Appendix O, Tributary Habitat Restoration

Attachment O.3 Sacramento River Weighted Usable Area Analysis

O.3.1 Model Overview

Weighted usable area (WUA) analysis is a method for estimating the availability of suitable habitat in rivers, streams, and floodplains under different flow conditions (Bovee et al. 1998). It has been used primarily for estimating spawning and rearing habitat of fish species. WUA is computed as the surface area of physical habitat available for spawning or rearing, weighted by its suitability. Habitat suitability is determined from field studies of the distributions of redds or rearing juveniles with respect to flow velocities, depths, and substrate or cover in the river or floodplain (Bovee et al. 1998). These data are used in hydraulic and habitat model simulations (e.g., PHABSIM or RIVER2D) that estimate the availability of suitable habitat in a portion of the river at a given flow. WUA curves showing suitable habitat availability versus flow are generated from the simulations. These curves facilitate evaluating how different flow regimes affect spawning and rearing habitat of important fish species.

O.3.2 Model Development

O.3.2.1 Methods

For this analysis, spawning and rearing WUA was estimated for winter-run, spring-run, fall-run, and late fall–run Chinook salmon and California Central Valley steelhead in the Sacramento River. Spawning and rearing WUA were estimated for the Biological Assessment and EIS modeled scenarios from CalSim 3 flow data for each month of the 93-year period of record.

O.3.2.1.1 Sacramento River Spawning WUA

The WUA curves used for Chinook salmon and steelhead spawning habitat in the Sacramento River were obtained from three U.S. Fish and Wildlife Service reports (U.S. Fish and Wildlife Service 2003a, 2005a, 2006). Modeling assumptions used to derive spawning 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 cataloguing conditions at active redds 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 combined to develop spawning habitat WUA curves (Bovee et al. 1998). The WUA curves and tables are used to look up the amount of spawning WUA available at different flows during the spawning periods of the race or species.

U.S. Fish and Wildlife Service (2003a) provides WUA curves and tables for spawning winter-run, fall-run, and late fall-run Chinook salmon and steelhead for three segments of the Sacramento River encompassing the reach from Keswick Dam to Battle Creek (Figure O.3-1). U.S. Fish and Wildlife Service (2005a) provides WUA curves and tables for spawning fall-run in an additional downstream segment (Battle Creek to the former location of the Red Bluff Diversion Dam [RBDD][1]) because spawning for fall-run occurs further downstream than it does for the other races of salmon (Figure O.3-1). The PHABSIM hydraulic model was used for these studies. All WUA tables were updated in 2006 using the more recently developed RIVER2D model (U.S. Fish and Wildlife Service 2006). No spawning WUA curves were developed for spring-run Chinook salmon, so the fall-run curves were used to quantify spring-run spawning habitat. The basis and potential uncertainties of this substitution are discussed below in the *Assumptions/Uncertainty* section below. Although fall-run spawning WUA curves were used as surrogates for spring-run spawning, CalSim 3 flows for the months of spring-run spawning, not those of fall-run spawning, were used to compute the spring-run WUA results. Also, the HSC used to develop the steelhead WUA curves for Sacramento River spawning were obtained from investigations of steelhead redds in the American River (U.S. Fish and Wildlife Service 2003b). The need for and uncertainty of this substitution are also discussed in the *Assumptions/Uncertainty* section below.

Figure O.3-2 through Figure O.3-5 show the flow versus spawning WUA results for winter-run, fall-run, late fall–run, and steelhead in the three upstream 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 by U.S. Fish and Wildlife Service (2003a). Figure O.3-3 shows spawning WUA results for fall-run in the more downstream segment (Segment 3 = Battle Creek to RBDD (U.S. Fish and Wildlife Service 2005a). Note that for Segment 6, separate WUA curves were developed for periods when the ACID Dam boards were installed (April through October) and for when the boards were out because installation of the boards affects water depths and flow velocities for some of the sampling transects used to develop the curves.

Several tributaries enter the Sacramento River between Keswick Dam and Battle Creek, resulting in differences in flow among the river segments. For the U.S. Fish and Wildlife Service studies, Sacramento River flows were measured directly at the sampling transects and were estimated as the sum of Keswick Dam flow releases and tributary gauge readings upstream of the transects. For the WUA analyses used in this analysis, the segment flows were estimated using Sacramento River CalSim 3 flows at Keswick Dam and the Clear Creek, Cow Creek, and Battle Creek confluences. Keswick Dam flows were used for Segment 6 and for Segment 5 upstream of the Clear Creek confluence. Flows at Clear Creek were used for Segment 5 downstream of the confluence. Flows at Cow Creek were used for Segment 4 and flows at Battle Creek were used for Segment 3. For Segment 6, the WUA curves for the months when the ACID Dam boards are installed (April through October) were used with the Keswick Dam 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.

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[1] For simplicity, this location is referred to as the Red Bluff Diversion Dam (RBDD) in this document despite dam decommissioning in 2013.

Mean spawning WUA for this analysis were examined for the principal months of winter-run, spring-run, fall-run, late fall-run and steelhead spawning periods (Table O.3-1) under each water year type and all water year types combined. Total spawning WUA for all months combined was computed by weighting the monthly results by monthly weighting factors (Table O.3-1). For winter-run and late fall-run, these weighting factors were estimated from the mean proportions of redds counted each months in the aerial redd surveys conducted by California Department of Fish and Wildlife during 2006 through 2021 (CDFW unpublished data). Information form Williams (2006) was also used in estimating the late fall-run spawning months. For spring-run and steelhead the weighting factors were derived from information on life-history timings of listed anadromous salmonids of the Central Valley in Appendix C, *Species Spatial and Temporal Domains*, and for fall-run the weighting factors were estimated from information in Moyle et al. 2017.

Table O.3-1. Monthly Weighting Factors for Sacramento River Winter-run, Spring-run, Fall-run, Late fall-run, and Steelhead Spawning.

Month	Winter-run	Spring-run	Fall-run	Late fall-run	Steelhead
January				0.4	0.15
February				0.1	0.35
March				0.1	0.35
April					0.15
May	0.1				
June	0.4				
July	0.4				
August	0.1	0.1			
September		0.6	0.1		
October		0.3	0.3		
November			0.4		
December			0.2	0.4	

For this analysis, spawning and rearing WUA was estimated for winter-run and spring-run Chinook salmon and California Central Valley steelhead in the Sacramento River. Spawning and rearing WUA was estimated for the baseline and alternative model scenarios from CalSim 3 flow data for each month of the 100-year period of record.

O.3.2.2 Methods

O.3.2.2.1 Sacramento River Spawning WUA

The WUA curves used for Chinook salmon and steelhead spawning habitat in the Sacramento River were obtained from three U.S. Fish and Wildlife Service reports (U.S. Fish and Wildlife Service 2003a, 2005a, 2006). Modeling assumptions used to derive spawning 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 cataloguing conditions at active redds 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 combined to develop spawning habitat WUA curves (Bovee et al. 1998). The WUA curves and tables are used to look up the amount of spawning WUA available at different flows during the spawning periods of the race or species.

U.S. Fish and Wildlife Service (2003a) provides WUA curves and tables for spawning winter-run, fall-run, and late fall-run Chinook salmon and steelhead for three segments of the Sacramento River encompassing the reach from Keswick Dam to Battle Creek (Figure O.3-1). The PHABSIM hydraulic model was used for these studies. All WUA tables were updated in 2006 using the more recently developed RIVER2D model (U.S. Fish and Wildlife Service 2006). No spawning WUA curves were developed for spring-run Chinook salmon, so the fall-run curves were used to quantify spring-run spawning habitat. The basis and potential uncertainties of this substitution are discussed below in the *Assumptions/Uncertainty* section below. Although fall-run spawning WUA curves were used as surrogates for spring-run spawning, CalSim 3 flows for the months of spring-run spawning, not those of fall-run spawning, were used to compute the spring-run WUA results. Also, the HSC used to develop the steelhead WUA curves for Sacramento River spawning were obtained from investigations of steelhead redds in the American River (U.S. Fish and Wildlife Service 2003b). The need for and uncertainty of this substitution are also discussed in the *Assumptions/Uncertainty* section below.

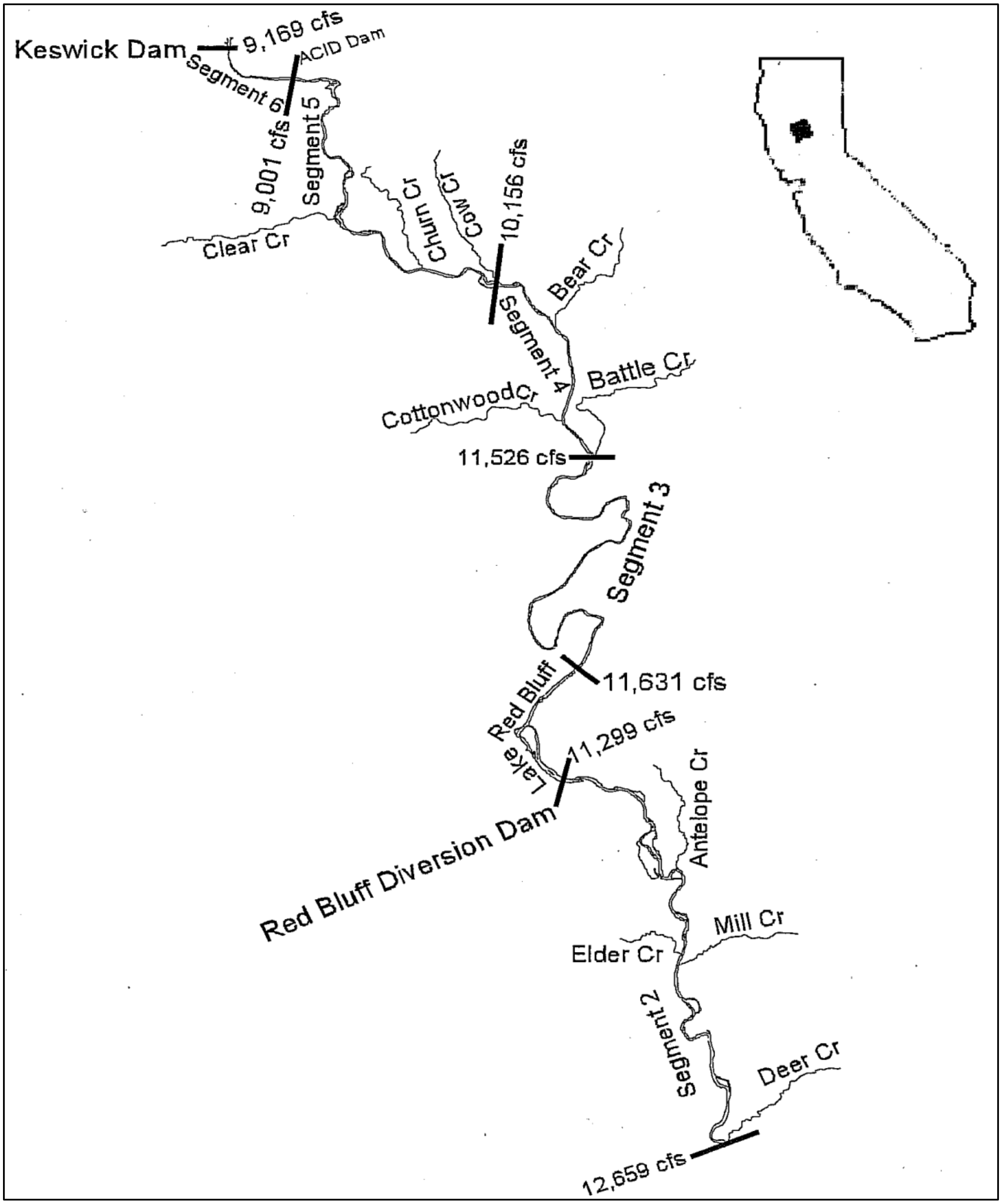
Figure O.3-2 through Figure O.3-5 show the flow versus spawning WUA results for winter-run, fall-run, and steelhead in the three upstream river segments (Segment 6 = Keswick to Anderson-Cottonwood Irrigation District [ACID] Dam, Segment 5 = ACID Dam to Cow Creek, and Segment 4 = Cow Creek to Battle Creek) as provided by U.S. Fish and Wildlife Service (2003a). Note that for Segment 6, separate WUA curves were developed for periods when the ACID Dam boards were installed (April through October) and for when the boards were out because installation of the boards affects water depths and flow velocities for some of the sampling transects used to develop the curves.

Several tributaries enter the Sacramento River between Keswick Dam and Battle Creek, resulting in differences in flow among the river segments. For the U.S. Fish and Wildlife Service studies, Sacramento River flows were measured directly at the sampling transects and were estimated as the sum of Keswick Dam flow releases and tributary gauge readings upstream of the transects. For the WUA analyses used in this report, the segment flows were estimated using Sacramento River CalSim 3 flows at Keswick Dam and the Clear Creek, Cow Creek, and Battle Creek confluences. Keswick Dam flows were used for Segment 6 and for Segment 5 upstream of the Clear Creek confluence. Flows at Clear Creek were used for Segment 5 downstream of the confluence. Flows at Cow Creek were used for Segment 4. For Segment 6, the WUA curves for the months when the ACID Dam boards are installed (April through October) were used with the Keswick Dam 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.

Mean spawning WUAs for this analysis were examined for the principal months of the winter-run, spring-run, and steelhead spawning periods (May through August for winter-run, August through October for spring-run, and January through April for steelhead) under each water year type and all water year types combined. Total spawning WUA for all months combined was computed by weighting the monthly average results by monthly weighting factors (Table O.3-1). For winter-run, these weighting factors were estimated from results of aerial redd surveys conducted by California Department of Fish and Wildlife during 2006 through 2021 (CDFW unpublished data). For spring-run and steelhead the weighting factors were derived from information on life-history timings of listed anadromous salmonids of the Central Valley in LTO Appendix C.

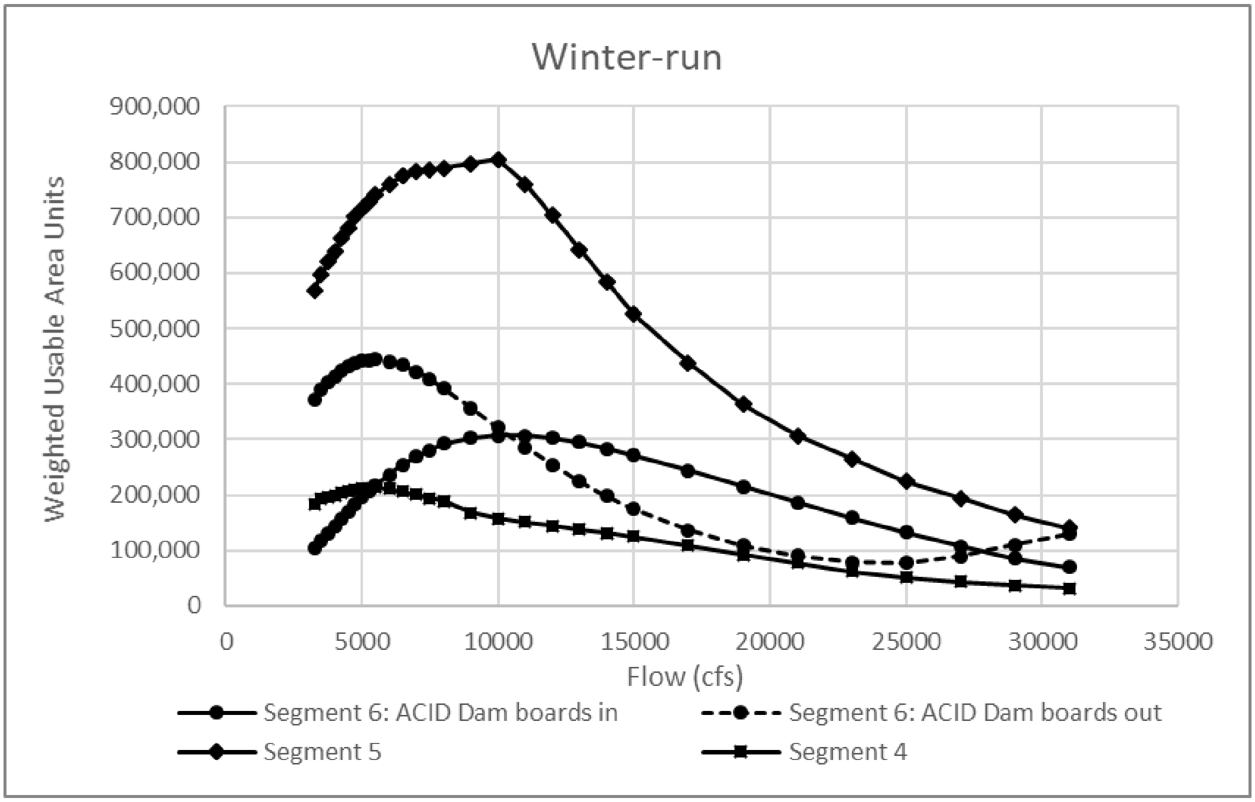
Table O.3-2. Monthly Weighting Factors for Sacramento River Winter-run, Spring-run, and Steelhead Spawning.

Month	Winter-run	Spring-run	Steelhead
January			0.15
February			0.35
March			0.35
April			0.15
May	0.1		
June	0.4		
July	0.4		
August	0.1	0.1	
September		0.6	
October		0.3	
November			
December			



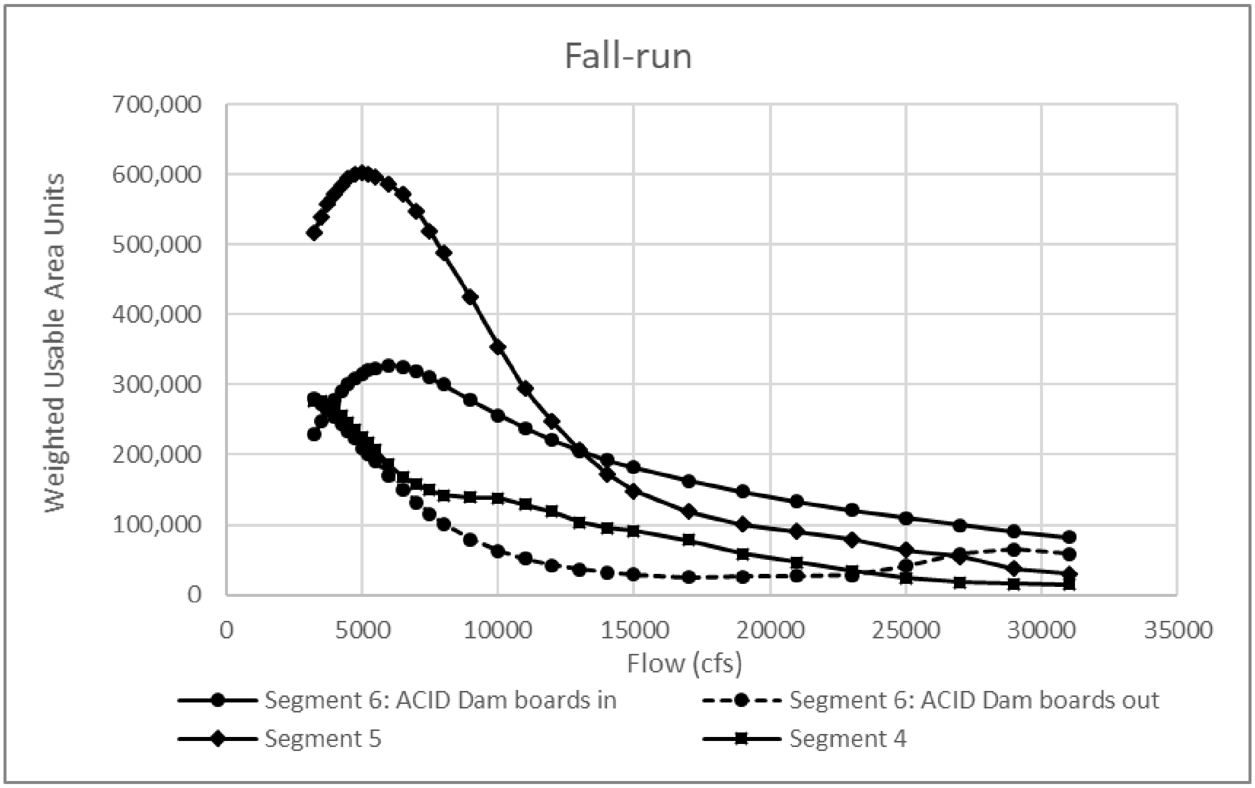
Source: U.S. Fish and Wildlife Service 2003a.
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-1. Segments 2–6 of the Sacramento River Used in U.S. Fish and Wildlife Service Studies to Determine Spawning and Rearing WUA (flows in the figure are the average flows at the upstream boundary of each segment for October 1974 to September 1993).



