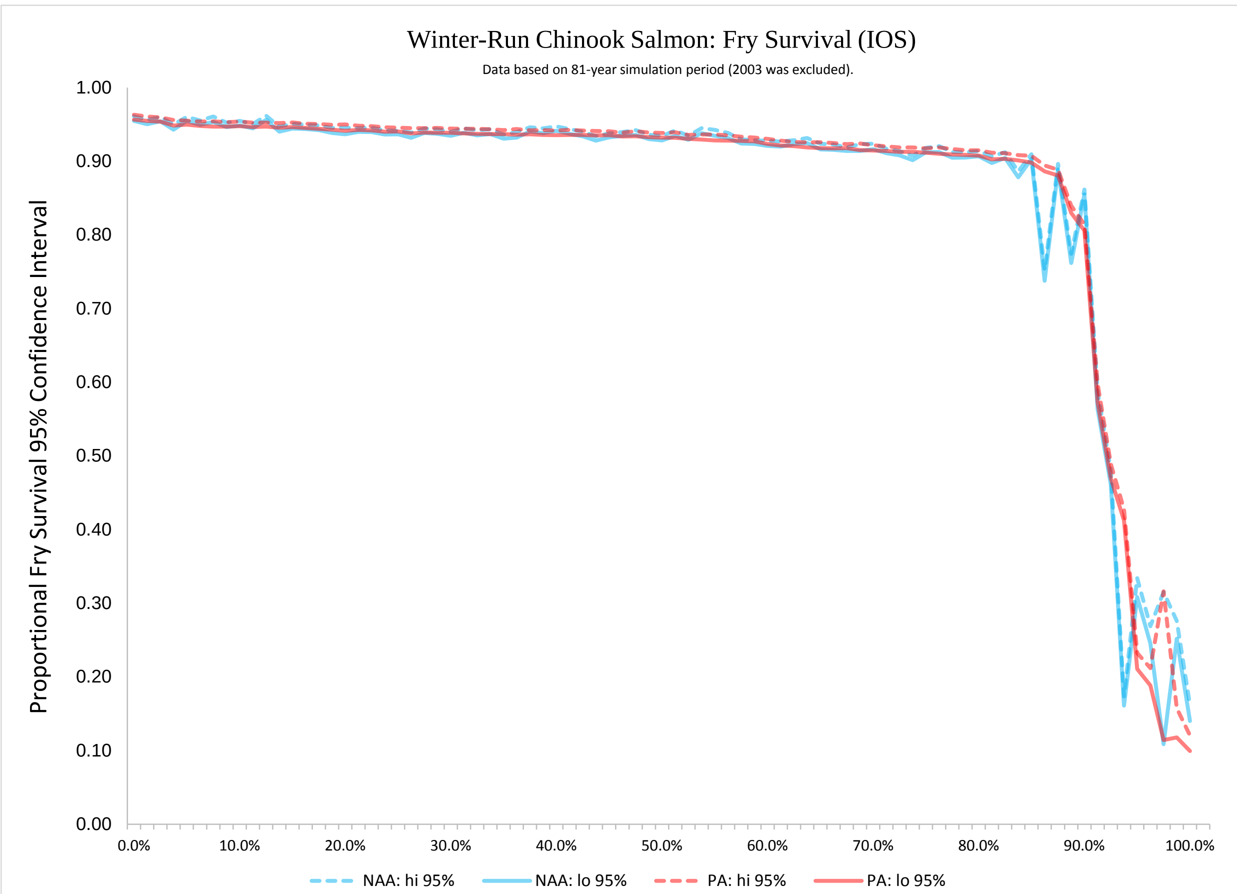


Figure 5.D-142. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Egg Survival Estimates.

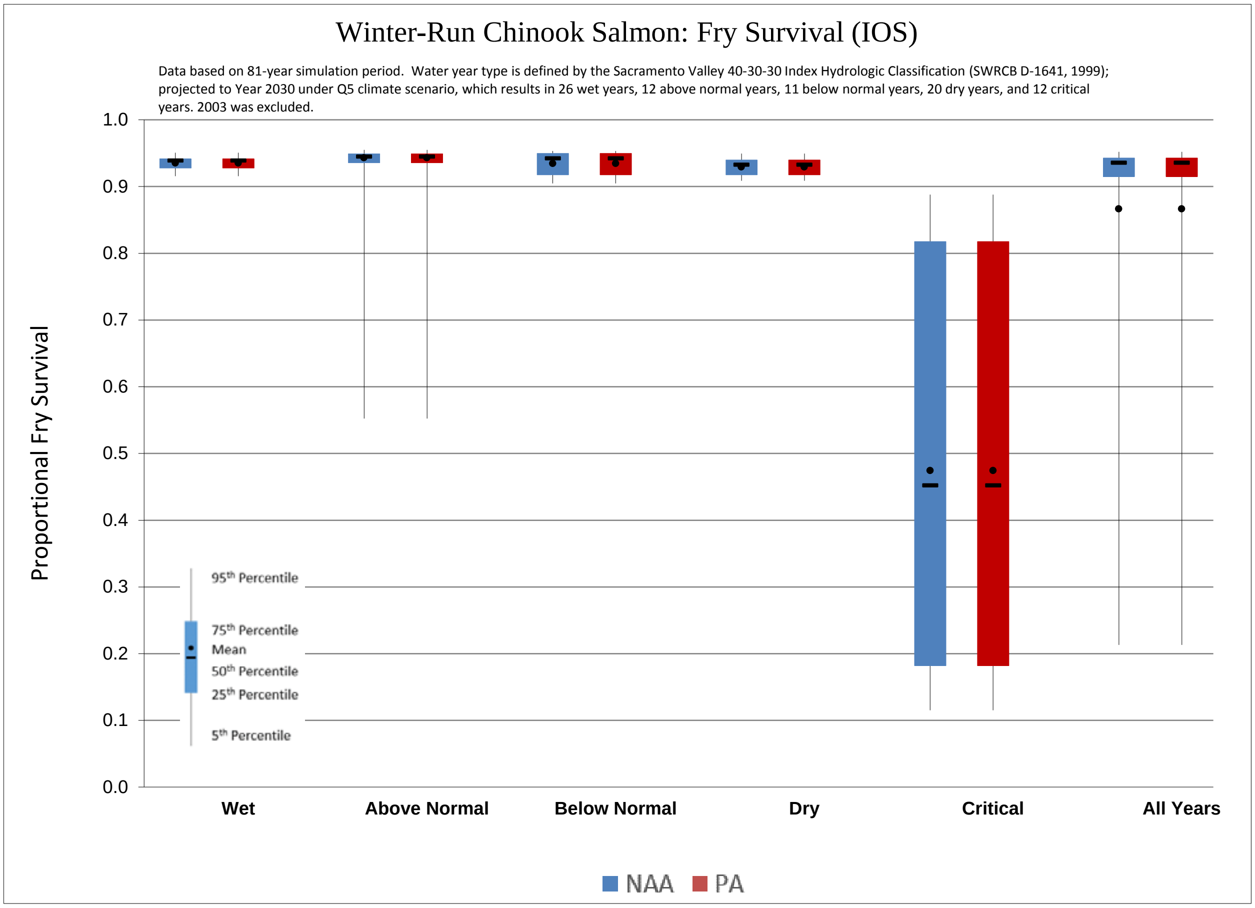
5.D.3.1.8.2 Fry Survival

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).