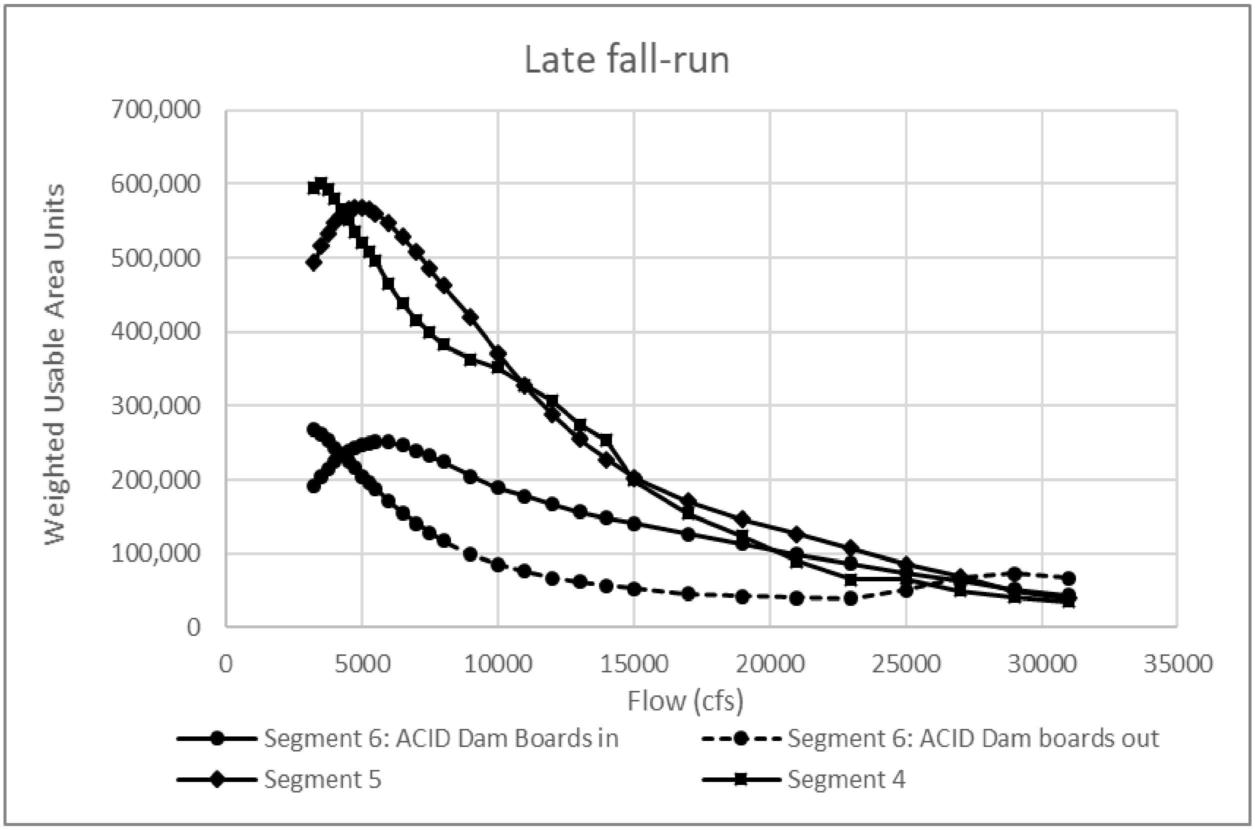
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-2. Spawning WUA curves for Winter-Run Chinook Salmon in the Sacramento River, Segments 4 to 6.



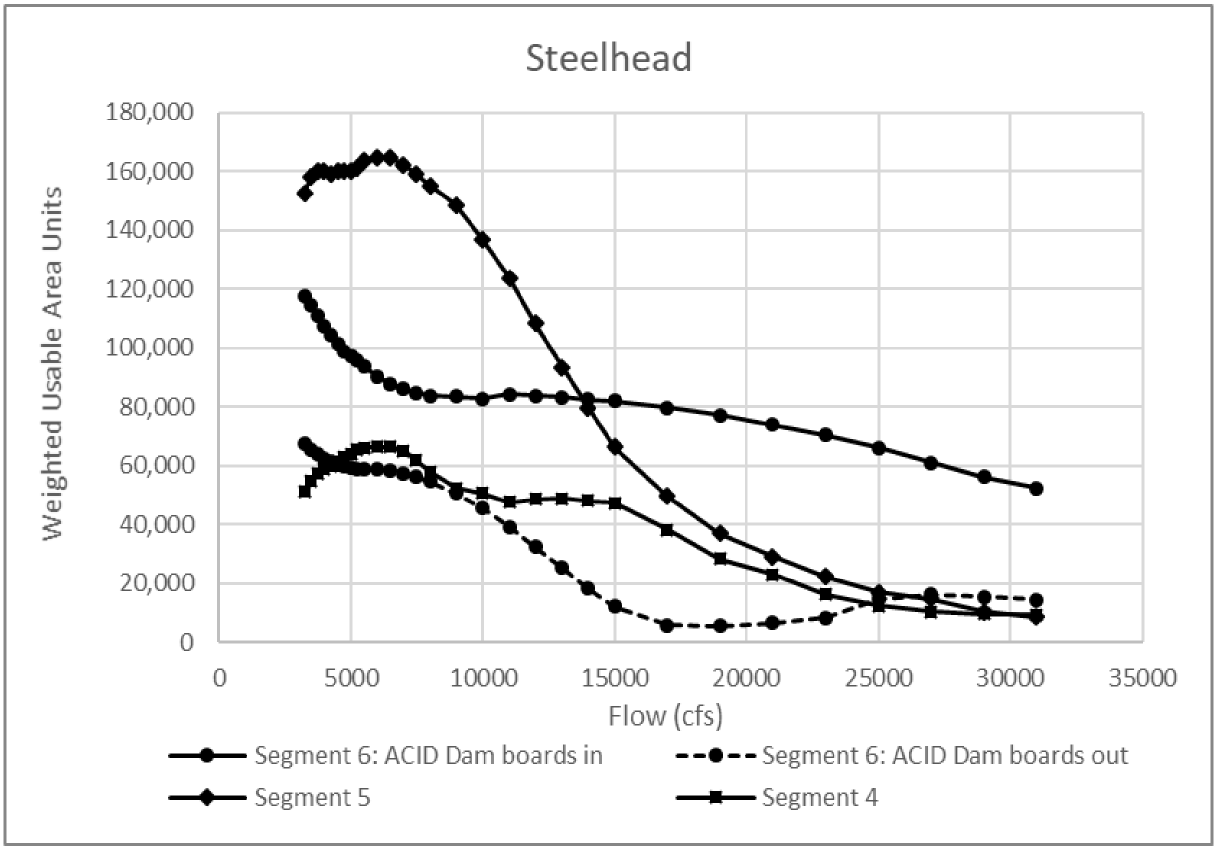
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-3. Spawning WUA Curves for Fall-Run Chinook Salmon in the Sacramento River, Segments 4 to 6. These Curves were used to Quantify Spring-run Spawning WUA, as Discussed in the Text.



ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-4. Spawning WUA Curves for Late Fall–Run Chinook Salmon in the Sacramento River, Segments 4 to 6.



ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-5. Spawning WUA curves for Steelhead in the Sacramento River, Segments 4 to 6.

To evaluate the relative importance of results from the river three segments (four segments for fall-run) for each of the salmon races, the typical spawning distributions of the races with respect to the segments (Table O.3-3) were estimated from the aerial redd surveys conducted by California Department of Fish and Wildlife during 2006 through 2021 (CDFW unpublished data). All races other than fall-run primarily spawn upstream of the Battle Creek confluence, and most fall-run spawning occurs upstream of the RBDD. Little is known about steelhead spawning locations in the Sacramento River, although it was assumed for this analysis that, because of constraints on water temperature and other habitat features, individuals spawn between Keswick Dam and RBDD, where nearly all Chinook salmon spawn (Table O.3-3). For the salmon races, the mean WUA results for the segments were weighted using the percentage in Table O.3-3 to compute total mean spawning WUAs. The total mean spawning WUA results, therefore, were computed to account for both the temporal (Table O.3-1) and spatial distributions (Table O.3-3) of spawning. WUA curves for steelhead were available only for Segments 4, 5, and 6 (Figure O.3-5). The steelhead spawning distribution among the three segments is uncertain, so the WUA results for the three segments were weighted equally in computing the total mean steelhead spawning WUA. Differences in the mean spawning WUA under the baseline scenario (NAA) and the seven management alternatives were examined for the months of the spawning periods of each race or species under each water year type and all water year types combined.

To account for differences in spawning density in the three river segments, the typical spawning distributions of the Chinook races with respect to the segments (Figure O.3-1) were estimated from aerial redd surveys conducted by California Department of Fish and Wildlife during 2006 through 2021 (CDFW unpublished data). All races other than fall-run primarily spawn upstream of the Battle Creek confluence, and most fall-run spawn upstream of the RBDD (Table O.3-3). Little is known about steelhead spawning locations in the Sacramento River, although it was assumed for this analysis that, because of constraints on water temperature and other habitat features, individuals spawn between Keswick Dam and RBDD, where nearly all Chinook salmon spawn (Table O.3-3). For winter-run and spring-run Chinook, the mean WUA results for the segments were weighted using the percentage in Table O.3-3 to compute total mean spawning WUAs. The total mean spawning WUA results, therefore, were computed to account for both the temporal distribution (Table O.3-1) and spatial distribution (Table O.3-3) of winter-run and spring-run spawning. WUA curves for steelhead were available only for Segments 4, 5, and 6 (Figure O.3-5). The steelhead spawning distribution among the three segments is uncertain, so the WUA results for the three segments were weighted equally in computing the total mean steelhead spawning WUA. The mean spawning WUA under the three baseline scenarios and the four management alternatives were examined for the months of the spawning periods of each race or species under each water year type and all water year types combined.

Table O.3-3. Distributions of Spawning Redds among WUA River Segments as Percent of Total in the Sacramento River for Chinook Salmon Runs.

Segment No.	Description	River Miles	Winter-Run	Spring-Run	Fall-Run	Late Fall–Run
6	Keswick to ACID	302-298.5	35.6%	5.9%	17.4%	62.0%
5	ACID to Cow Creek	298.5-280	63.0%	72.1%	32.9%	19.8%
4	Cow Creek to Battle Creek	280-271	0.4%	6.7%	14.2%	8.7%
3	Battle Creek to RBDD	271-243	0.2%	3.6%	18.1%	3.7%
2	Downstream of RBDD	—	0.8%	11.7%	17.4%	5.8%

ACID = Anderson-Cottonwood Irrigation District; RBDD = Red Bluff Diversion Dam.

O.3.2.2.2 Sacramento River Rearing WUA

The rearing habitat WUA curves used for Chinook salmon rearing habitat in the Sacramento River were obtained from a U.S. Fish and Wildlife Service report (U.S. Fish and Wildlife Service 2005b). As noted above for spawning habitat, WUA is computed as the surface area of physical habitat available weighted by its suitability. Modeling assumptions used to derive rearing 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 of cover. The race- or species-specific suitability of the habitat with respect to these variables is determined from field observations and measurements of habitat use by the fish, which is used to develop HSC for each race or species. Hydraulic modeling (using PHABSIM in the U.S. Fish and Wildlife Service 2005b study) is then used to estimate the amount of rearing habitat available for different HSC levels at different river flows, and the results are used to develop rearing habitat WUA curves and tables (Bovee et al. 1998). These curves and tables are used to look up the amount of rearing WUA available at different flows.

U.S. Fish and Wildlife Service (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 (Figure O.3-1). 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 steelhead, but as discussed below in the *Assumptions/Uncertainty* section, the fall-run curves were used to quantify spring-run rearing habitat and the late fall–run curves were used for steelhead. Although fall-run rearing WUA curves were used as surrogates for spring-run rearing, CalSim 3 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 steelhead rearing WUA results. Figure O.3-6 through Figure O.3-11 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 ACID Dam, Segment 5 = ACID Dam to Cow Creek, and Segment 4 = Cow Creek to Battle Creek) as provided in U.S. Fish and Wildlife Service (2005b). Note that for Segment 6, separate WUA curves were developed for periods when the ACID Dam boards are installed (April through October) and for when the boards are out because installation of the boards affects water depths and flow 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.

As previously noted, several tributaries enter the Sacramento River between Keswick Dam and Battle Creek, resulting in differences in flow among the river segments. For the U.S. Fish and Wildlife Service studies, flows were measured directly at the sampling transects and were estimated as the sum of Keswick flow releases and tributary gauge readings upstream of the transects. To estimate rearing WUA for this analysis, the segment flows were estimated using Sacramento River CalSim 3 flows at Keswick Dam and the confluences at Clear Creek and Battle Creek for Segments 6, 5, and 4, respectively. Keswick Dam flows were also used for Segment 5 upstream of the Clear Creek confluence. 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. Differences in the mean rearing WUA under baseline conditions and alternatives were examined for the months of the fry and juvenile rearing periods for each race or species under each water year type and all water year types combined.

It should be noted that many winter-run fry begin moving downstream shortly after emerging and a majority of the fry may rear primarily downstream of the RBDD (Martin 2001). This may also be true for fry of the other salmon runs and steelhead. Unfortunately, no rearing WUA studies have been conducted for the Sacramento River downstream of the RBDD. Because of uncertainties and variability in the distribution of fry and juvenile rearing with respect to the three river segments for which rearing WUA curves were developed, results from the three segments were weighted equally in computing the total mean WUAs.

Mean fry rearing WUAs from each of the river segments were determined for the principal months of rearing for winter-run, spring-run, and steelhead fry (Table O.3-4) under each water year type and all water year types combined. Mean rearing WUA for all months combined was computed by weighting the monthly average results by monthly weighting factors (Table O.3-4). The weighting factors for winter-run, spring-run, and steelhead were estimated from results of the rotary screw trap monitoring at RBDD provided in the USFWS Sac PAS online database [link]. The primary months of fry rearing for fall-run and late fall-run were obtained in consultations with NMFS for the CWF project [don't know how to cite this – Rick may be able to help]. The months of the rearing period for these two races were weighted equally.

Table O.3-4. Monthly Weighting Factors for Fry Rearing of Sacramento River Winter-run, Spring-run, Fall-run, Late Fall-run and Steelhead.

Month	**Winter-run**	**Spring-run**	**Fall-run**	**Late Fall-run**	**Steelhead**
January		0.2	0.25		
February		0.22	0.25		
March		0.2	0.25	0.25	
April		0.18		0.25	0.05
May				0.25	0.15
June				0.25	0.2
July					0.25
August	0.05				0.2
September	0.35				0.1
October	0.35				0.05
November	0.2	0.05			
December	0.05	0.15	0.25		

The beginning of the juvenile (length >60 millimeters) rearing period was difficult to derive from field study data because of a high level of temporal overlap with the end of the fry rearing period. Therefore, the juvenile period was assumed to begin a fixed period after the start of the fry period. Fry upstream of RBDD have a growth rate of about 0.33 millimeters per day (Healey 1991) and the initial length of fry at emergence is about 40 millimeters (McMichael et al. 2005; Geist et al. 2006), so the juvenile period was determined to begin two months after the start of the fry period: October for winter-run, January for spring-run, February for fall-run, May for late fall-run, and June for steelhead. Young of year juveniles largely move downstream below RBDD by January for winter-run, by May for spring-run, and by September for steelhead (see Figures 2, 27, and 34, respectively, in LTO Appendix C). Therefore, juvenile rearing WUA was computed for October through January for winter-run, January through May for spring-run, and June through September for steelhead. The juvenile rearing periods upstream of RBDD for fall-run and later fall-run were assumed to be similar in duration to those of spring-run. No monthly weighting factors were used for these periods because monthly variations in abundance of the juveniles is highly uncertain. Mean fry and juvenile rearing WUA under the three baseline scenarios and four management alternatives were examined for the months of the rearing periods of each race or species under each water year type and all water year types combined.

O.3.2.2.3 Sacramento River Rearing WUA

The rearing habitat WUA curves used for Chinook salmon rearing habitat in the Sacramento River were obtained from a U.S. Fish and Wildlife Service report (U.S. Fish and Wildlife Service 2005b). As noted above for spawning habitat, WUA is computed as the surface area of physical habitat available weighted by its suitability. Modeling assumptions used to derive rearing 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 of cover. The race- or species-specific suitability of the habitat with respect to these variables is determined from field observations and measurements of habitat use by the fish, which is used to develop HSC for each race or species. Hydraulic modeling (using PHABSIM in the U.S. Fish and Wildlife Service 2005b study) is then used to estimate the amount of rearing habitat available for different HSC levels at different river flows, and the results are used to develop rearing habitat WUA curves and tables (Bovee et al. 1998). These curves and tables are used to look up the amount of rearing WUA available at different flows.

U.S. Fish and Wildlife Service (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 (Figure O.3-1). 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 steelhead, but as discussed below in the *Assumptions/Uncertainty* section, the fall-run curves were used to quantify spring-run rearing habitat and the late fall–run curves were used for steelhead. Although fall-run rearing WUA curves were used as surrogates for spring-run rearing, CalSim 3 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 steelhead rearing WUA results.

The use of the fall-run and late fall–run Chinook salmon rearing WUA curves as surrogates to model rearing habitat for spring-run and steelhead, respectively, has been endorsed by Mark Gard, who led the USFWS studies that produced the Sacramento River WUA curves (Gard pers. comm.). These substitutions have been adopted in other studies. For instance, the SacEFT model, which produces spawning and rearing WUA outputs for CV spring-run Chinook salmon and steelhead, derives the spring-run spawning and rearing WUA results using the fall-run WUA curves as surrogates and the steelhead rearing WUA results using the late fall–run WUA curves as surrogates (ESSA Technologies 2011; Robinson pers. comm.). It should be noted that this practice introduces additional uncertainty to the spring-run and steelhead results.

Figure O.3-6 through Figure O.3-11 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 ACID Dam, Segment 5 = ACID Dam to Cow Creek, and Segment 4 = Cow Creek to Battle Creek) as provided in U.S. Fish and Wildlife Service (2005b). Note that for Segment 6, separate WUA curves were developed for periods when the ACID Dam boards are installed (April through October) and for when the boards are out because installation of the boards affects water depths and flow velocities for some of the sampling transects used to develop the curves. All rearing WUA analyses were limited to young of year juveniles (< one year old).

As previously noted, several tributaries enter the Sacramento River between Keswick Dam and Battle Creek, resulting in differences in flow among the river segments. For the U.S. Fish and Wildlife Service studies, flows were measured directly at the sampling transects and were estimated as the sum of Keswick flow releases and tributary gauge readings upstream of the transects. To estimate rearing WUA for this analysis, the segment flows were estimated using Sacramento River CalSim 3 flows at Keswick Dam and the confluences at Clear Creek and Battle Creek for Segments 6, 5, and 4, respectively. Keswick Dam flows were also used for Segment 5 upstream of the Clear Creek confluence. 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.

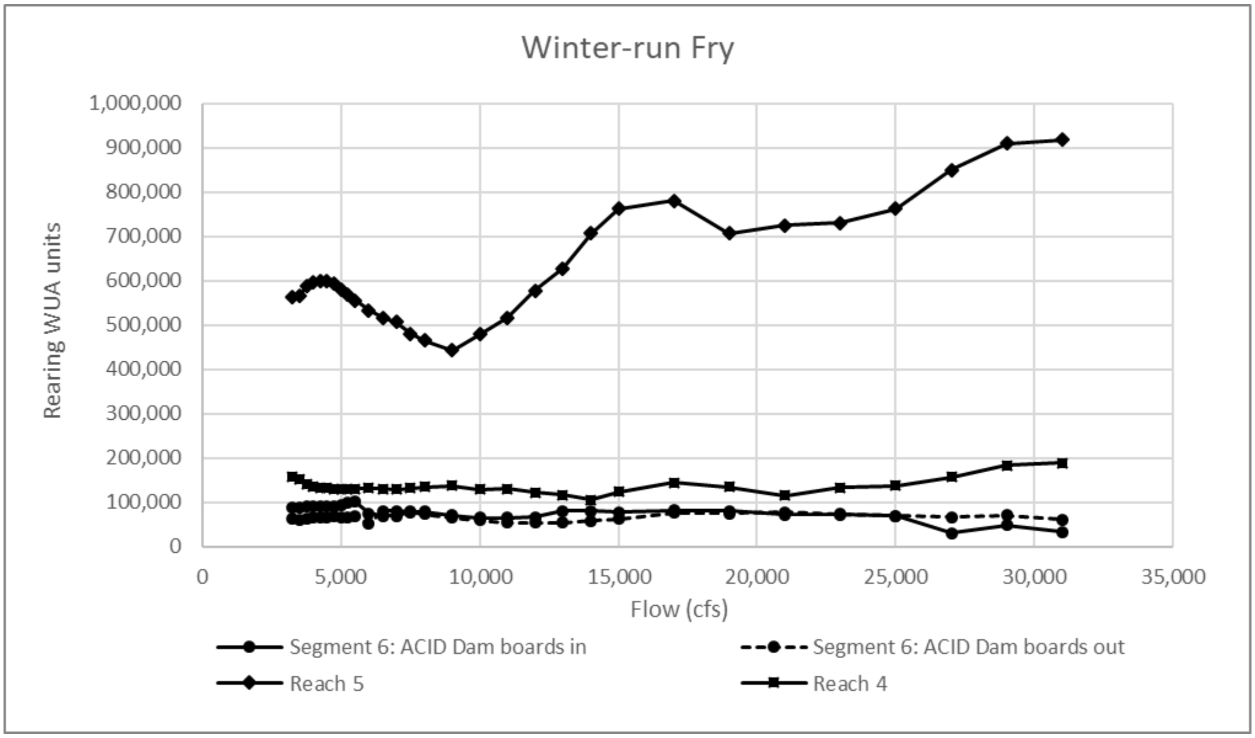
It should be noted that many winter-run fry begin moving downstream shortly after emerging and a majority of the fry may rear primarily downstream of the RBDD (Martin 2001). This may also be true for fry of the other salmon runs and steelhead. Unfortunately, no rearing WUA studies have been conducted for the Sacramento River downstream of the RBDD. Because of uncertainties and variability in the distribution of fry and juvenile rearing with respect to the three river segments for which rearing WUA curves were developed, results from the three segments were weighted equally in computing the total mean WUAs.

Mean fry rearing WUAs from each of the river segments were determined for the principal months of rearing for winter-run, spring-run, and steelhead fry (Table O.3-5) under each water year type and all water year types combined. Total mean rearing WUA for all months combined was computed by weighting the monthly average results by monthly weighting factors (Table O.3-5). These weighting factors were estimated from results of the rotary screw trap monitoring at RBDD provided in the USFWS Sac PAS online database [link].

The beginning of the juvenile (length >60 millimeters) rearing period was difficult to derive from field study data because of a high level of temporal overlap with the end of the fry rearing period. Therefore, the juvenile period was assumed to begin a fixed period after the start of the fry period. Fry upstream of RBDD have a growth rate of about 0.33 millimeters per day (Healey 1991) and the initial length of fry at emergence is about 40 millimeters (McMichael et al. 2005; Geist et al. 2006), so the juvenile period was determined to begin two months after the start of the fry period: October for winter-run, January for spring-run, and June for steelhead. Young of year juveniles largely move downstream below RBDD by January for winter-run, by May for spring-run, and by September for steelhead (see Figures 2, 27, and 34, respectively, in LTO Appendix C). Therefore, juvenile rearing WUA was computed for October through January for winter-run, January through May for spring-run, and June through September for steelhead. No monthly weighting factors were used for these periods because monthly variations in abundance of the juveniles is highly uncertain. Mean fry and juvenile rearing WUA under the three baseline scenarios and four management alternatives were examined for the months of the rearing periods of each race or species under each water year type and all water year types combined.

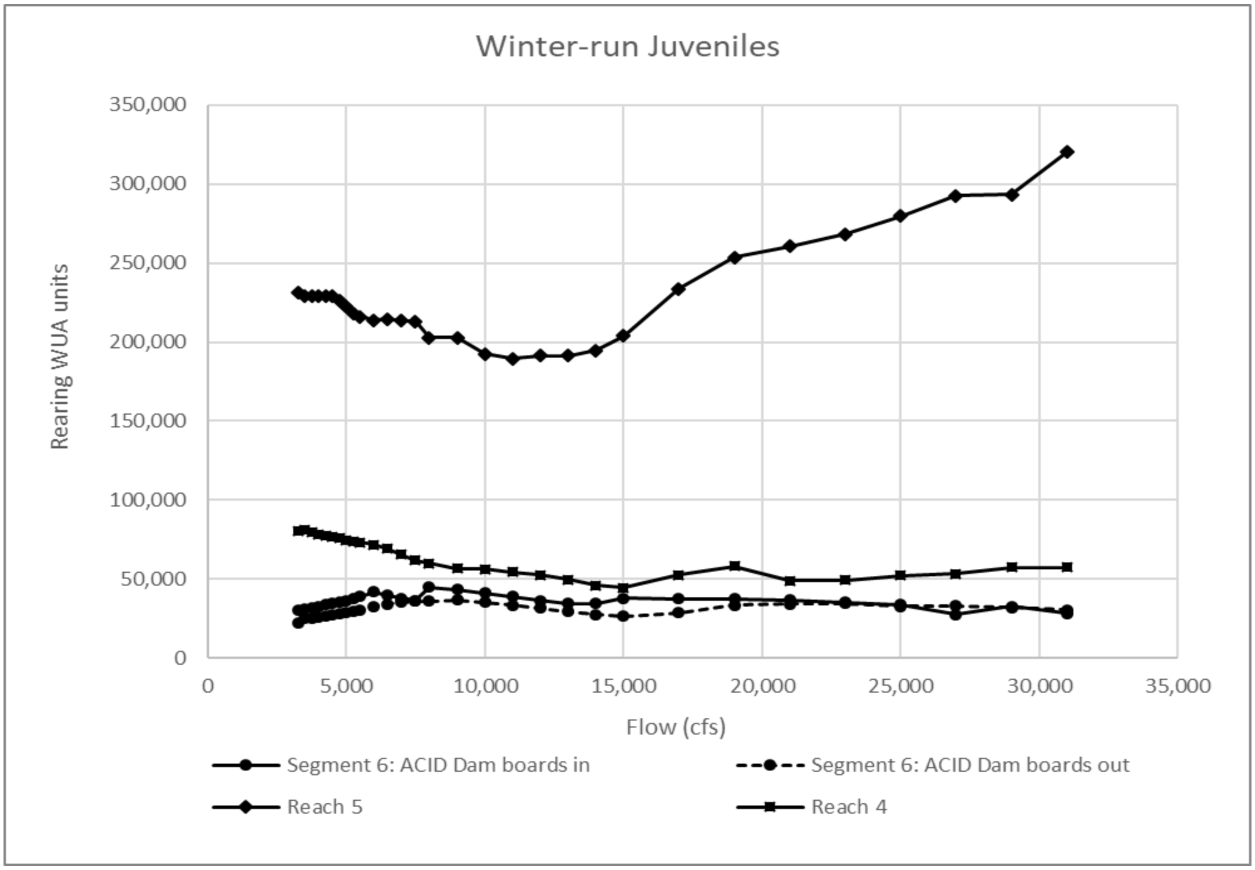
Table O.3-5. Monthly Weighting Factors for Sacramento River Winter-run, Spring-run, and Steelhead Fry Rearing.

Month	Winter-run	Spring-run	Steelhead
January		0.2	
February		0.22	
March		0.2	
April		0.18	0.05
May			0.15
June			0.2
July			0.25
August	0.05		0.2
September	0.35		0.1
October	0.35		0.05
November	0.2	0.05	
December	0.05	0.15	



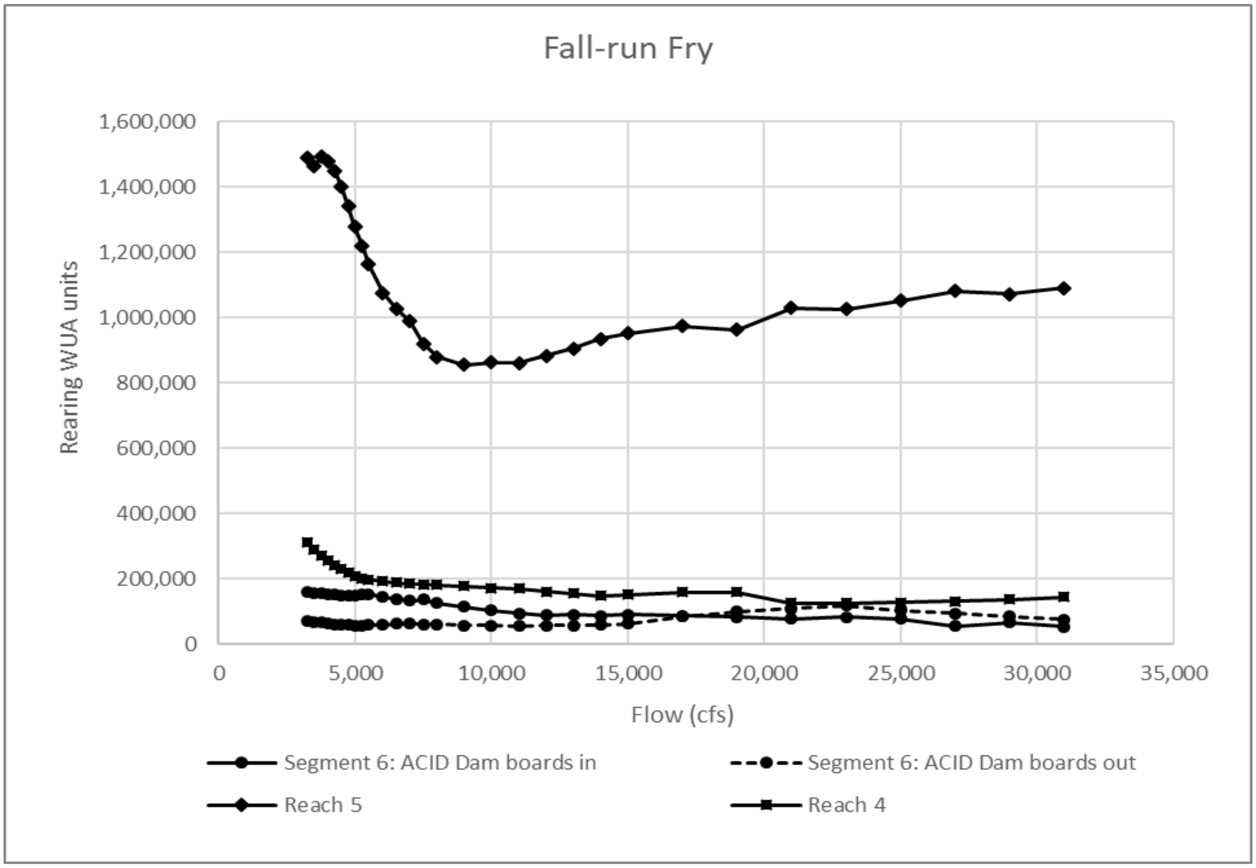
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-6. Rearing WUA Curves for Winter-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6.



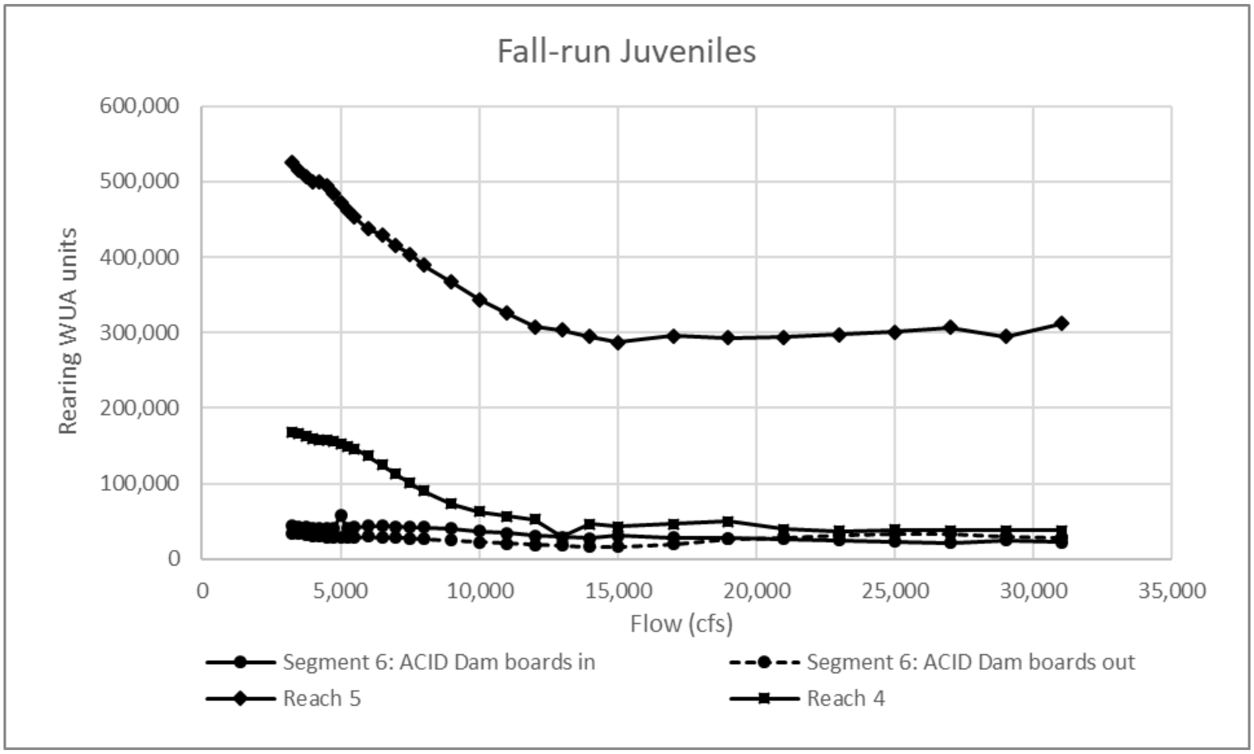
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-7. Rearing WUA Curves for Winter-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6.



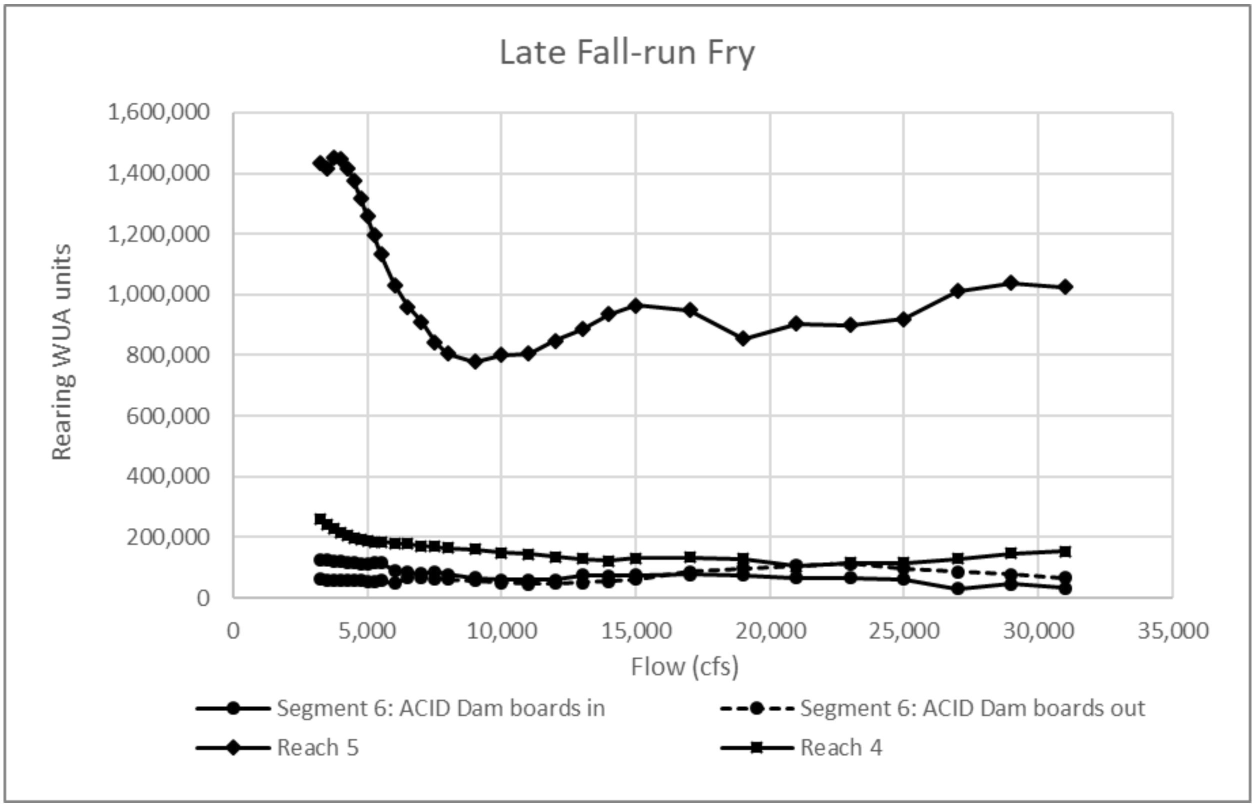
These Curves were used to Quantify Spring-run Fry Rearing WUA, as Discussed in the Text.
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-8. Rearing WUA Curves for Fall-Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6.