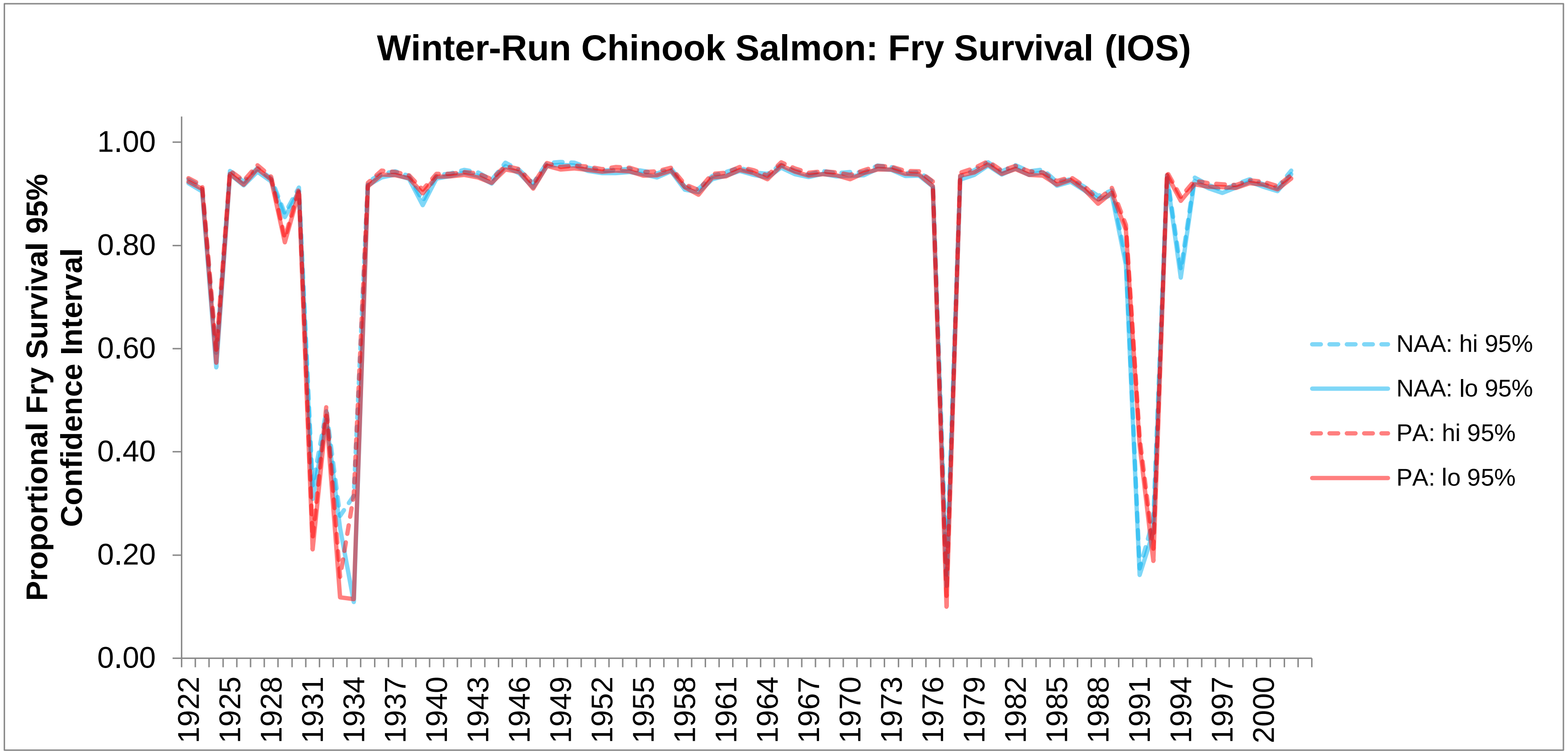
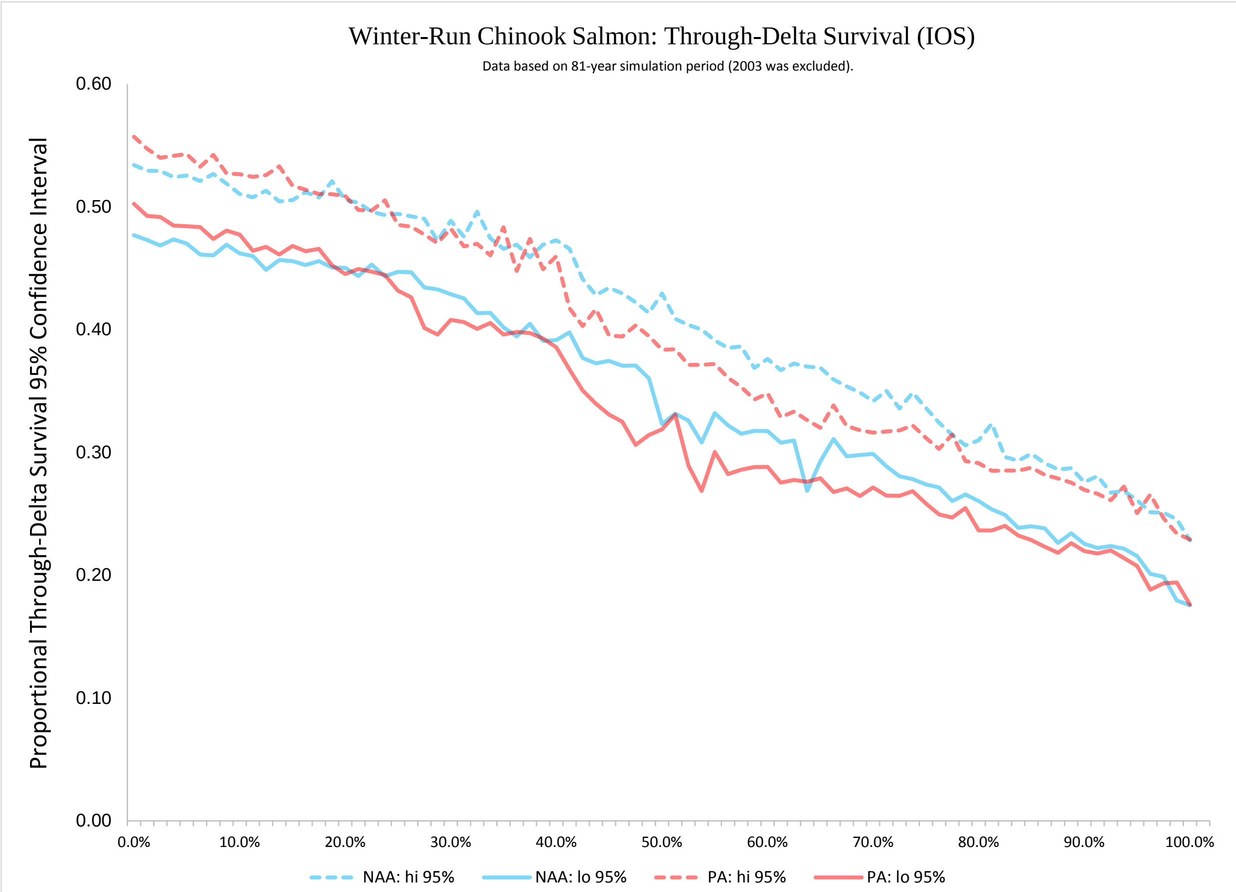


Figure 5.D-145. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Fry Survival Estimates.

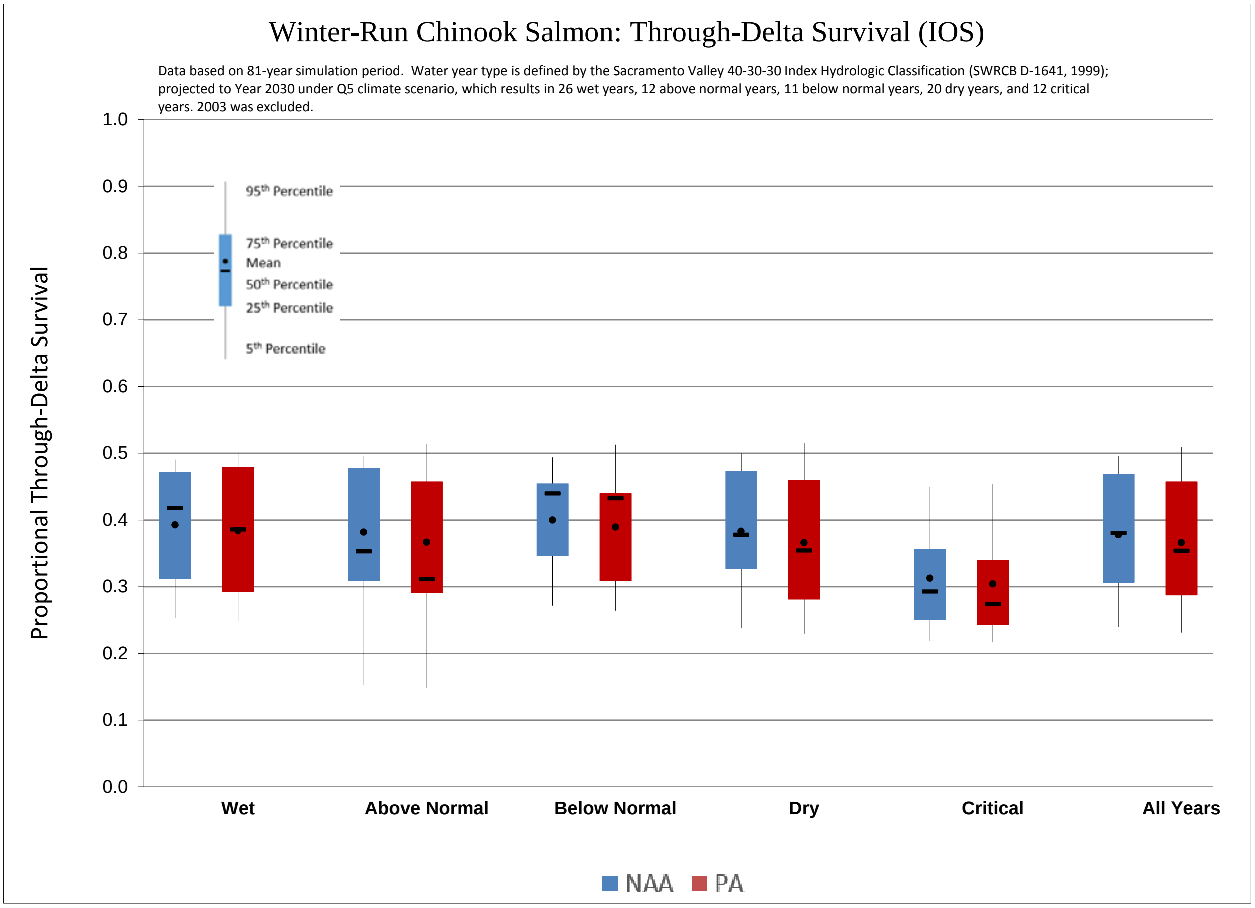
5.D.3.1.8.3 Through-Delta Survival

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).