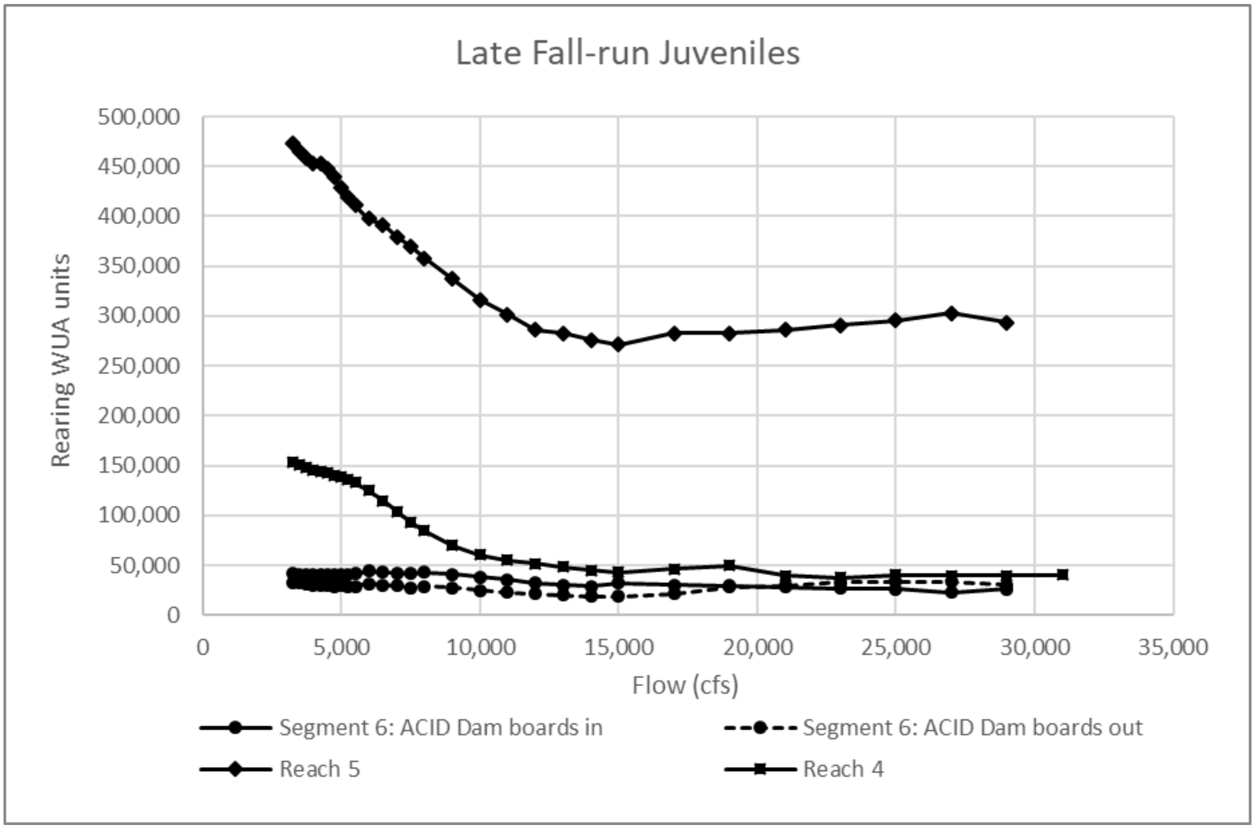
These Curves were used to Quantify Spring-run Juvenile WUA, as Discussed in the Text.
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-9. Rearing WUA Curves for Fall-Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6.



These Curves were used to Quantify Steelhead Fry Rearing WUA, as Discussed in the Text.
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-10. Rearing WUA Curves for Late Fall–Run Chinook Salmon Fry in the Sacramento River, Segments 4 to 6.



These Curves were used to Quantify Steelhead Juvenile Rearing WUA, as Discussed in the Text.
ACID = Anderson-Cottonwood Irrigation District.

Figure O.3-11. Rearing WUA Curves for Late Fall–Run Chinook Salmon Juveniles in the Sacramento River, Segments 4 to 6.

A potential limitation of all the WUA curves presented above, as of all such habitat-based 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 would continue to do so through the life of the Project. If the channel characteristics substantially change, the shape of the curves may no longer be applicable. A further limitation of the rearing WUA curves is that they were developed for the Sacramento River upstream of Battle Creek, but all races of Chinook salmon and steelhead spend time rearing downstream of this part of the river.

O.3.2.3 Assumptions/Uncertainty

This section includes two subsections. The first subsection provides a list of some important uncertainties and assumptions of the WUA analyses used for this analysis. The second subsection provides a more general discussion of the validity of WUA analysis, responding to concerns that have been raised in the scientific literature.

O.3.2.3.1 Important Uncertainties and Assumptions of the WUA Analyses Conducted for the Effects Analyses

1. The CalSim 3 operations model used to estimate spawning and rearing WUA under the baseline and the alternatives employs a monthly timestep. Therefore, the WUA results should be treated as monthly averages. Monthly average WUA results faithfully represent the average conditions affecting the fish. Therefore, using monthly averages to compare WUA results is acceptable for showing differences in the effects of the different flow regimes under baseline and alternatives conditions. Weighting by the weighting factors in Table O.3-1 and Table O.3-5 ensures that the comparisons account for differences in the amount of spawning occurring in each month, improving the validity of the results.

2. As noted previously, fall-run Chinook salmon WUA curves were used to model Sacramento River spring-run habitat in the analysis. This substitution follows previous practice. For instance, two models that currently produce spawning WUA outputs for spring-run Chinook salmon, SALMOD and Sacramento River Ecological Flows Tool (SacEFT), derive the spring-run WUA results using the fall-run Chinook salmon spawning WUA curves as surrogates (Bartholow 2004; ESSA Technologies 2011). Mark Gard, who led the U.S. Fish and Wildlife Service studies that produced the Sacramento River WUA curves, has endorsed this practice (Gard pers. comm.). This practice introduces additional uncertainty to the spring-run Chinook salmon results.

3. As described previously, the habitat suitability criteria used to develop the steelhead WUA curve for Sacramento River spawning were obtained from investigations of steelhead redds in the American River (U.S. Fish and Wildlife Service 2003b) because few steelhead redds were observed in the Sacramento River and 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 (U.S. Fish and Wildlife Service 2003a).

4. Rearing WUA curves were developed for the Sacramento River only for reaches upstream of Battle Creek, but all races of Chinook salmon and steelhead spend time rearing downstream of this part of the river. This limitation creates uncertainty regarding effects of the baseline and alternatives on rearing habitat in the Sacramento River downstream of Battle Creek.

5. As previously discussed, no spring-run Chinook salmon or steelhead rearing WUA curves were developed in the U.S. Fish and Wildlife Service studies. Following previous practice, the fall-run and late fall–run Chinook salmon rearing WUA curves were used as surrogates in this analysis to model rearing habitat for spring-run and steelhead, respectively. Mark Gard, who led the U.S. Fish and Wildlife Service studies that produced the Sacramento River WUA curves, has endorsed this practice for both spring-run Chinook salmon and steelhead (Gard pers. comm.). The use of these substitutions has previously been adopted for the SacEFT model (ESSA Technologies 2011; Robinson pers. comm.). It should be

noted that this practice introduces additional uncertainty to the spring-run and steelhead results.

6. The suitability of physical habitat for salmon and steelhead spawning is largely a function of substrate particle size, water depth, and flow velocity. Other unmeasured factors (e.g., flow vortices, water quality, etc.) could influence habitat suitability, contributing to uncertainty in the results.
7. The suitability of physical habitat for salmon and steelhead fry and juvenile rearing is largely a function of availability of cover, water depth, and flow velocity. Other unmeasured factors (e.g., flow vortices, complex feeding behaviors, water quality, etc.) could influence habitat suitability, contributing to uncertainty in the results.
8. The output of the WUA analysis, Weighted Usable Area, is an index of habitat suitability, not an absolute measure of habitat surface area. In the literature, Weighted Usable Area is often expressed as square feet, square meters, or acres for a given linear distance of stream, which is misleading and can result in unsupported conclusions (Payne 2003; Railsback 2016; Reiser and Hilgert 2018).
9. Both spawning and rearing WUA analyses assume that the channel characteristics of the river, such as proportions of mesohabitat types, during the time of field data collection by U.S. Fish and Wildlife Service (1995–1999) have remained in dynamic equilibrium to the present time and will continue to do so through the life of the Project. If the channel characteristics substantially changed, the shape of the curves might no longer be applicable.

O.3.2.3.2 Discussion Regarding Validity of Weighted Usable Area Analysis

WUA analysis is among the most widely used and recognized analytical tools for assessing effects of flow on fish populations (Reiser and Hilgert 2018). Procedures for quantifying WUA were developed and standardized by USFWS in the 1970s and they have since been widely adopted by researchers (e.g., Bourgeois et al. 1996; Beecher et al. 2010; Railsback 2016; Naman et al. 2020). However, WUA analysis has received some criticism from instream flow analysis practitioners, especially in recent years. Many conclusions in this analysis regarding effects on fish of changes in flow resulting from operations are based on WUA analyses. Therefore, it is important to understand and evaluate the criticisms of WUA analysis and consider any potential limitations for assessing flow-related effects.

Two frequent criticisms of the WUA analysis that are most potentially relevant with regard to the results and conclusions of the analysis are: (1) WUA analysis fails to directly evaluate many factors that are known to be important to fish population production, including water quality (especially temperature), predation, competition, and food supply (Beecher et al. 2010; Railsback 2016; Naman et al. 2019, 2020), and (2) the models employed to develop the WUA curves (especially PHABSIM) are antiquated, the field observations and measurements used to run the models are not sufficiently fine-grained to capture important highly localized factors, and the models do not adequately capture many dynamic properties of fish habitat use (Railsback 2016; Reiser and Hilgert 2018).

Regarding the first criticism, PHABSIM and the WUA curves they produce were never meant to address all factors affecting fish populations. As noted in a recent paper rebutting many of the criticisms of PHABSIM (Stalnaker et al. 2017): "PHABSIM is a component of instream flow incremental methodology (IFIM), which is a multifaceted decision support system that looks at riverine ecology for the purpose of making water management decisions." The IFIM uses a suite of evaluation tools (including PHABSIM) and investigates water quality factors and other factors that affect fish in addition to the hydraulic-related habitat conditions analyzed using PHABSIM or other hydraulic habitat models (Beecher 2017). These methods typically include evaluation tools for assessing effects of water temperatures, redd dewatering, adult migration passage, emigrating juvenile salmonid survival, water diversion entrainment, and other factors. Analysis methods other than PHABSIM are used to evaluate the other factors, which may or may not be affected by flow. Conclusions regarding effects of the Project on a species are based on evaluations of the results for all the factors analyzed.

The second criticism is more specific to the modeling tools used for WUA analyses. Many of the limitations of PHABSIM cited by critics are acknowledged by its defenders (Beecher 2017; Stalnaker et al. 2017; Reiser and Hilgert 2018). Some of the cited shortcomings are common to any model that attempts to simulate complex ecological systems. Others reflect that PHABSIM is antiquated; newer, more powerful procedures have been incorporated into newer models. In fact, many studies have replaced PHABSIM with more powerful tools in recent years, including the RIVER2D hydraulic and habitat model that was used by USFWS to develop the Sacramento River spawning WUA curves used for the [Project] WUA analyses (U.S. Fish and Wildlife Service 2006). The field data used for the hydraulic/habitat modeling have also been refined and improved. For instance, improvements have been made in the flow velocity data used to represent the full range of flow velocity conditions affecting drift-feeding juvenile salmonids (Naman et al. 2019). The U.S. Fish and Wildlife Service studies of Sacramento River rearing WUA include such a modification to represent flow velocities (U.S. Fish and Wildlife Service 2005a). In addition, improvements have been developed to include a broader range of factors in the modeling, including some of those mentioned in the previous paragraph. One of these includes modeling of bioenergetic factors (Naman et al. 2020). Such methods are promising, but they are not currently available for use in analyzing flow effects on fish populations in the Sacramento River system.

Some shortcomings of WUA analysis are more difficult to remedy. For instance, competition within a cohort of juvenile salmonids may affect habitat use such that dominant fish exclude sub-dominants from optimal habitat locations, resulting in the highest densities of fish occupying sub-optimal habitat (Beecher et al. 2010; Beecher 2017). Some such biases are inevitable in any effort to model fish populations, but improvements in sampling and modeling techniques can be expected to lead to more accurate models in the future. PHABSIM and similar models, despite their shortcomings, continue to be among the most used and useful analytical tools for assessing instream-flow-related issues (Reiser and Hilgert 2018).

O.3.2.4 Code and Data Repository

[TBD]

O.3.3 Results

The following results provide the estimates of spawning and rearing WUA for winter-run, spring-run, fall-run, and late fall-run Chinook salmon and steelhead. For each race and species, the spawning and rearing WUA results are provided separately, with tables and figures for the Biological Assessment and EIS modeled scenarios included in each section.

O.3.3.1 Winter-run Chinook Salmon

O.3.3.1.1 Spawning Weighted Usable Area

Table O.3-6 and Table O.3-7 provide the spawning WUA results for Sacramento River winter-run Chinook salmon under the Biological Assessment modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by average proportion of redds counted per month (Table O.3-5) and per river segment (Table O.3-3). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-7).

The results for both the Biological Assessment and EIS modeled scenarios show modest and inconsistent variation in mean spawning WUA with water year type among the three baseline scenarios, but under both all Biological Assessment and EIS modeled scenarios for alternatives, the variation in mean spawning WUA among water year types is consistent, with the highest WUA under critically dry water years and lowest in above normal water years. For the EIS modeled scenarios, the largest difference between the NAA and the scenarios was a 5.6% increase for Alt 3 in above normal water years (Table O.3-7). The largest reduction is 1.4% for Alt 1 in above normal water years.

Table O.3-6. Expected WUA for Winter-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three BA modeled Alt 2 Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	503,647	576,192	545,135	548,494	548,607	548,848
AN	477,951	594,047	518,502	522,694	523,507	530,681
BN	469,563	599,138	532,471	538,253	538,289	546,497
Dry	468,443	601,967	547,915	560,634	557,712	564,350
Critical	421,055	598,986	582,871	583,645	578,943	580,022
All	472,251	592,655	545,832	551,576	550,275	554,590

Table O.3-7. Expected WUA for Winter-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

Water Year Type	**NAA**	**Alt1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt3**	**Alt4**
Wet	545,135	547,715	548,572	548,494	548,607	548,848	543,711	548,569
AN	518,502	511,277	522,731	522,694	523,507	530,681	547,419	522,906
BN	532,471	527,984	538,123	538,253	538,289	546,497	554,780	534,410
Dry	547,915	549,027	561,083	560,634	557,712	564,350	552,224	558,365
Critical	582,871	578,374	582,443	583,645	578,943	580,022	581,003	585,336
All	545,832	544,283	551,495	551,576	550,275	554,590	554,232	550,661
Wet	545,135	0.47	0.63	0.62	0.64	0.68	-0.26	0.63
AN	518,502	-1.39	0.82	0.81	0.97	2.35	5.58	0.85
BN	532,471	-0.84	1.06	1.09	1.09	2.63	4.19	0.36
Dry	547,915	0.20	2.40	2.32	1.79	3.00	0.79	1.91
Critical	582,871	-0.77	-0.07	0.13	-0.67	-0.49	-0.32	0.42
All	545,832	-0.28	1.04	1.05	0.81	1.60	1.54	0.88

The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

Figure O.3-12 and Figure O.3-13 show the full variation in estimated spawning WUA for winter-run under the Biological Assessment and EIS modeled scenarios, respectively. The upper and lower limits or the range in WUA values are determined by the ranges of the spawning WUA curves from which they are estimated (Figure O.3-2). The estimated spawning WUA values under the Biological Assessment and EIS modeled scenarios are similar for May, June, and August, but the values are lower and more variable for July. The CalSim 3 flows are substantially higher in July than in the other months, which could result in lower and more variable spawning WUA results.

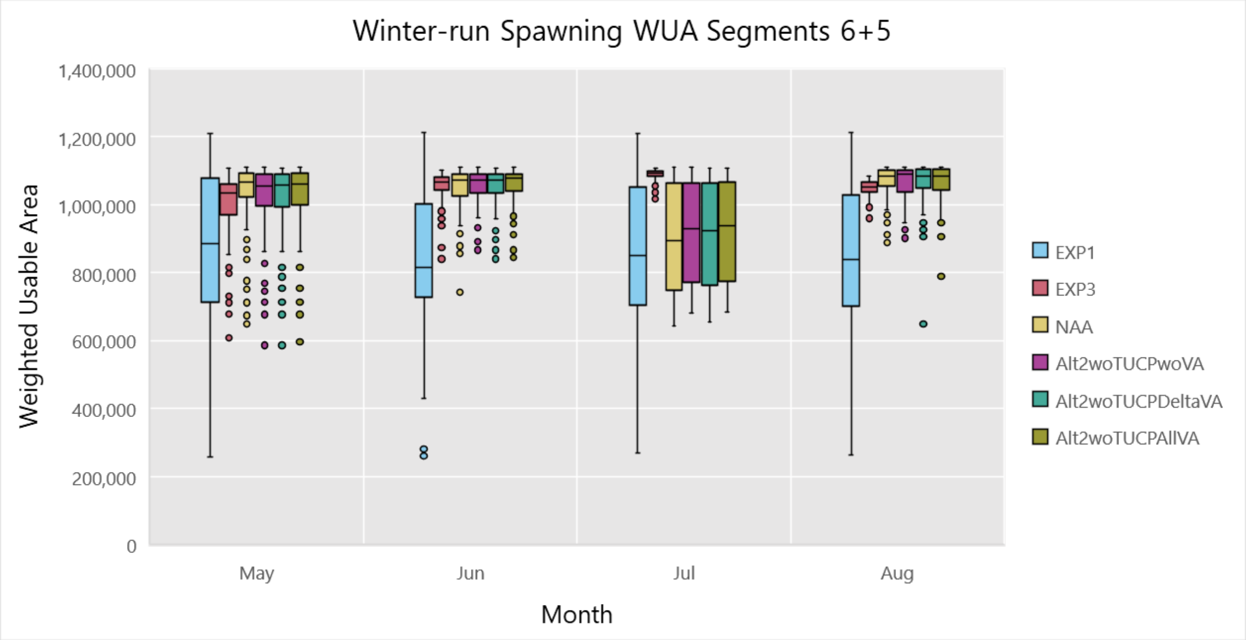


Figure O.3-12. Expected WUA for Winter-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for the Baseline Scenarios EXP1, EXP3, NAA, and three BA Modeled Scenarios (Alternative 2) by Month

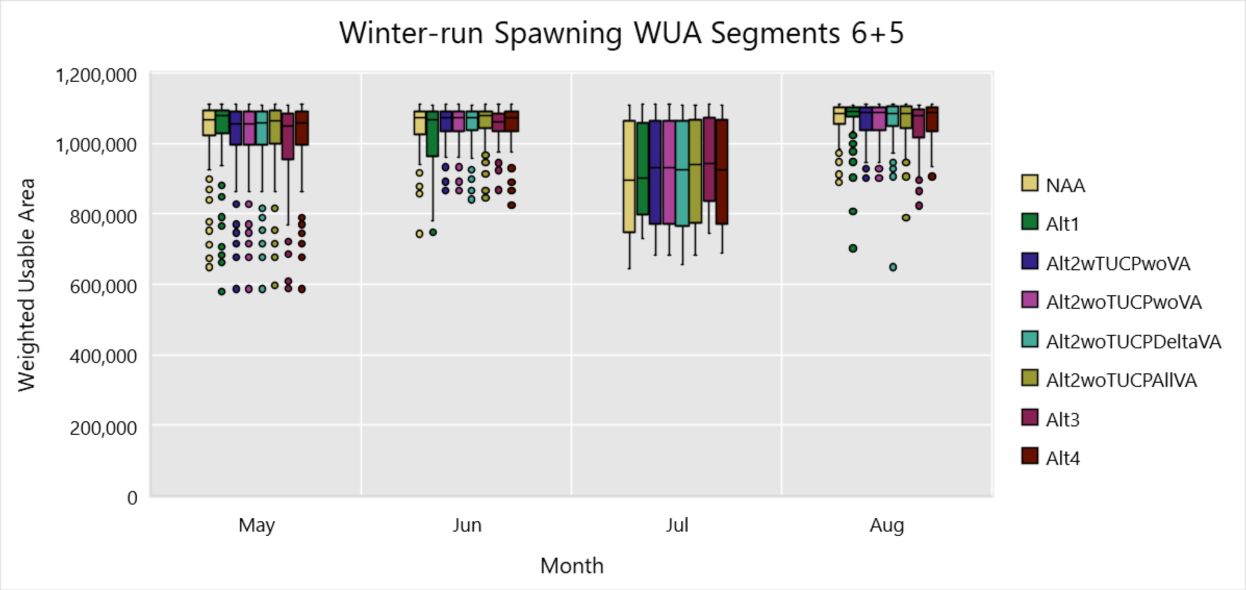


Figure O.3-13. Expected WUA for Winter-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for the EIS Modeled Scenarios by Month

O.3.3.1.2 Rearing Weighted Usable Area

Table O.3-8 through Table O.3-11 provide the rearing WUA results for fry and juveniles of Sacramento River winter-run under the Biological Assessment modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by estimated monthly average abundance as discussed above in the *Methods* section. The tables for the EIS modeled scenarios include the percent differences between the results of the NAA and the alternatives (Table O.3-9 and Table O.3-11).

The results for both the Biological Assessment and EIS modeled scenarios show modest and inconsistent variation in mean fry rearing WUA with water year type among the three baseline scenarios, but under both all Biological Assessment and EIS modeled scenarios for alternatives, the variation in mean rearing WUA among water year types is generally consistent, with the highest WUA under critically dry water years and lowest in above normal or wet water years (Table O.3-8 and Table O.3-9). However, the variation among water year types is small. For the EIS modeled scenarios, the largest difference between the NAA and the scenarios is a 3.2% increase for Alt 1 in above normal water years (Table O.3-9). The largest reduction is 1.5% for Alt 1 in critical water years.

Table O.3-8. Expected WUA for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three BA modeled Alt 2 Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	266,854	268,280	235,210	234,984	234,656	234,938
AN	257,580	266,879	237,840	236,715	236,564	236,501
BN	228,209	265,673	254,387	253,464	253,344	252,334
Dry	210,866	264,051	257,409	256,880	257,399	257,864
Critical	188,143	262,792	257,398	259,957	255,456	255,519
All	232,888	265,748	247,838	247,705	246,996	247,008

Table O.3-9. Expected WUA for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	235,210	237,442	234,968	234,984	234,656	234,938	240,093	234,997
AN	237,840	245,321	236,761	236,715	236,564	236,501	242,387	236,813
BN	254,387	251,034	253,021	253,464	253,344	252,334	257,933	252,214
Dry	257,409	256,959	256,873	256,880	257,399	257,864	259,847	257,277
Critical	257,398	253,475	263,028	259,957	255,456	255,519	262,727	262,259

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
All	247,838	248,220	248,095	247,705	246,996	247,008	251,909	247,946
Wet	235,210	0.95	-0.10	-0.10	-0.24	-0.12	2.08	-0.09
AN	237,840	3.15	-0.45	-0.47	-0.54	-0.56	1.91	-0.43
BN	254,387	-1.32	-0.54	-0.36	-0.41	-0.81	1.39	-0.85
Dry	257,409	-0.17	-0.21	-0.21	0.00	0.18	0.95	-0.05
Critical	257,398	-1.52	2.19	0.99	-0.75	-0.73	2.07	1.89
All	247,838	0.15	0.10	-0.05	-0.34	-0.33	1.64	0.04

The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

Figure O.3-14 and Figure O.3-15 show the full variation in estimated fry rearing WUA for winter-run under the Biological Assessment and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the fry rearing WUA curves from which they are estimated (Figure O.3-6). The estimated fry rearing WUA values under the Biological Assessment and EIS modeled scenarios are similar for the five months of winter-run fry rearing, August through December. However, extreme WUA results, particularly results with higher WUA values, are much more prevalent for December and somewhat more prevalent for November, presumably because of more frequent high flows. This result is due to the increasing rearing WUA values for higher flows in the winter-run fry rearing WUA curve (Figure O.3-6). Winter-run is the only Sacramento River salmonid race or species that shows this pattern.

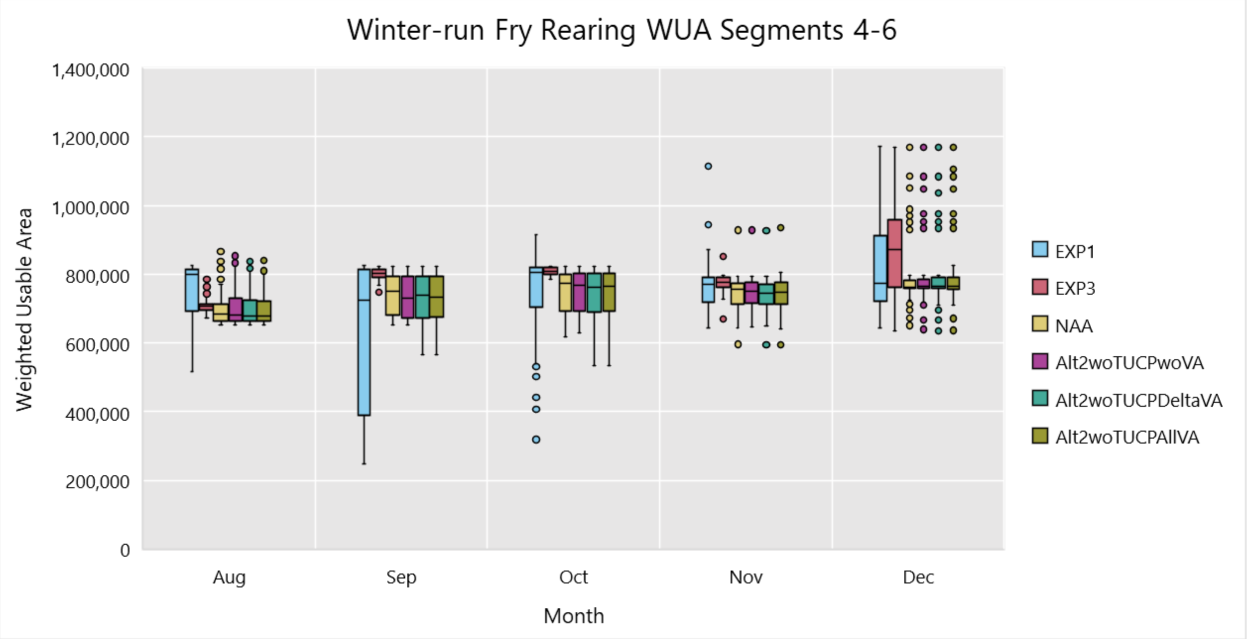


Figure O.3-14. Expected WUA for Winter-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

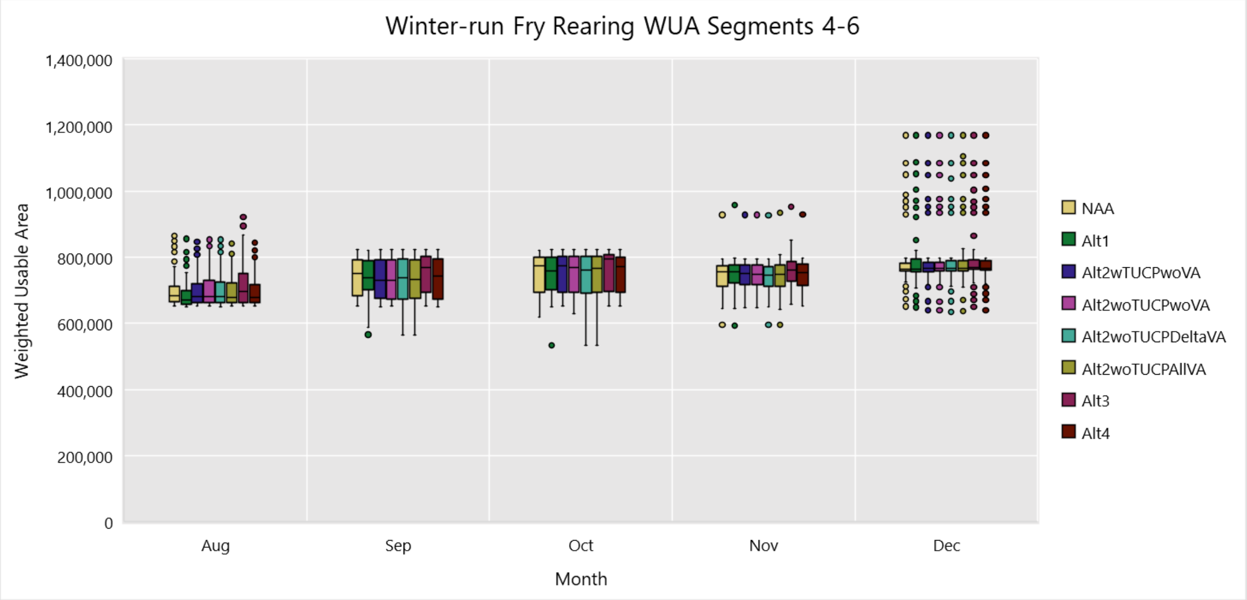


Figure O.3-15. Expected WUA for Winter-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

The results for both the Biological Assessment and EIS modeled scenarios show little variation in mean winter-run juvenile rearing WUA with water year type for the baseline scenarios and the Biological Assessment and EIS modeled scenarios (Table O.3-10 and Table O.3-11). For the EIS modeled scenarios, the largest difference between the NAA and the scenarios is a 0.7% increase for Alt 4 in critical water years (Table O.3-11). The largest reduction is 0.5% for Alt2 Without UCP Systemwide VA in below normal water years.

Table O.3-10. Expected WUA for Winter-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three BA modeled Alt 2 Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wo TUCPwoVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	137,825	141,579	136,563	136,574	136,480	136,502
AN	136,925	136,994	134,859	134,439	134,260	134,429
BN	128,529	136,520	133,640	133,246	133,121	132,936
Dry	129,802	136,889	136,003	135,658	135,872	135,853
Critical	123,629	137,292	135,317	135,360	135,209	135,298

Water Year Type	EXP1	EXP3	NAA	Alt2wo TUCPwoVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
All	131,931	138,215	135,453	135,245	135,200	135,208

Table O.3-11. Expected WUA for Winter-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	136,563	136,945	136,582	136,574	136,480	136,502	137,149	136,587
AN	134,859	135,568	134,399	134,439	134,260	134,429	135,149	134,599
BN	133,640	133,516	133,217	133,246	133,121	132,936	133,037	133,030
Dry	136,003	136,234	135,643	135,658	135,872	135,853	135,789	135,874
Critical	135,317	135,259	136,207	135,360	135,209	135,298	136,203	136,324
All	135,453	135,691	135,360	135,245	135,200	135,208	135,635	135,431
Wet	136,563	0.28	0.01	0.01	-0.06	-0.04	0.43	0.02
AN	134,859	0.53	-0.34	-0.31	-0.44	-0.32	0.21	-0.19
BN	133,640	-0.09	-0.32	-0.29	-0.39	-0.53	-0.45	-0.46
Dry	136,003	0.17	-0.26	-0.25	-0.10	-0.11	-0.16	-0.09
Critical	135,317	-0.04	0.66	0.03	-0.08	-0.01	0.66	0.74
All	135,453	0.18	-0.07	-0.15	-0.19	-0.18	0.13	-0.02

The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

Figure O.3-16 and Figure O.3-17 show the full variation in estimated juvenile rearing WUA for winter-run under the Biological Assessment and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the juvenile rearing WUA curves from which they are estimated (Figure O.3-7). The estimated juvenile rearing WUA values under the Biological Assessment and EIS modeled scenarios are similar for the five months of winter-run fry rearing, August through December. However, as reported for the fry rearing results (Figure O.3-14 and Figure O.3-15), extreme WUA results, particularly results with higher WUA values, are much more prevalent for November and December, presumably because of more frequent high flows. This result is due to the increasing rearing WUA values for higher flows in the winter-run juvenile rearing WUA curve (Figure O.3-7). As noted for the rearing WUA curve, winter-run is the only Sacramento River salmonid race or species that shows this pattern.

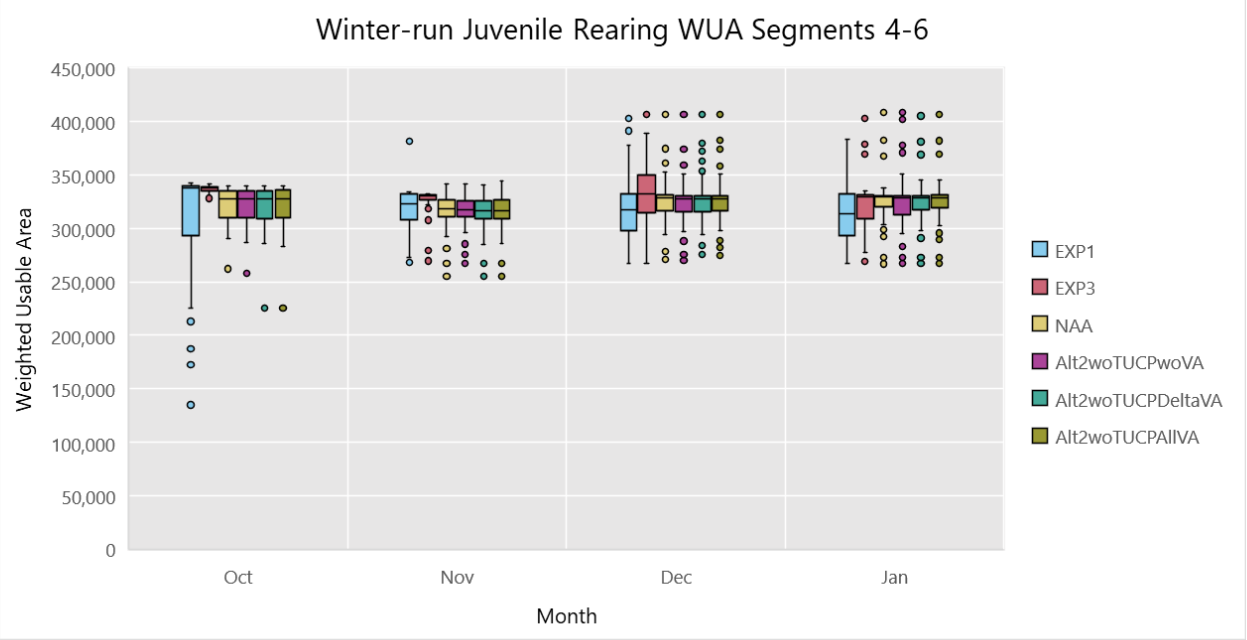


Figure O.3-16. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

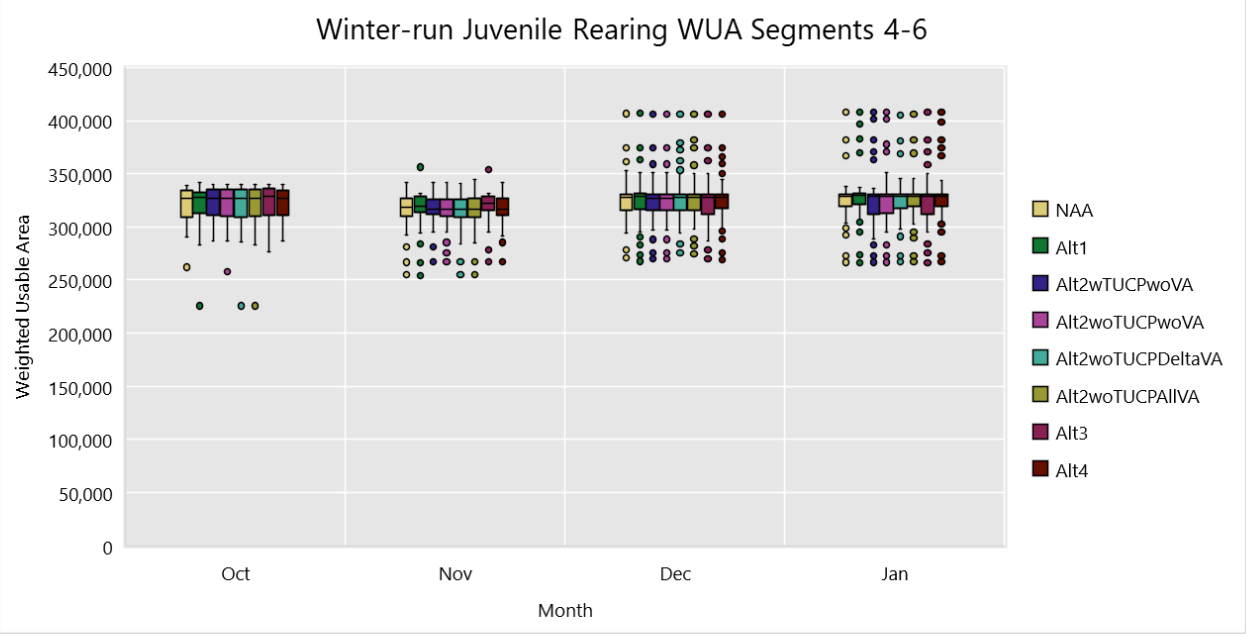


Figure O.3-17. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month three baseline scenarios (EXP 1, EXP 3, NAA) and four management alternatives (ALT 2 v1 with TUCP, ALT2 v1 without TUCP, ALT 2 Delta VAs, and ALT 2 All VAs). The results for fry rearing are the means for all years analyzed, weighted by average proportion of redds counted per month (Table O.3-5). No weightings were used for combining the rearing WUA results from the three river segments because, as discussed in the *Methods* section and the *Assumptions/Uncertainty* section, the distributions of rearing fry and juveniles with respect to the river segments is uncertain. Also, no weightings were used in combining the juvenile rearing WUA results for different months because the monthly variations in juvenile abundance within the rearing period are highly uncertain.

Most of the rearing WUA results under the three baseline scenarios and the four management alternatives vary substantially among water year types for spring-run and steelhead (Table O.3-21 through Table O.3-24), but most of the results for winter-run show less such variation (Table O.3-19 and Table O.3-20). This is especially true of the juvenile WUA results (Table O.3-20, Table O.3-22, and Table O.3-24), which can be attributed to the higher variation in WUA with flow for the fall-run (surrogate for spring-run) and late fall-run (surrogate for steelhead) rearing WUA curves (Figure O.3-10 and Figure O.3-13) than for the winter-run curve (Figure O.3-8). The portions of the curves that cover flows less than 15,000 cfs have the greatest effects on the results, because such flows constitute most of the flows in the CalSim 3 record for all scenarios and alternatives.

O.3.3.2 Spring-run Chinook Salmon

Table O.3-12 and Table O.3-13provide the spawning WUA results for Central Valley spring-run Chinook salmon under the Biological Assessment modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by average proportion of redds counted per month (Table O.3-5) and per river segment (Table O.3-3). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-13).