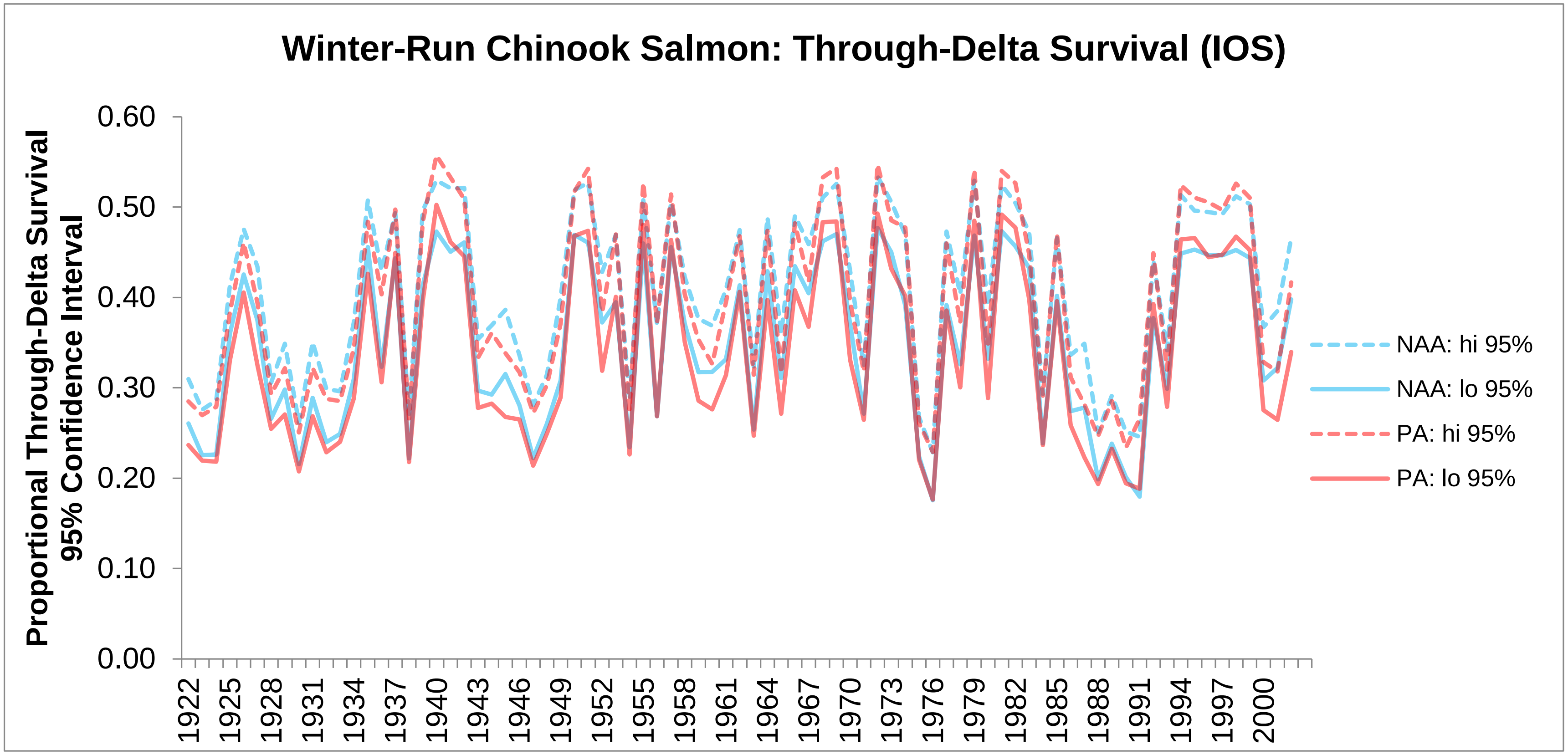
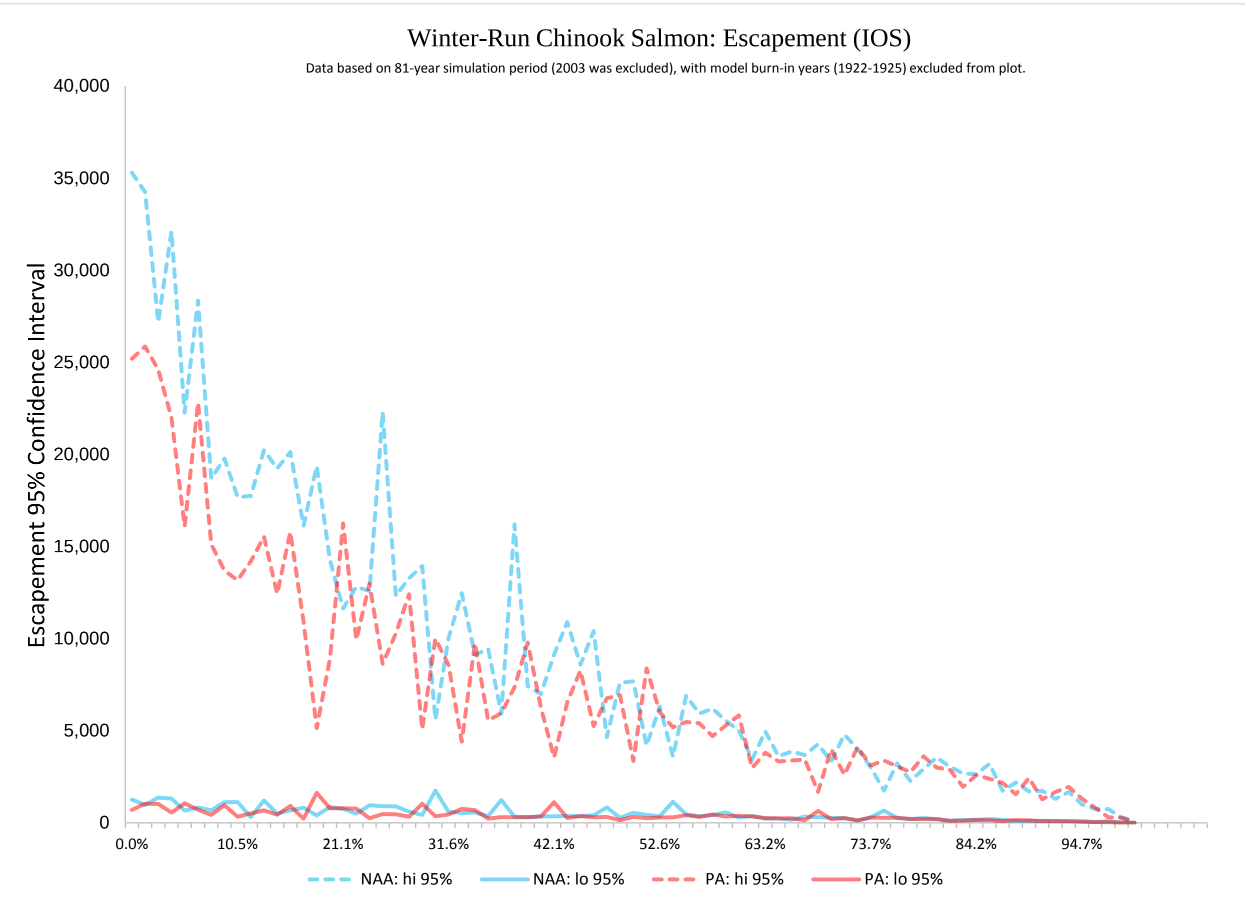


Figure 5.D-148. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Through-Delta Survival Estimates.

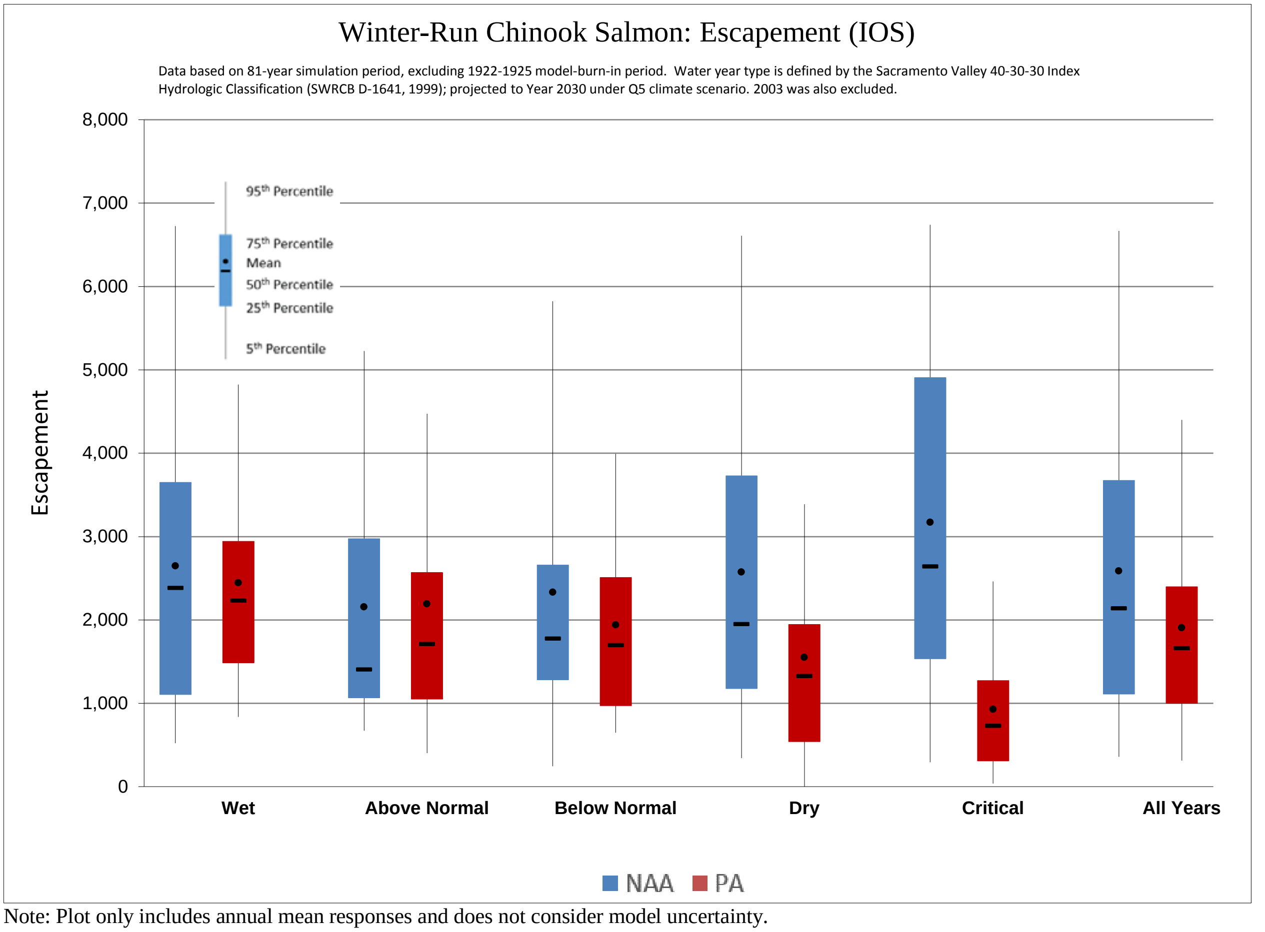
5.D.3.1.8.4 Escapement

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).

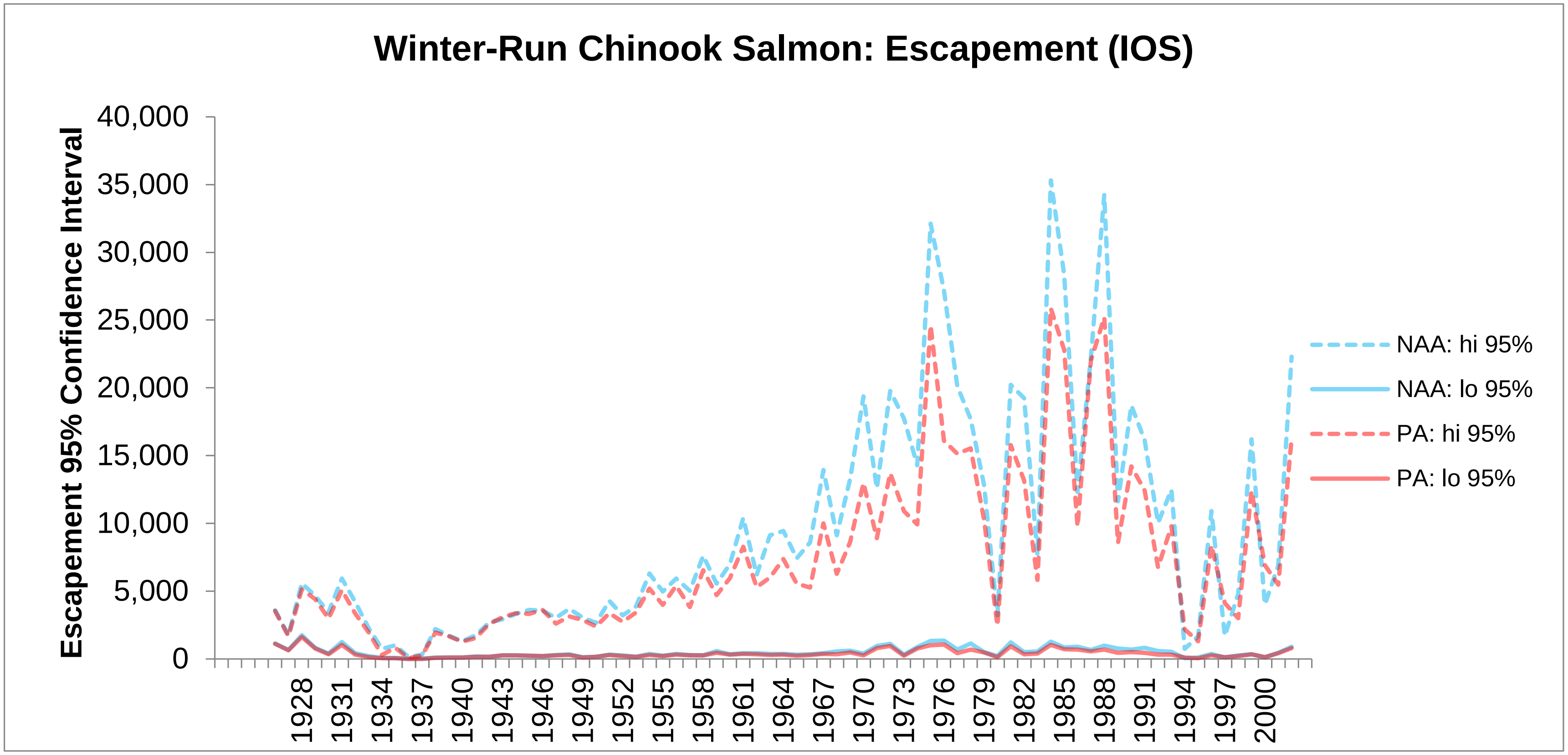


Figure 5.D-151. Time Series of 95% Confidence Interval IOS Annual Winter-Run Chinook Salmon Escapement Estimates.

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 25th and 75th 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- 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.

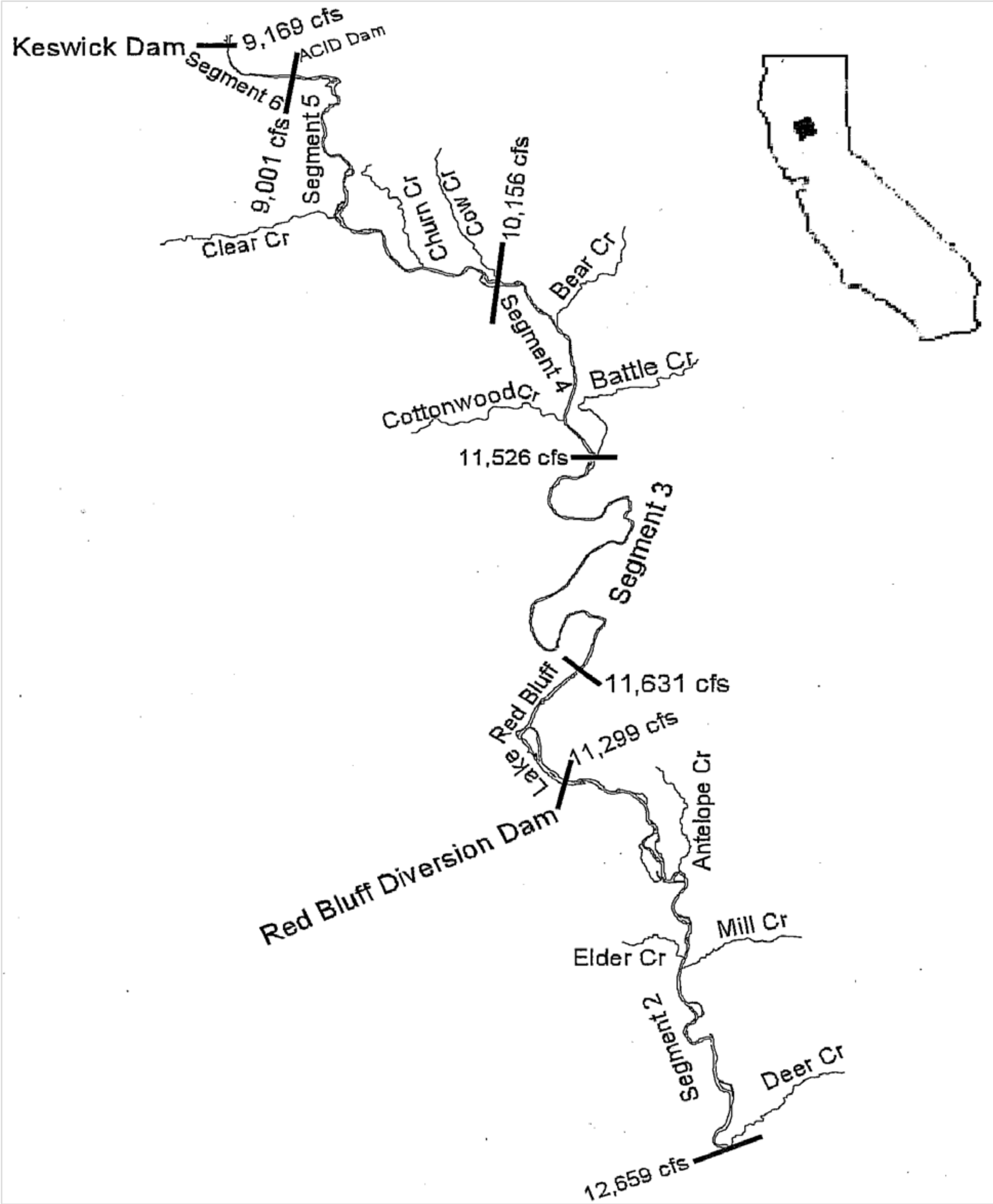


Figure 5.D-86. Segments 2–6 of the Sacramento River Used in USFWS Studies to Determine Spawning Weighted Usable Area (WUA) (flows in the figure are the average flows at the upstream boundary of each segment for October 1974 to September 1993). Source: USFWS 2003a.