The results for both the Biological Assessment and EIS modeled scenarios show modest and inconsistent variation in mean spawning WUA with water year type among the three baseline scenarios, but under both all Biological Assessment and EIS modeled scenarios for alternatives, the variation in mean spawning WUA among water year types is generally consistent, with the highest WUA under critically dry or dry water years and lowest in above normal water years. For the EIS modeled scenarios, much the largest difference between the NAA and the scenarios is a 15.5% increase for Alt 1 in above normal water years (Table O.3-13). The largest reduction is 2.7% for Alt 1 in critical water years.

Table O.3-12. Expected WUA for Spring-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three BA modeled Alt 2 Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	439,130	451,262	340,515	343,070	342,592	342,214

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
AN	401,963	453,809	359,947	352,226	350,776	352,152
BN	330,606	451,585	429,354	428,824	431,627	430,136
Dry	273,640	452,989	440,725	440,399	441,154	440,956
Critical	247,091	459,597	443,545	448,282	435,218	435,186
All	344,395	453,360	399,692	399,840	398,123	397,909

Table O.3-13. Expected WUA for Spring-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
W	340,515	359,262	343,188	343,070	342,592	342,214	355,495	343,198
AN	359,947	415,812	352,157	352,226	350,776	352,152	380,542	352,056
BN	429,354	424,073	427,272	428,824	431,627	430,136	418,510	427,753
D	440,725	439,070	440,393	440,399	441,154	440,956	434,659	440,213
C	443,545	431,449	456,308	448,282	435,218	435,186	451,937	457,579
All	399,692	409,562	400,832	399,840	398,123	397,909	404,640	401,066
W	340,515	5.51	0.78	0.75	0.61	0.50	4.40	0.79
AN	359,947	15.52	-2.16	-2.14	-2.55	-2.17	5.72	-2.19
BN	429,354	-1.23	-0.48	-0.12	0.53	0.18	-2.53	-0.37
D	440,725	-0.38	-0.08	-0.07	0.10	0.05	-1.38	-0.12
C	443,545	-2.73	2.88	1.07	-1.88	-1.88	1.89	3.16
All	399,692	2.47	0.29	0.04	-0.39	-0.45	1.24	0.34

The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

Figure O.3-22 and Figure O.3-23 show the full variation in estimated spawning WUA for spring-run under the Biological Assessment and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the spawning WUA curves from which they are estimated (Figure O.3-3). The estimated spawning WUA values under the Biological Assessment and EIS modeled scenarios are similar for September and October but are lower for August. The CalSim 3 flows are generally higher in August than in the other months, which could result in lower spawning WUA results. The fall-run spawning WUA curves (Figure O.3-3), which were used to estimate spring-run spawning WUA, peak at relatively low flows (3,000 to 6,000 cfs).

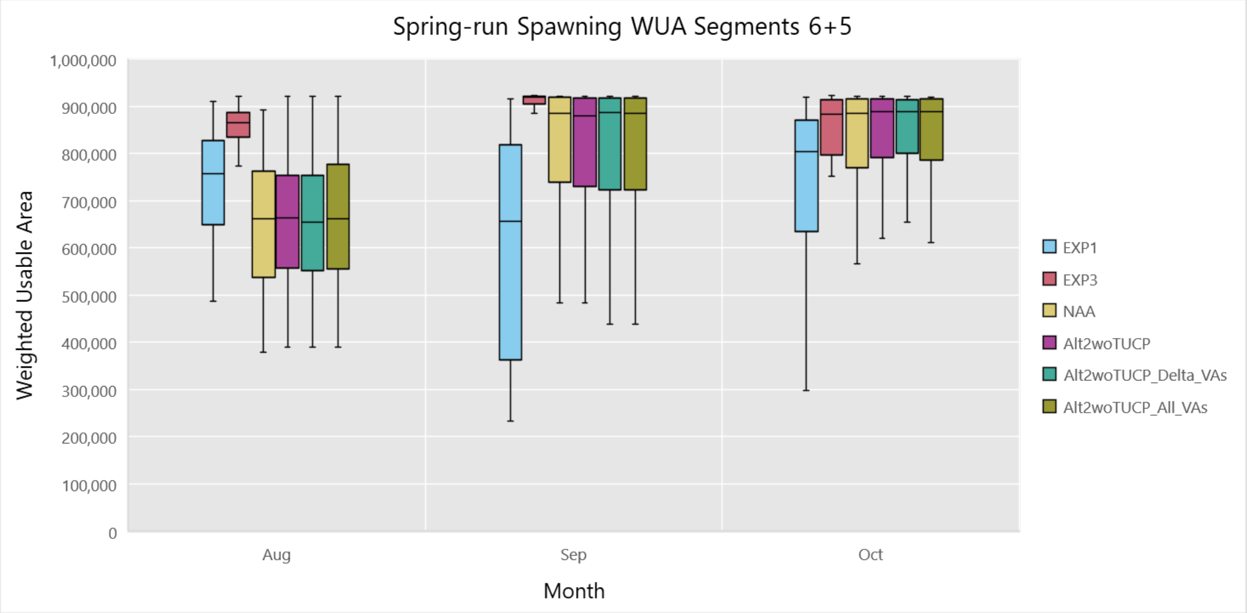


Figure O.3-18. Expected WUA for Spring-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

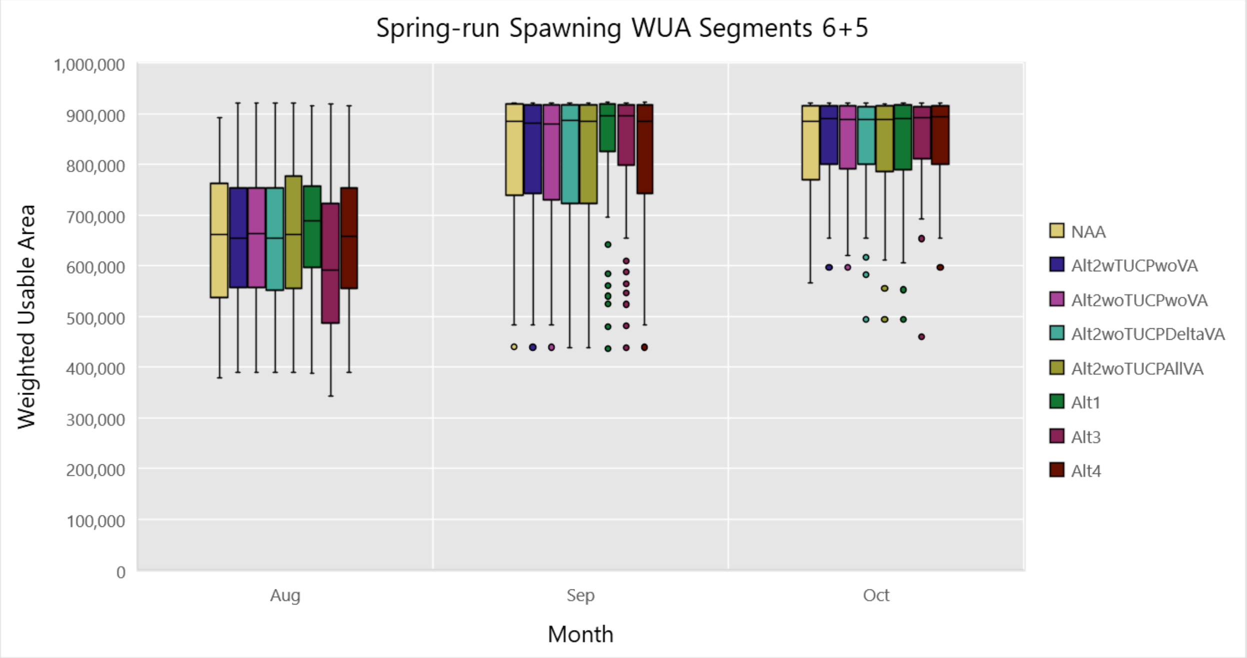


Figure O.3-19. Expected WUA for Spring-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

O.3.3.2.1 Rearing Weighted Usable Area

Table O.3-14 through Table O.3-17 provide the rearing WUA results for fry and juveniles of Sacramento River spring-run under the Biological Assessment modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by estimated monthly average abundance as discussed above in the *Methods* section. The tables for the EIS modeled scenarios include the percent differences between the results of the NAA and the alternatives (Table O.3-15 and Table O.3-17).

The results for both the Biological Assessment and EIS modeled scenarios show consistent variation in mean spring-run fry rearing WUA with water year type among the three baseline scenarios and all Biological Assessment and EIS modeled scenarios for alternatives, with the highest WUA under critically dry water years and lowest wet water years (Table O.3-14 and Table O.3-15). For the EIS modeled scenarios, the fry rearing WUA results were generally lower under the EIS modeled scenarios than under the NAA. The largest reductions between the NAA and the scenarios are 2.6% reductions for Alt2 Without TUCP Delta VA and Alt2 Without TUCP Systemwide VA under critical water years (Table O.3-15).

Table O.3-14. Expected WUA for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three BA modeled Alt 2 Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	266,854	268,280	235,210	234,984	234,656	234,938
AN	257,580	266,879	237,840	236,715	236,564	236,501
BN	228,209	265,673	254,387	253,464	253,344	252,334
Dry	210,866	264,051	257,409	256,880	257,399	257,864
Critical	188,143	262,792	257,398	259,957	255,456	255,519
All	232,888	265,748	247,838	247,705	246,996	247,008

Table O.3-15. Expected WUA for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
W	235,210	237,442	234,968	234,984	234,656	234,938	240,093	234,997
AN	237,840	245,321	236,761	236,715	236,564	236,501	242,387	236,813
BN	254,387	251,034	253,021	253,464	253,344	252,334	257,933	252,214
D	257,409	256,959	256,873	256,880	257,399	257,864	259,847	257,277
C	257,398	253,475	263,028	259,957	255,456	255,519	262,727	262,259
All	247,838	248,220	248,095	247,705	246,996	247,008	251,909	247,946

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
W	235,210	0.95	-0.10	-0.10	-0.24	-0.12	2.08	-0.09
AN	237,840	3.15	-0.45	-0.47	-0.54	-0.56	1.91	-0.43
BN	254,387	-1.32	-0.54	-0.36	-0.41	-0.81	1.39	-0.85
D	257,409	-0.17	-0.21	-0.21	0.00	0.18	0.95	-0.05
C	257,398	-1.52	2.19	0.99	-0.75	-0.73	2.07	1.89
All	247,838	0.15	0.10	-0.05	-0.34	-0.33	1.64	0.04

The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

Figure O.3-20 and Figure O.3-21 show the full variation in estimated fry rearing WUA for spring-run under the Biological Assessment and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the fry rearing WUA curves from which they are estimated (Figure O.3-20). The estimated fry rearing WUA values under the Biological Assessment and EIS modeled scenarios are similar for primary months of spring-run fry rearing, December through March, but they are lower for November and April (Figure O.3-20 and Figure O.3-21). For the December through March period, the results show little variation in the upper quartile of the WUA distributions. This occurs because the fry rearing WUA curves peak at lowest flows encountered in the river (Figure O.3-20).

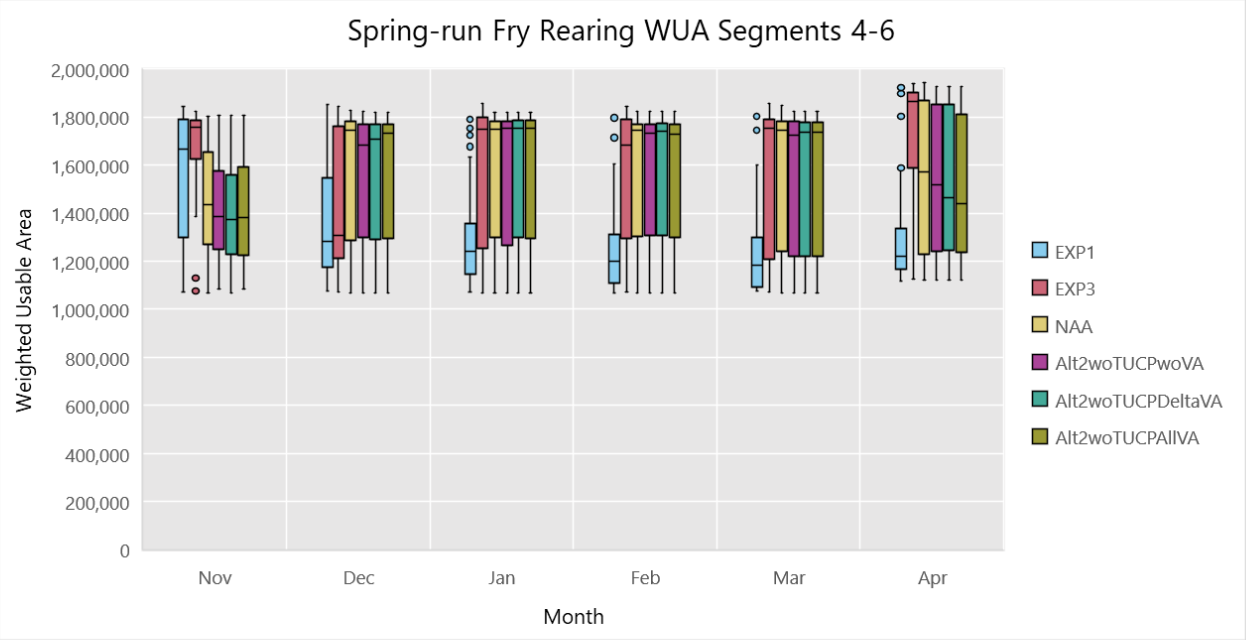


Figure O.3-20. Expected WUA for Spring-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

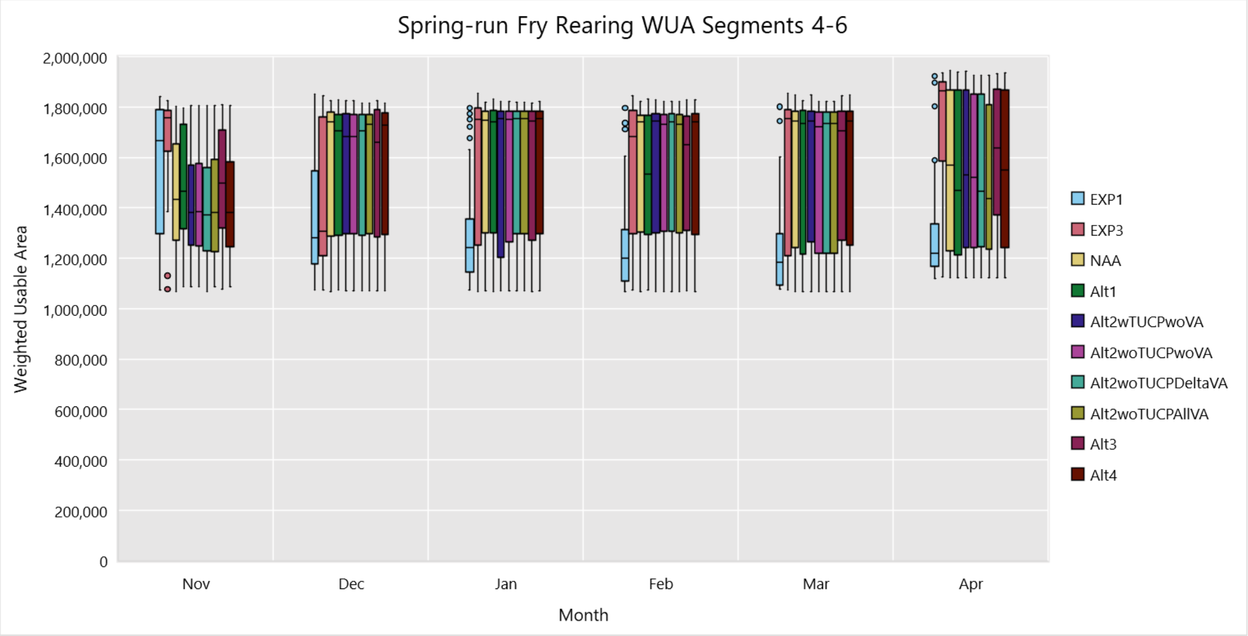


Figure O.3-21. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

The results for both the Biological Assessment and EIS modeled scenarios show consistent variation in mean spring-run juvenile rearing WUA with water year type among the three baseline scenarios and all Biological Assessment and EIS modeled scenarios for alternatives, with the highest WUA under critically dry water years and lowest wet water years (Table O.3-16 and Table O.3-17). The only exception to this pattern of variation is for EXP1, which has higher rearing WUA under above normal years than in wet water years. For the EIS modeled scenarios, the fry rearing WUA results were generally modestly lower under the EIS modeled scenarios than under the NAA. The largest reduction between the NAA and the scenarios is 1.7% for Alt 3 under critical water years (Table O.3-17).

Table O.3-16. Expected WUA for Spring-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three BA modeled Alt 2 Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	182,154	183,641	176,621	175,478	175,359	175,491
AN	187,247	192,085	191,772	189,570	188,849	189,116
BN	182,973	209,016	205,613	203,723	203,074	202,858
Dry	192,028	216,519	217,257	214,433	215,220	214,642
Critical	193,690	229,142	226,675	223,881	224,132	224,786
All	187,336	204,369	201,520	199,430	199,407	199,410

Table O.3-17. Expected WUA for Spring-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
W	176,621	177,085	175,420	175,478	175,359	175,491	178,542	176,308
AN	191,772	193,605	188,962	189,570	188,849	189,116	191,760	190,139
BN	205,613	205,328	203,557	203,723	203,074	202,858	203,781	202,808
D	217,257	217,108	214,448	214,433	215,220	214,642	214,799	215,985
C	226,675	225,580	225,044	223,881	224,132	224,786	222,811	224,606
All	201,520	201,681	199,471	199,430	199,407	199,410	200,552	200,065
W	176,621	0.26	-0.68	-0.65	-0.71	-0.64	1.09	-0.18
AN	191,772	0.96	-1.47	-1.15	-1.52	-1.38	-0.01	-0.85
BN	205,613	-0.14	-1.00	-0.92	-1.23	-1.34	-0.89	-1.36
D	217,257	-0.07	-1.29	-1.30	-0.94	-1.20	-1.13	-0.59
C	226,675	-0.48	-0.72	-1.23	-1.12	-0.83	-1.70	-0.91
All	201,520	0.08	-1.02	-1.04	-1.05	-1.05	-0.48	-0.72

The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

Figure O.3-22 and Figure O.3-23 show the full variation in estimated juvenile rearing WUA for spring-run under the Biological Assessment and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the juvenile rearing WUA curves from which they are estimated (Figure O.3-9). The estimated juvenile rearing WUA values under the Biological Assessment and EIS modeled scenarios are similar for three wettest months of spring-run juvenile rearing period, January through March, but they are lower for April and May (Figure O.3-22 and Figure O.3-23). For the January through March period, as described for the the results show little variation in the upper quartile of the WUA distributions. This occurs because the fry rearing WUA curves peak at lowest flows encountered in the river (Figure O.3-8).

The estimated juvenile rearing WUA values under the Biological Assessment and EIS modeled scenarios are similar for the five months of winter-run fry rearing, August through December. However, as reported for the fry rearing results (Figure O.3-19 and Figure O.3-20), extreme WUA results, particularly results with higher WUA values, are much more prevalent for November and December, presumably because of more frequent high flows. This result is due to the increasing rearing WUA values for higher flows in the winter-run juvenile rearing WUA curve (Figure O.3-7). As noted for the rearing WUA curve, winter-run is the only Sacramento River salmonid race or species that shows this pattern.

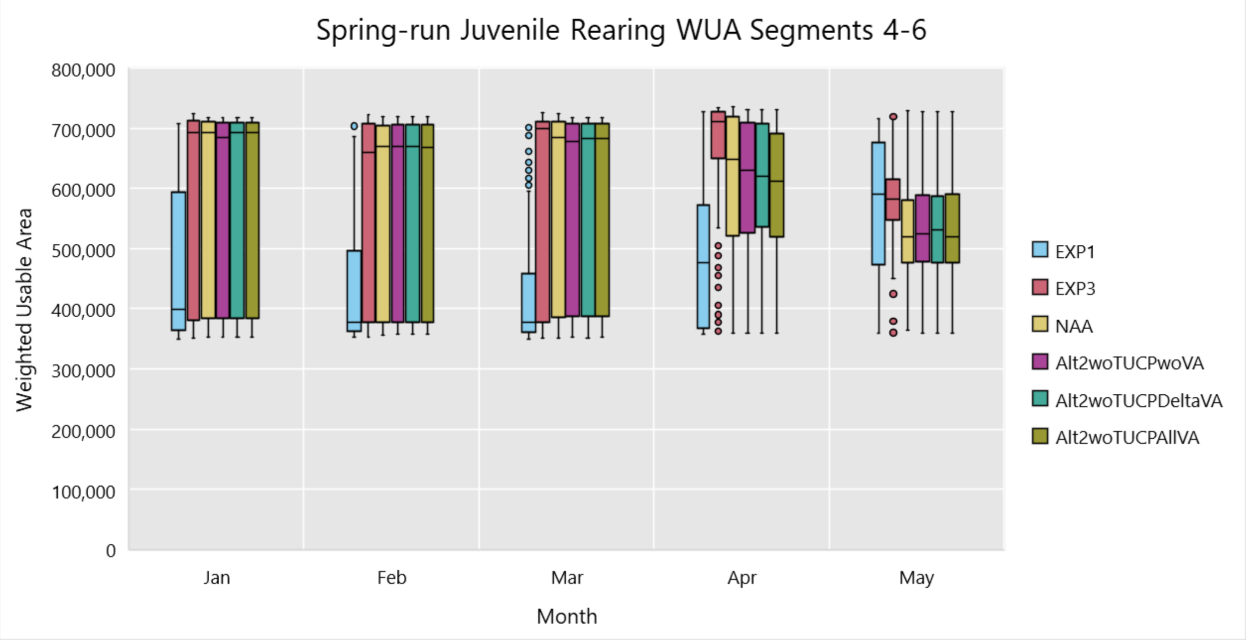


Figure O.3-22. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

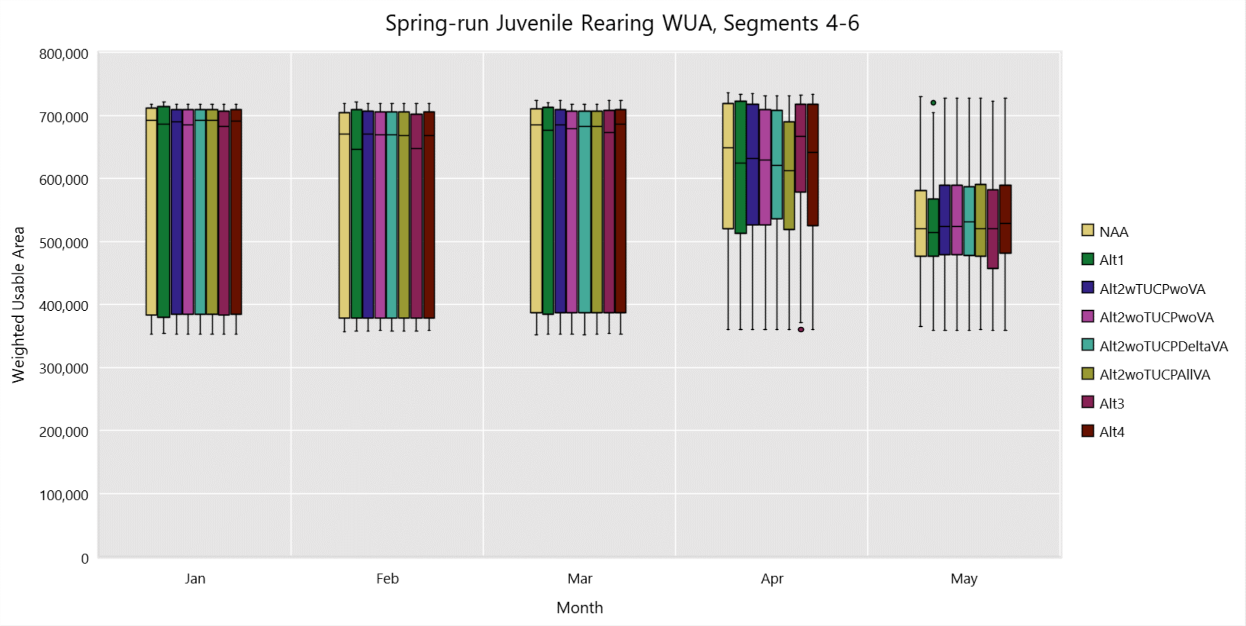


Figure O.3-23. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Tables X-7 and X-8 provide the spawning WUA results for Central Valley spring-run Chinook salmon under the Biological Assessment modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by average proportion of redds counted per month (Table X-3) and per river segment (Table X-2). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table X-6).

The results for both the Biological Assessment and EIS modeled scenarios show modest and inconsistent variation in mean spawning WUA with water year type among the three baseline scenarios, but under both all Biological Assessment and EIS modeled scenarios for alternatives, the variation in mean spawning WUA among water year types is generally consistent, with the highest WUA under critically dry or dry water years and lowest in above normal water years. For the EIS modeled scenarios, much the largest difference between the NAA and the scenarios is a 15.5% increase for Alt 1 in above normal water years (Table X-8). The largest reduction is 2.7% for Alt 1 in critical water years.

Table O.3-18. Expected WUA for Steelhead Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2wo TUCPAllVA
Wet	41,897	68,022	68,940	68,872	68,889	68,907	68,835
AN	53,504	82,616	85,350	85,338	86,419	86,071	85,715
BN	89,406	112,719	115,190	114,540	114,543	114,585	114,042
Dry	98,693	115,715	118,718	118,804	118,798	118,827	118,828
Critical	117,244	120,505	120,314	119,788	120,229	120,958	120,945
All	77,760	97,954	99,729	99,528	99,753	99,841	99,671

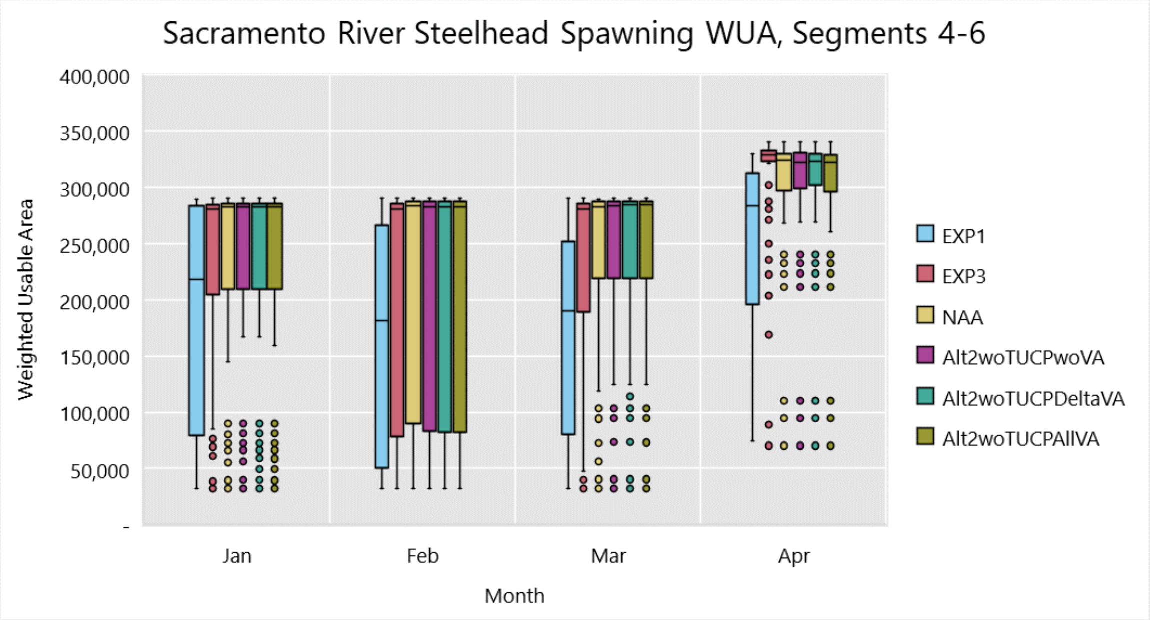


Figure O.3-24. Expected WUA for Steelhead Spawning in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

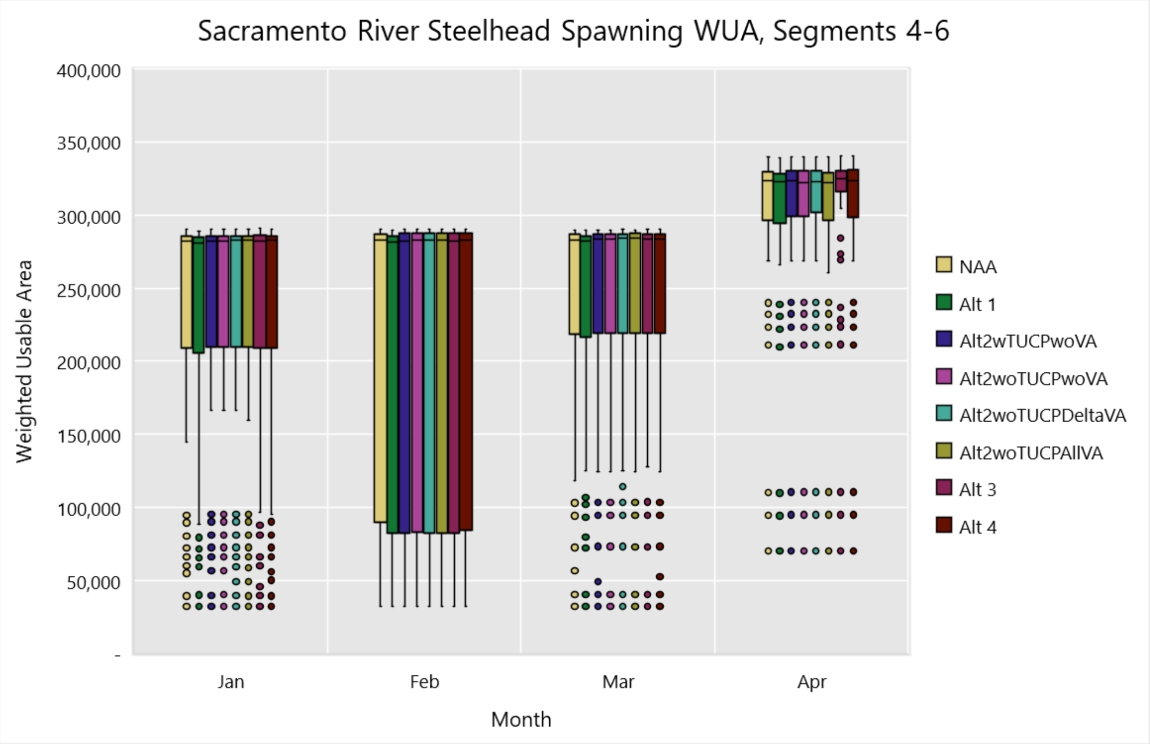


Figure O.3-25. Expected WUA for Steelhead Spawning in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

O.3.3.2.2 Rearing Weighted Usable Area

Table O.3-18 through Table O.3-24 provide the rearing WUA results for fry and juveniles of Sacramento River winter-run and spring-run Chinook salmon and Central Valley steelhead under three baseline scenarios (EXP 1, EXP 3, NAA) and four management alternatives (ALT 2 v1 with TUCP, ALT2 v1 without TUCP, ALT 2 Delta VAs, and ALT 2 All VAs). The results for fry rearing are the means for all years analyzed, weighted by average proportion of redds counted per month (Table O.3-5). No weightings were used for combining the rearing WUA results from the three river segments because, as discussed in the *Methods* section and the *Assumptions/Uncertainty* section, the distributions of rearing fry and juveniles with respect to the river segments is uncertain. Also, no weightings were used in combining the juvenile rearing WUA results for different months because the monthly variations in juvenile abundance within the rearing period are highly uncertain.

Most of the rearing WUA results under the three baseline scenarios and the four management alternatives vary substantially among water year types for spring-run and steelhead (Table O.3-21 through Table O.3-24), but most of the results for winter-run show less such variation (Table O.3-19 and Table O.3-20). This is especially true of the juvenile WUA results (Table O.3-20, Table O.3-22, and Table O.3-24), which can be attributed to the higher variation in WUA with flow for the fall-run (surrogate for spring-run) and late fall-run (surrogate for steelhead) rearing WUA curves (Table O.3-20 and Table O.3-22) than for the winter-run curve (Table O.3-18). The portions of the curves that cover flows less than 15,000 cfs have the greatest effects on the results, because such flows constitute most of the flows in the CalSim 3 record for all scenarios and alternatives.

Table O.3-19. Expected WUA for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	266,854	268,280	235,210	234,968	234,984	234,656	234,938
AN	257,580	266,879	237,840	236,761	236,715	236,564	236,501
BN	228,209	265,673	254,387	253,021	253,464	253,344	252,334
Dry	210,866	264,051	257,409	256,873	256,880	257,399	257,864
Critical	188,143	262,792	257,398	263,028	259,957	255,456	255,519
All	232,888	265,748	247,838	248,095	247,705	246,996	247,008

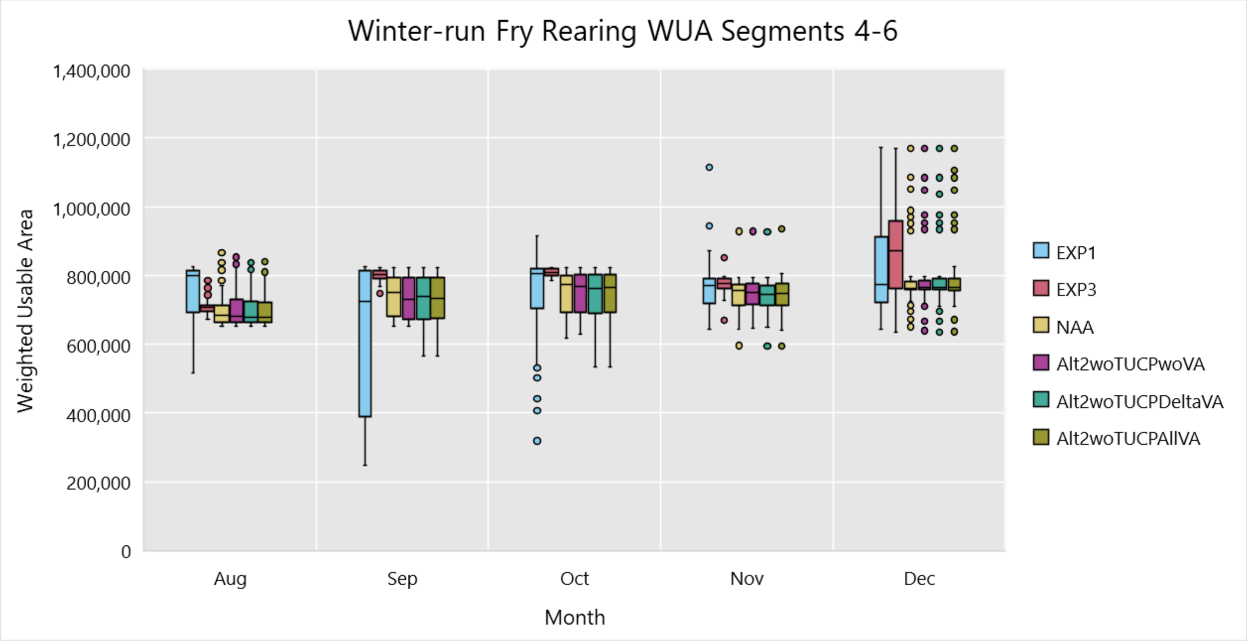


Figure O.3-26. Expected WUA for Winter-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

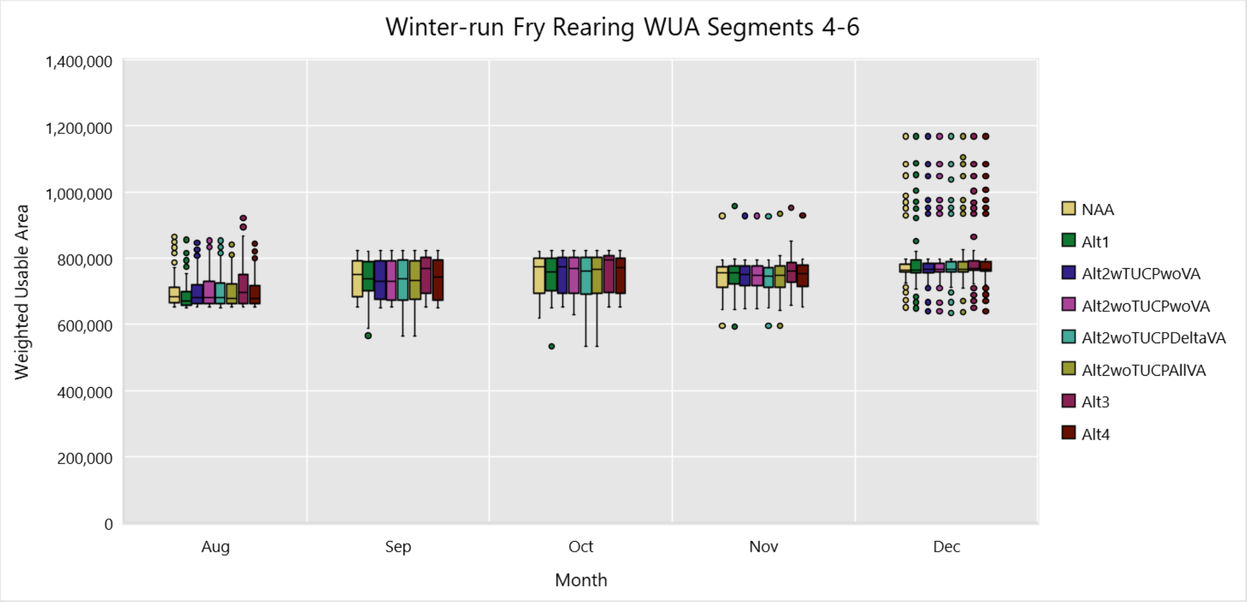


Figure O.3-27. Expected WUA for Winter-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Table O.3-20. Expected WUA for Winter-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	435,946	447,821	427,387	427,153	427,120	426,732	426,836
AN	435,105	434,142	424,729	422,561	422,819	422,194	422,635
BN	413,030	439,929	427,204	426,192	426,307	425,894	425,235
Dry	416,909	441,111	436,694	435,399	435,418	436,082	436,343
Critical	390,762	439,502	433,305	436,711	433,694	432,892	433,274
All	420,315	441,545	430,117	429,744	429,348	429,115	429,216