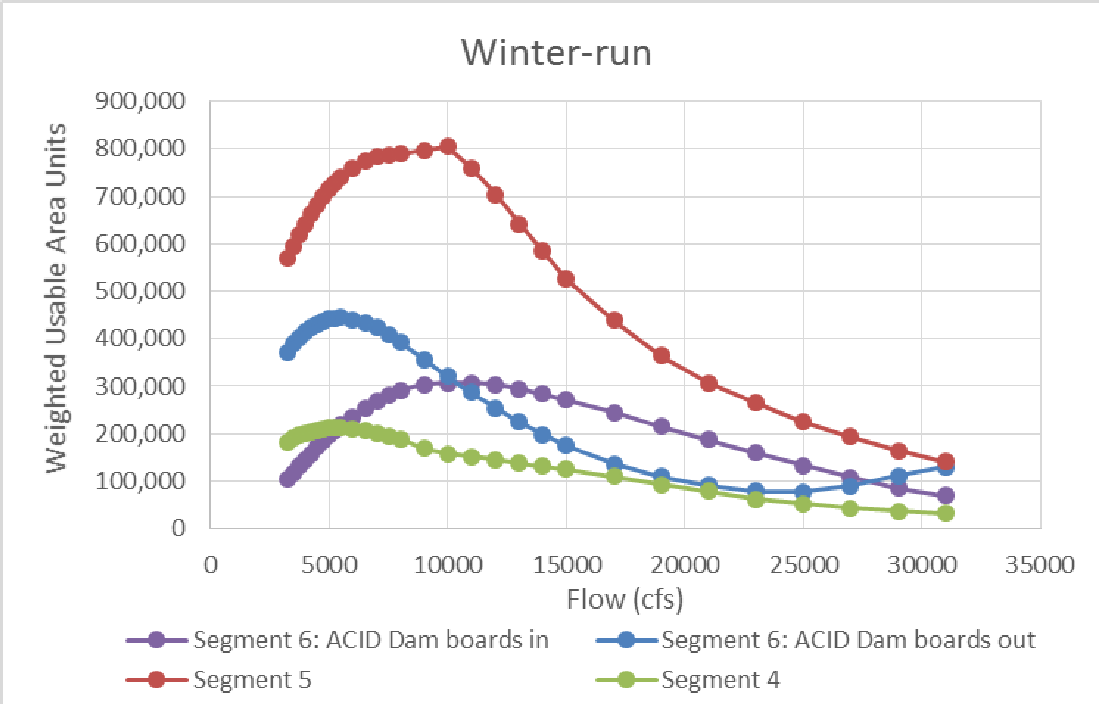


Figure 5.D-87. Spawning WUA curves for Winter-Run Chinook Salmon in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District

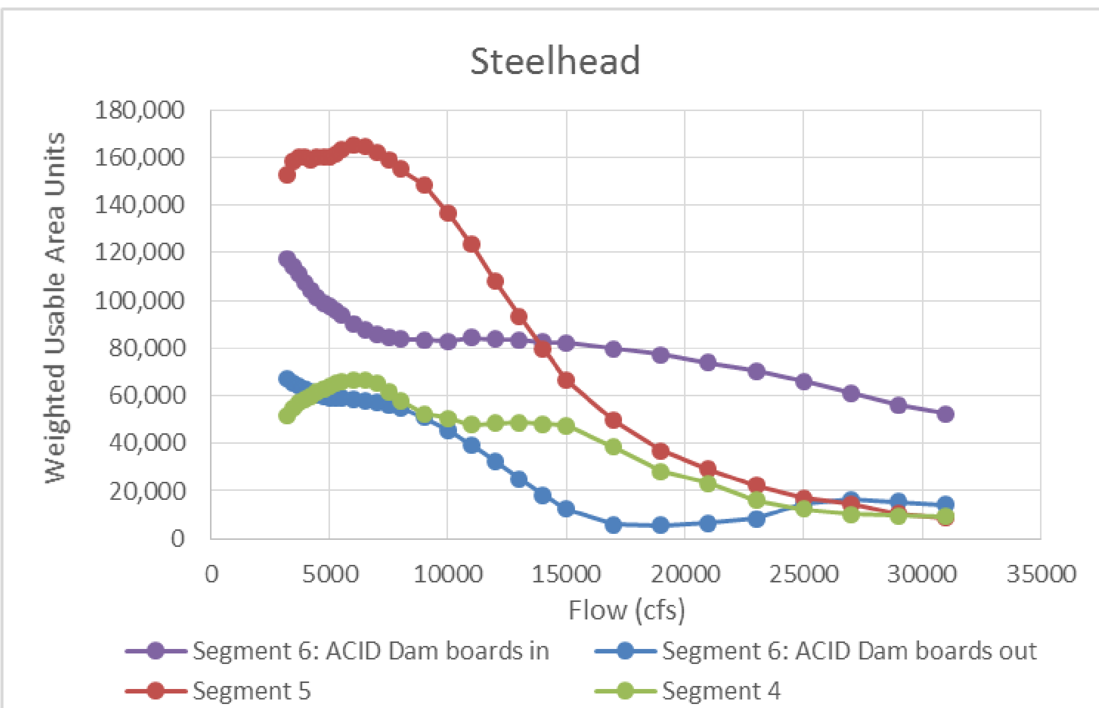


Figure 5.D-88. Spawning WUA curves for California Central Valley Steelhead in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District

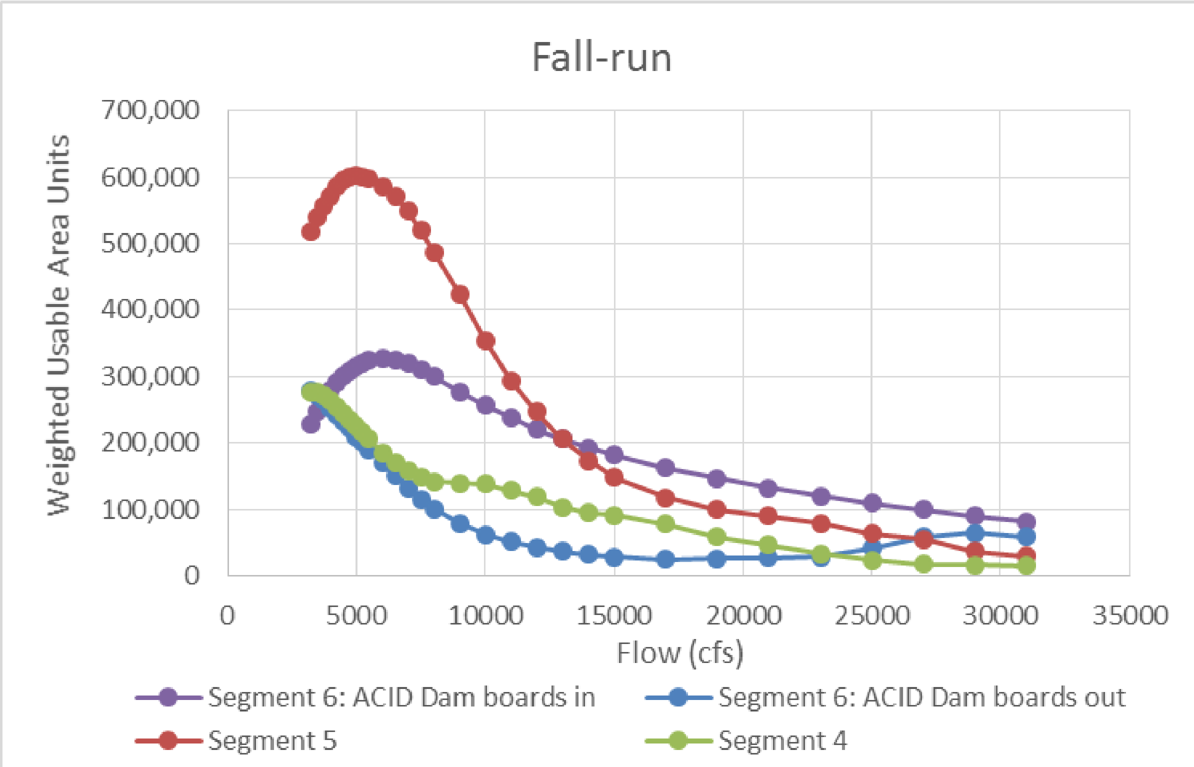


Figure 5.D-89. Spawning WUA Curves for Fall-Run Chinook Salmon in the Sacramento River, Segments 4 to 6. The fall-run curves were used to quantify spring-run Chinook salmon WUA, as discussed in the text. ACID = Anderson-Cottonwood Irrigation District

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.

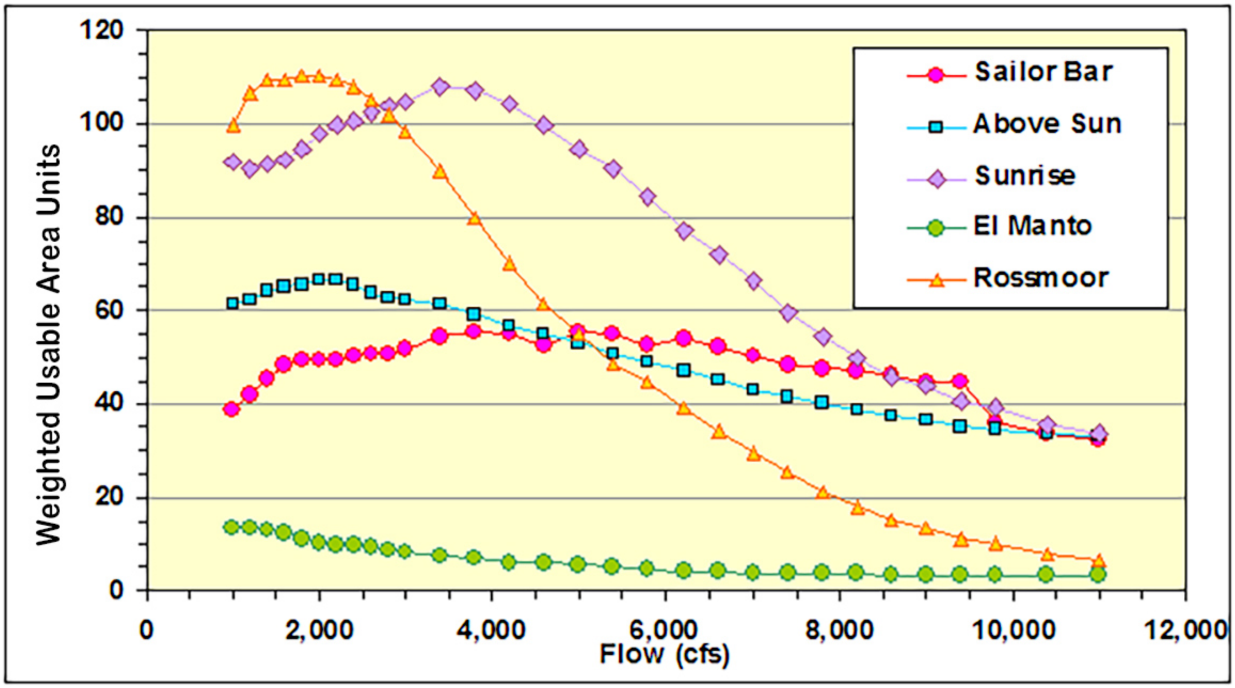


Figure 5.D-90. Spawning WUA Curves for Steelhead in the American River.

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											
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	43.2	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											
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	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																
		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
Dewatering Flow	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																
		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
Dewatering Flow	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											
		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

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.

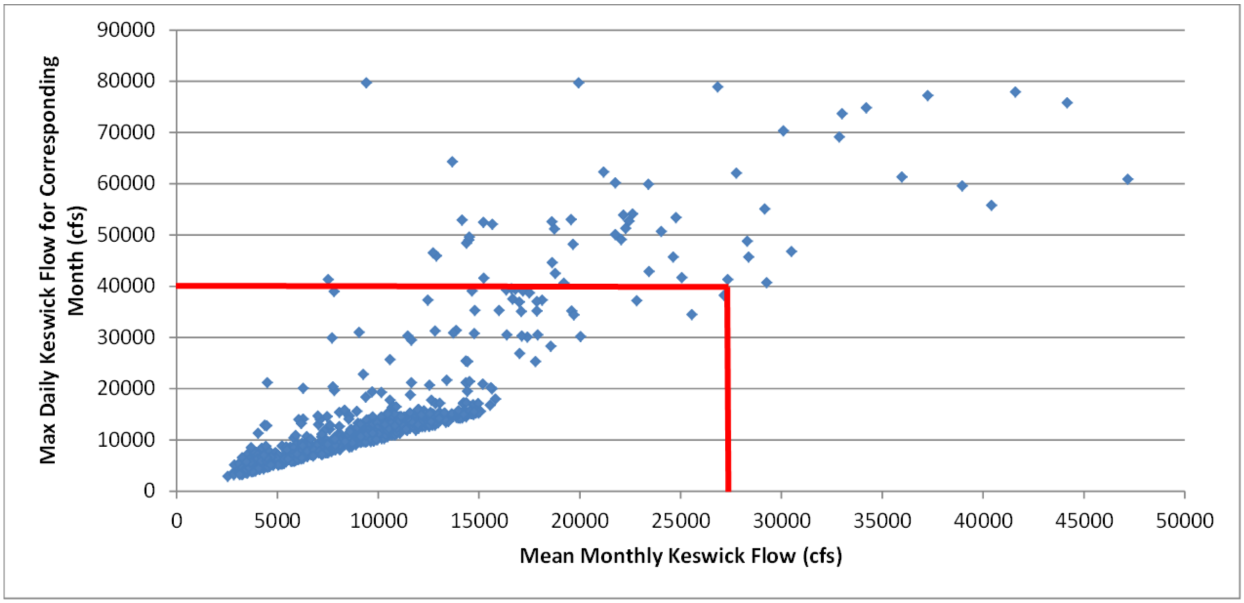


Figure 5.D-91. Relationship between Mean Monthly Flows and Maximum Daily Flows during December through April, Sacramento River at Keswick 1938–2015. Minimum monthly flow is identified in red.

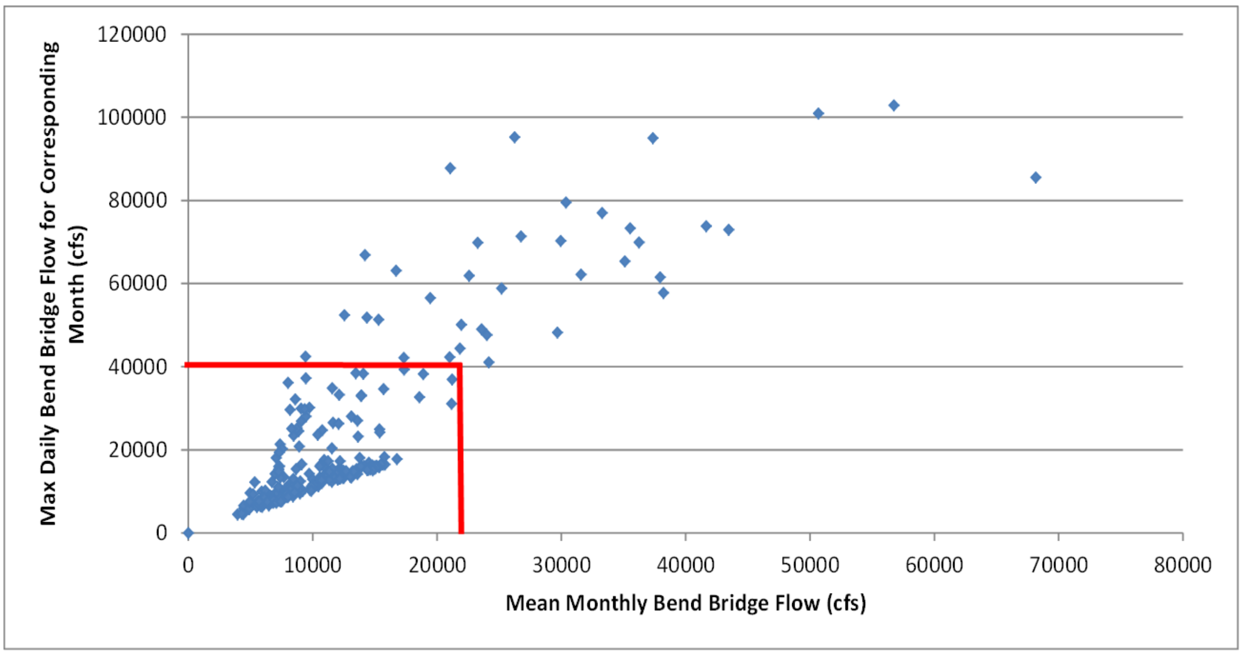


Figure 5.D-92. Relationship between Mean Monthly Flows and Maximum Daily Flows during December through April, Sacramento River at Bend Bridge, 1993–2015. Minimum monthly flow is identified in red.

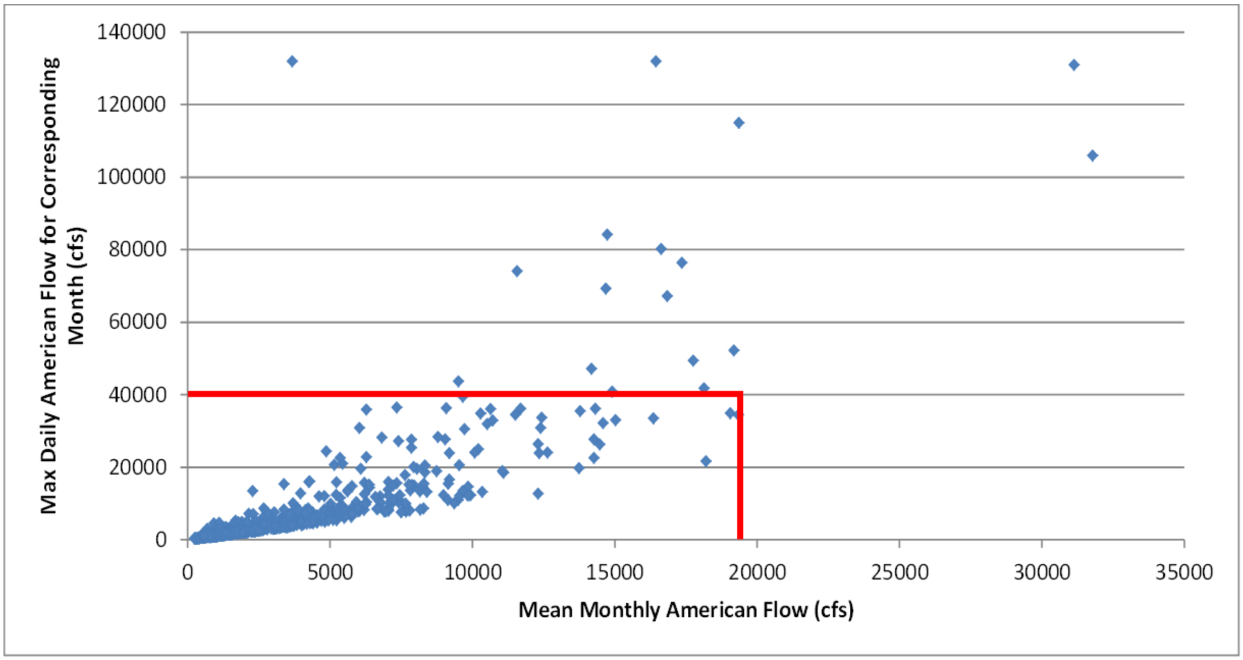


Figure 5.D-93. Relationship between Mean Monthly Flows and Maximum Daily Flows during December through April, American River Downstream of Hazel Avenue, 1950–2015. Minimum monthly flow is identified in red.

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 25th and 75th 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.

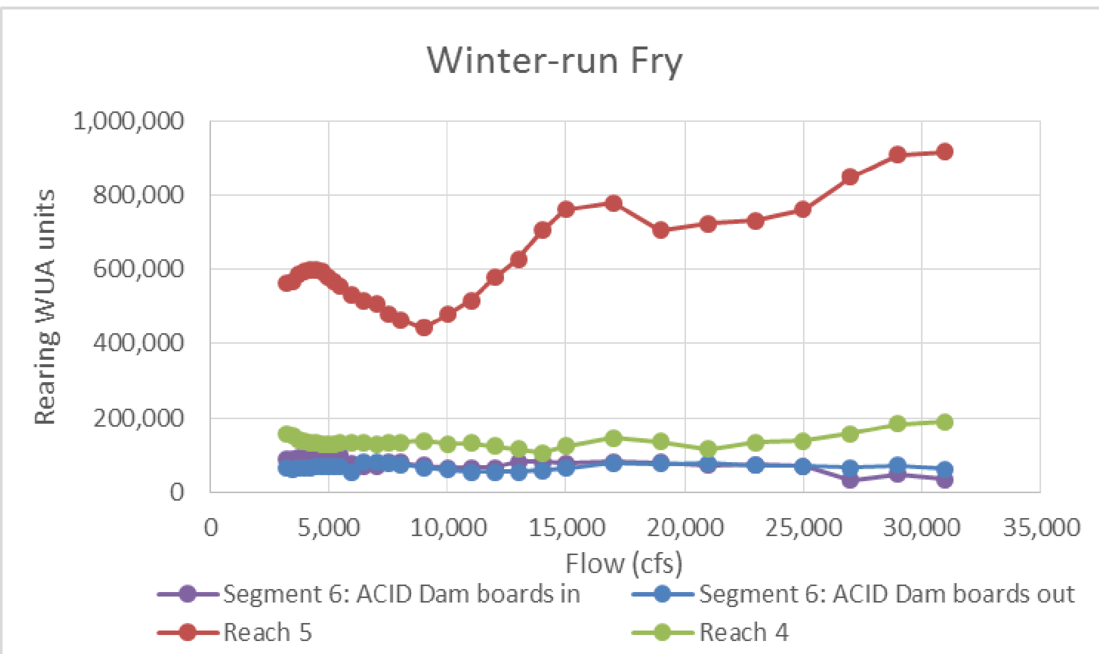


Figure 5.D-94. Rearing WUA curves for Winter-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District.

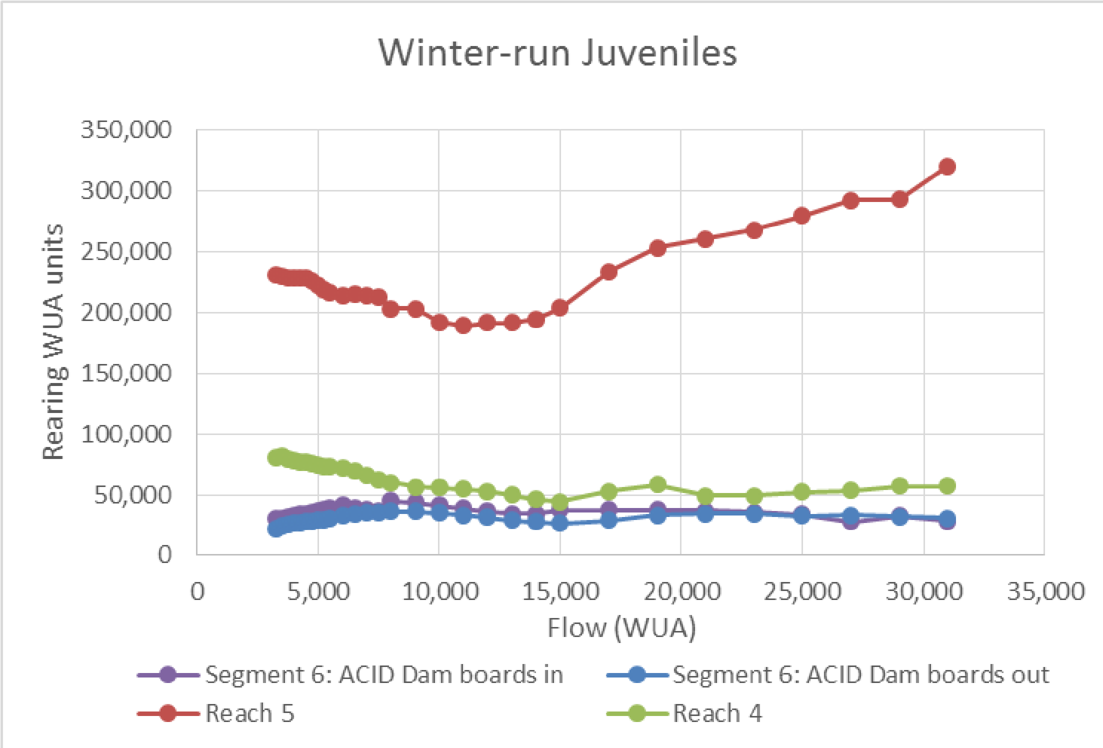


Figure 5.D-95. Rearing WUA curves for Winter-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6. ACID = Anderson-Cottonwood Irrigation District.

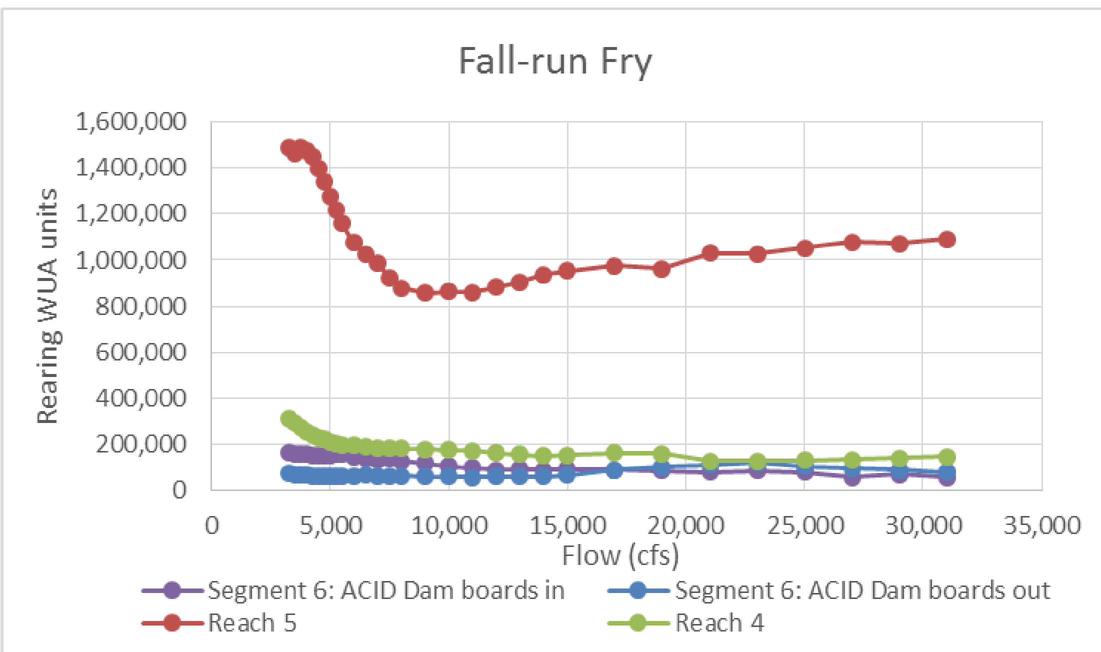


Figure 5.D-96. Rearing WUA Curves for Fall-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6. (The fall-run curves were used to quantify spring-run Chinook salmon WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.

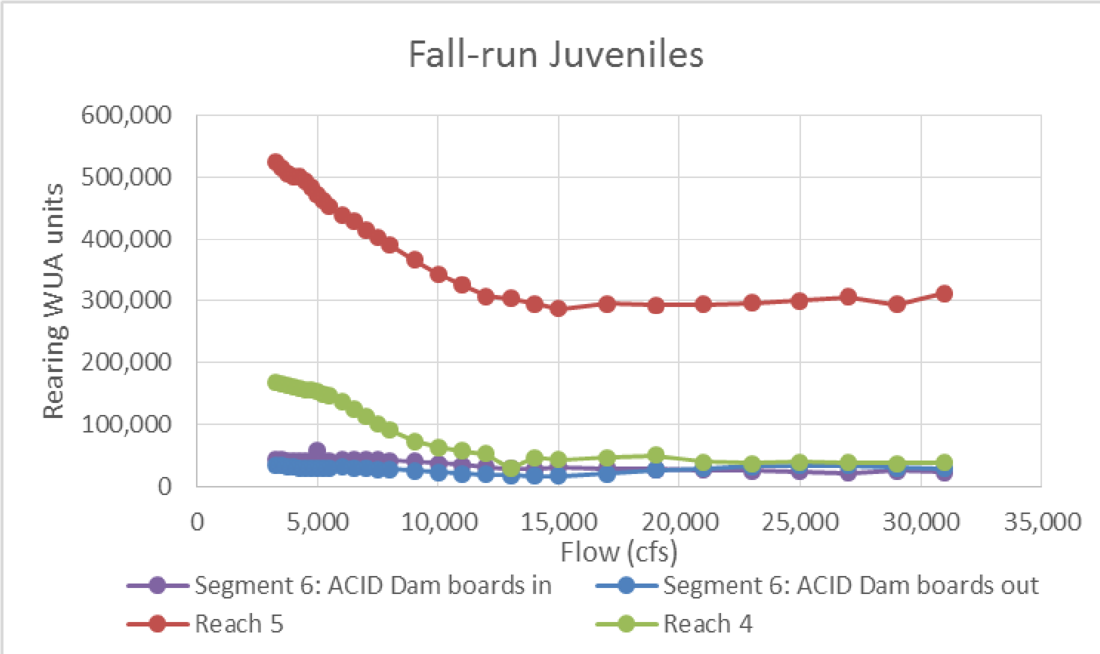


Figure 5.D-97. Rearing WUA Curves for Fall-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6. (The fall-run curves were used to quantify spring-run Chinook salmon WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.

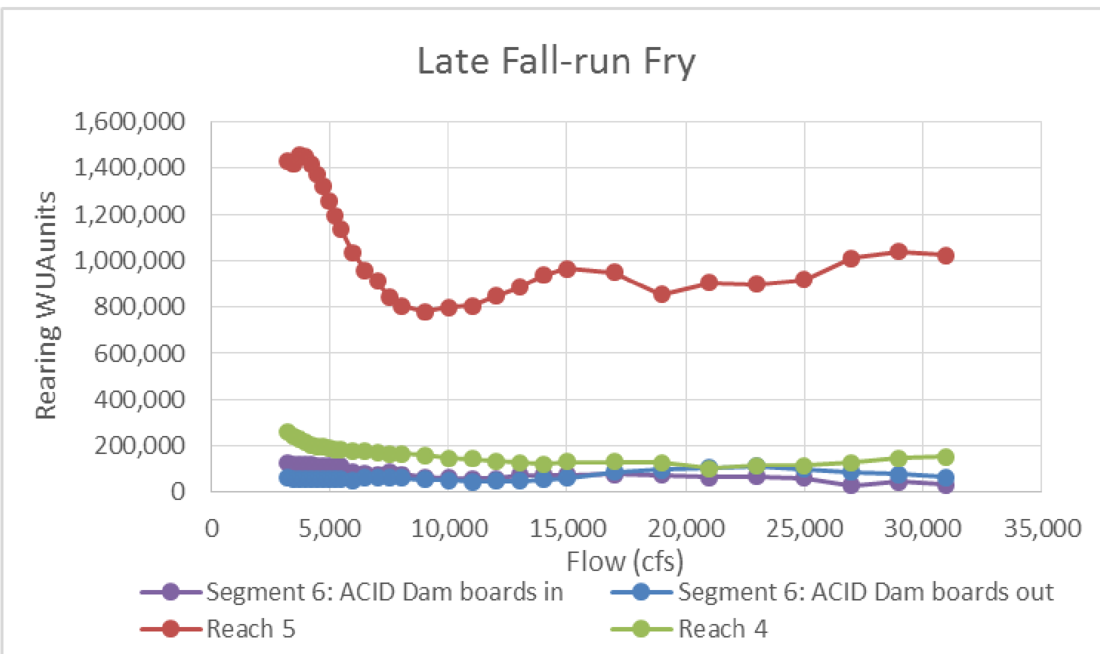


Figure 5.D-98. Rearing WUA Curves for Late Fall-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6. (The late fall-run curves were used to quantify CCV steelhead rearing WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.

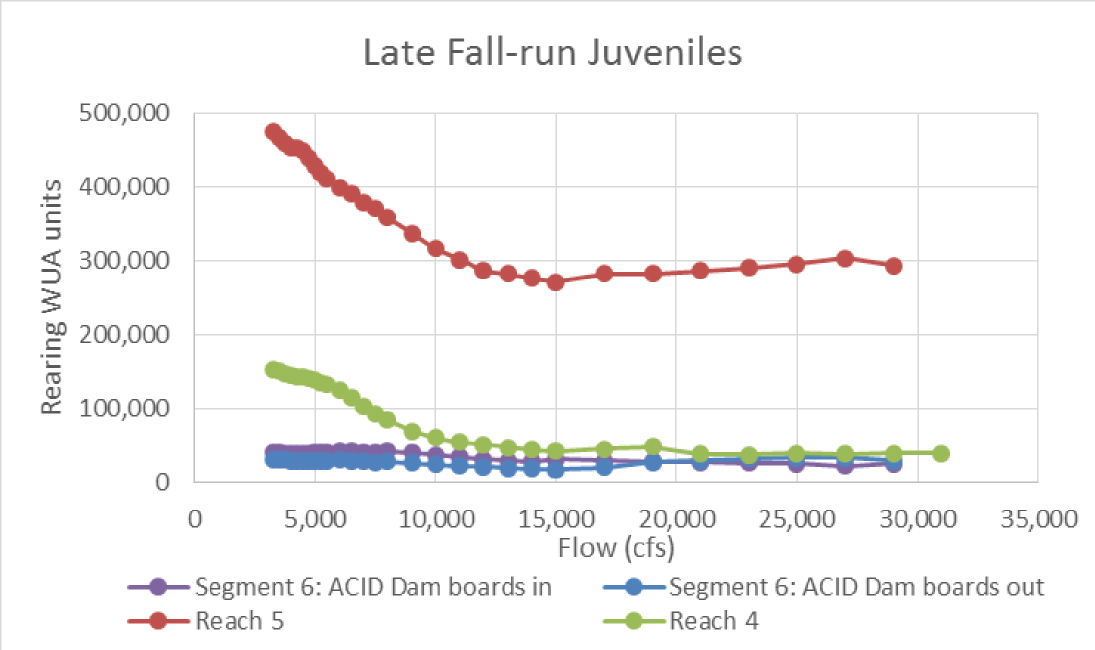


Figure 5.D-99. Rearing WUA Curves for Late Fall-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6. (The late fall-run curves were used to quantify CCV steelhead rearing WUA, as discussed in the text.) ACID = Anderson-Cottonwood Irrigation District.

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 25th- and 75th-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