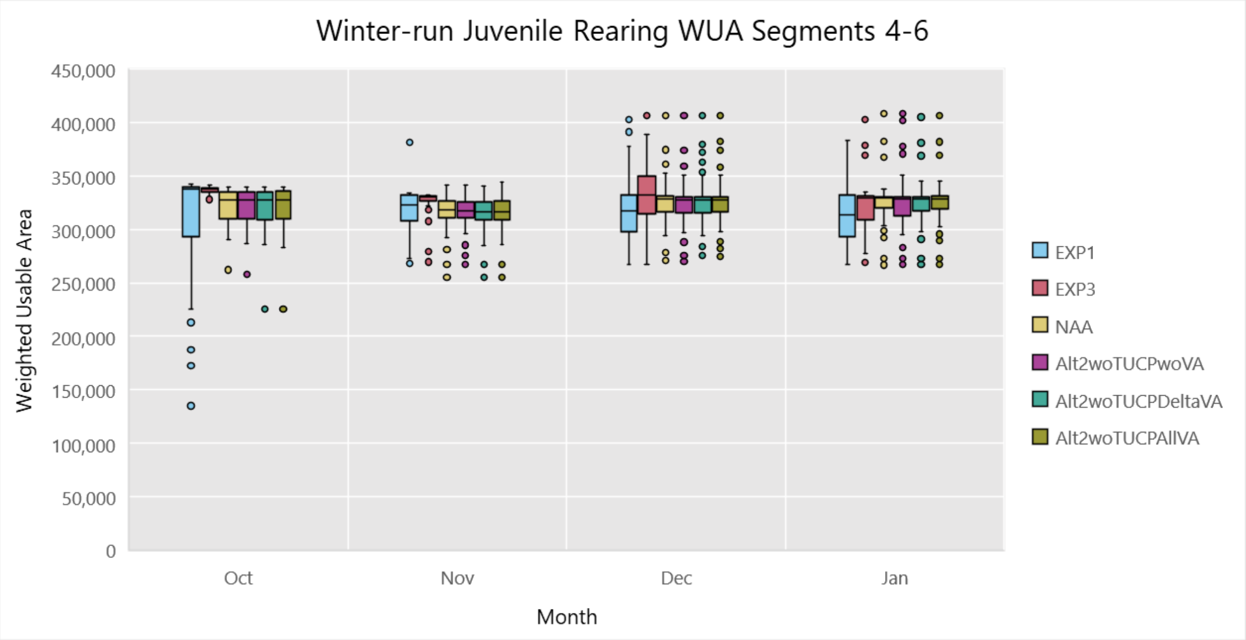


Figure O.3-28. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

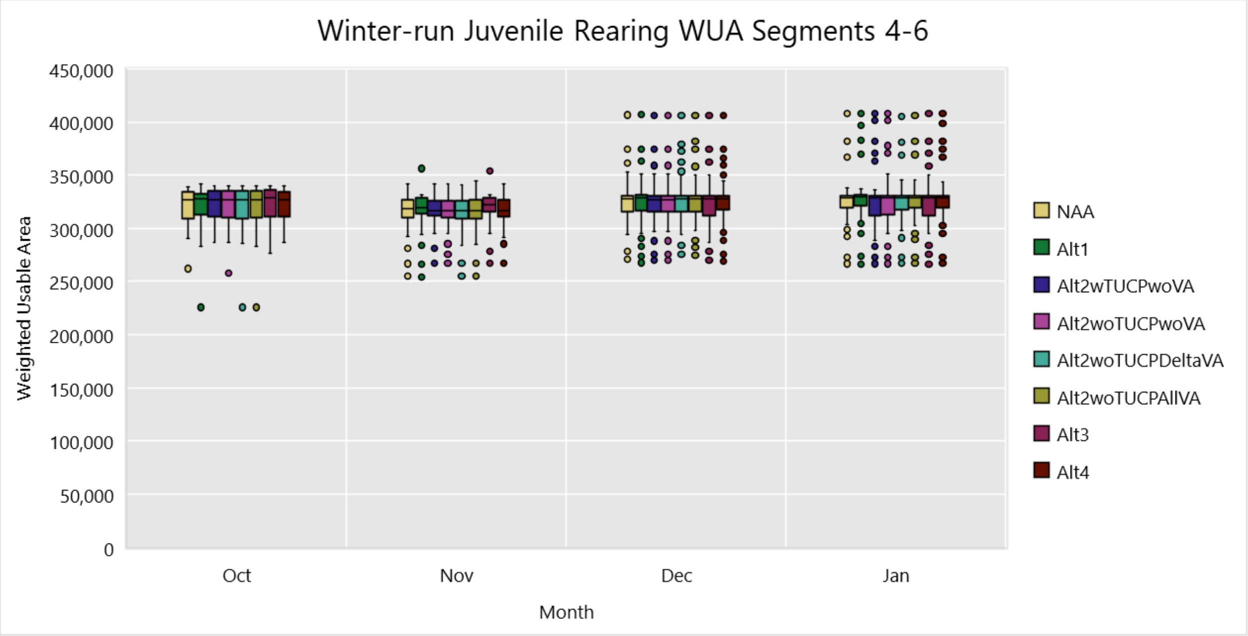


Figure O.3-29. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Table O.3-21. Expected WUA for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	416,795	457,583	455,508	453,553	453,691	454,147	453,937
AN	413,508	480,525	491,821	488,294	489,252	489,809	485,585
BN	416,041	537,650	528,229	523,923	523,994	524,594	520,618
Dry	431,463	554,191	549,399	541,788	542,669	546,266	544,527
Critical	484,777	595,099	580,491	579,203	567,869	565,212	565,304
All	430,544	520,166	516,082	512,255	510,841	511,587	509,814

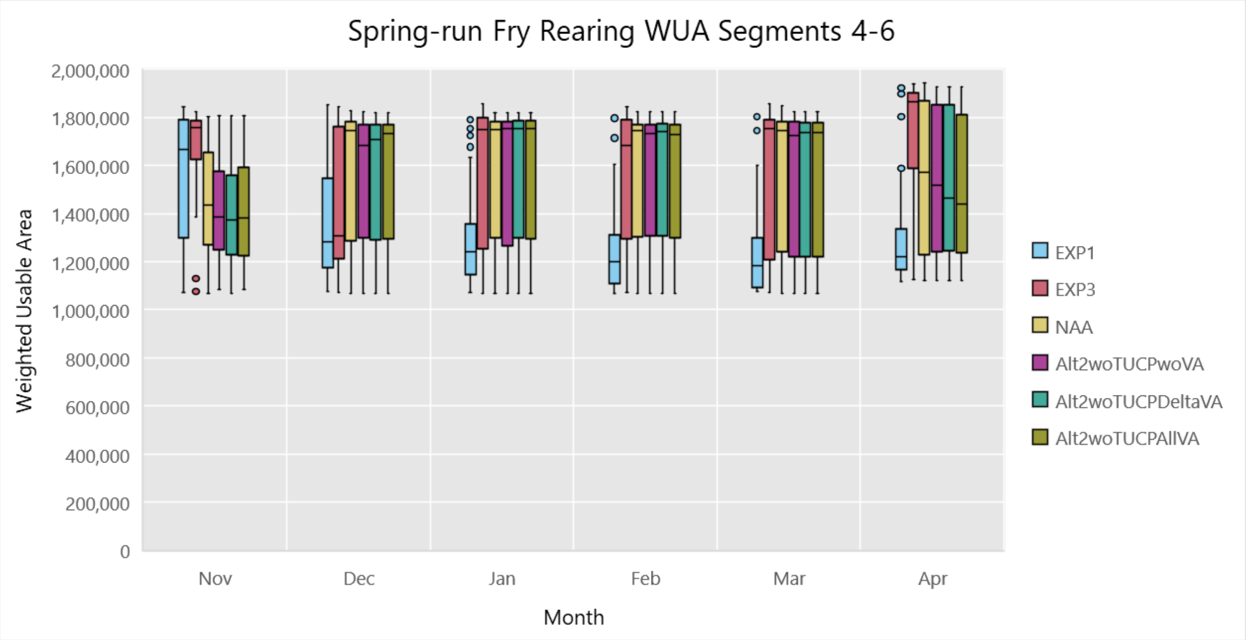


Figure O.3-30. Expected WUA for Spring-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

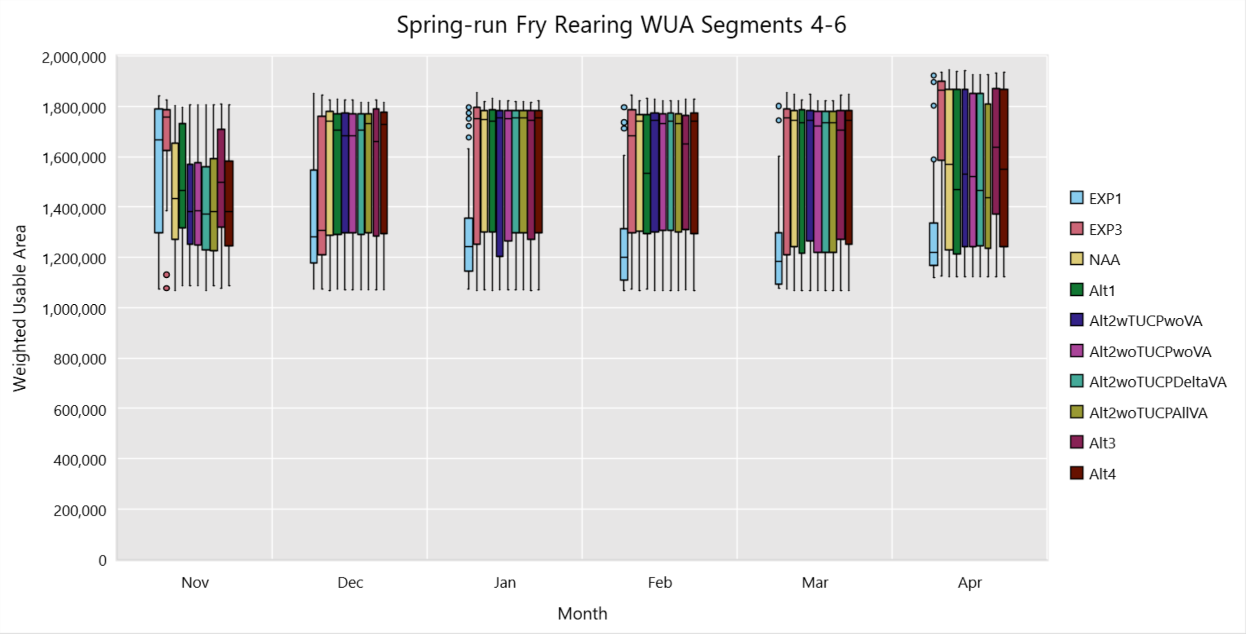


Figure O.3-31. Expected WUA for Spring-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Table O.3-22. Expected WUA for Spring-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	728,614	734,565	706,482	701,681	701,911	701,435	701,964
AN	748,987	768,341	767,087	755,849	758,281	755,395	756,466
BN	731,893	836,066	822,451	814,226	814,894	812,297	811,433
Dry	768,111	866,077	869,028	857,793	857,733	860,880	858,568
Critical	774,758	916,570	906,698	900,178	895,524	896,526	899,145
All	749,345	817,476	806,080	797,885	797,721	797,626	797,642

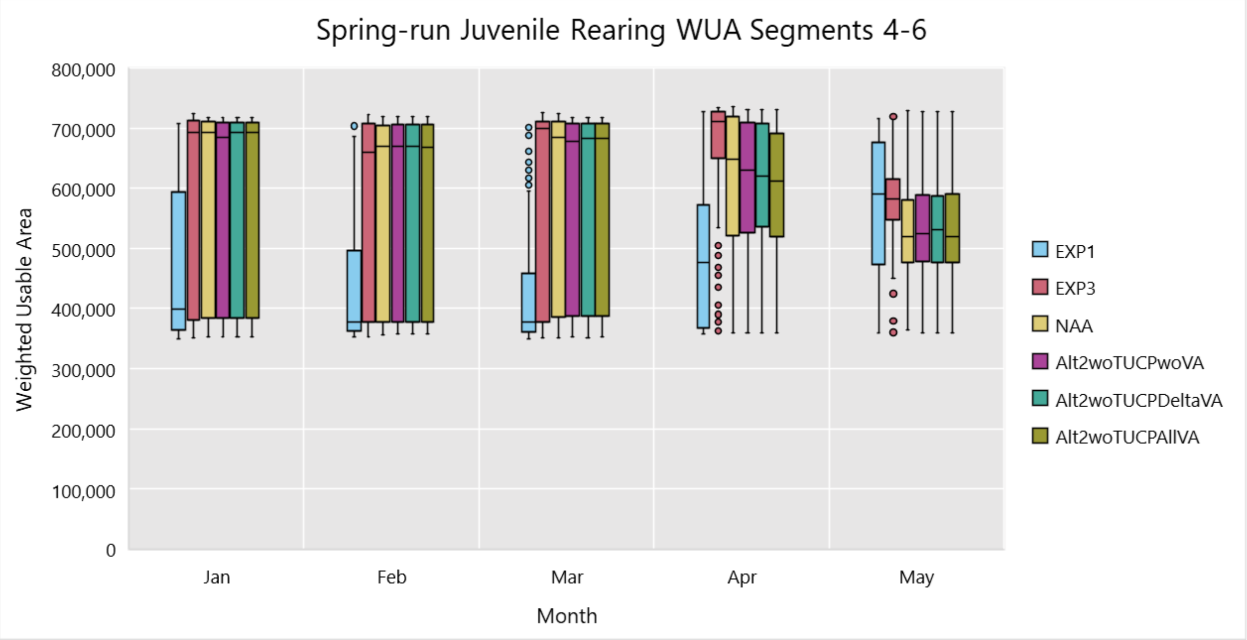


Figure O.3-32. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

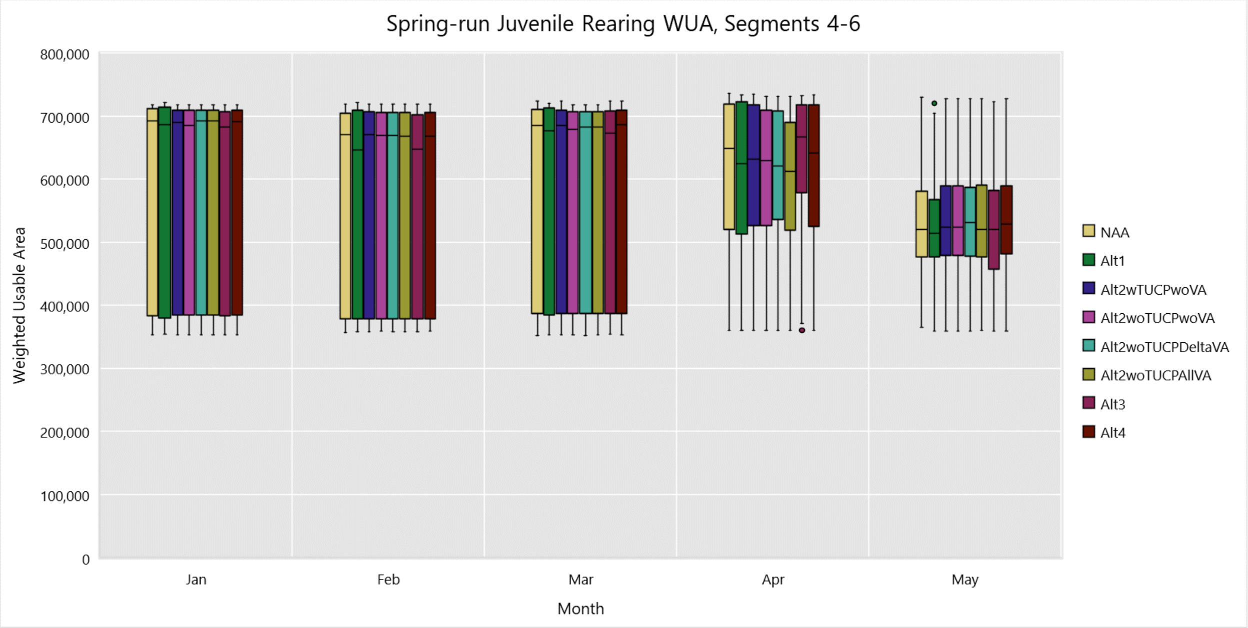


Figure O.3-33. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Table O.3-23. Expected WUA for Steelhead Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	517,053	429,915	369,731	369,257	369,270	369,217	369,514
AN	532,254	412,169	370,176	370,059	370,052	369,569	368,182
BN	524,923	399,469	379,819	376,446	377,485	378,388	375,573
Dry	506,445	397,856	383,413	380,896	381,072	382,286	383,068
Critical	500,494	400,888	395,872	418,908	415,011	412,754	411,061
All	515,476	409,637	379,021	381,336	380,946	380,961	380,262

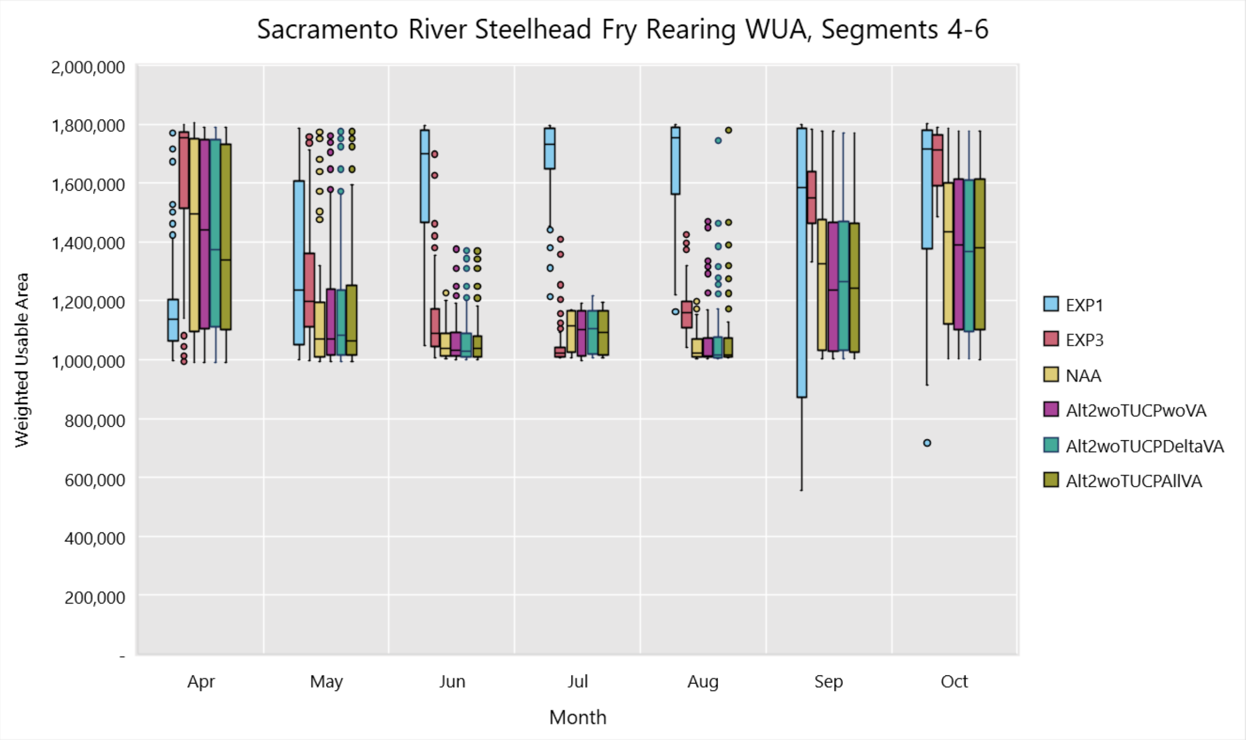


Figure O.3-34. Expected WUA for Steelhead Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

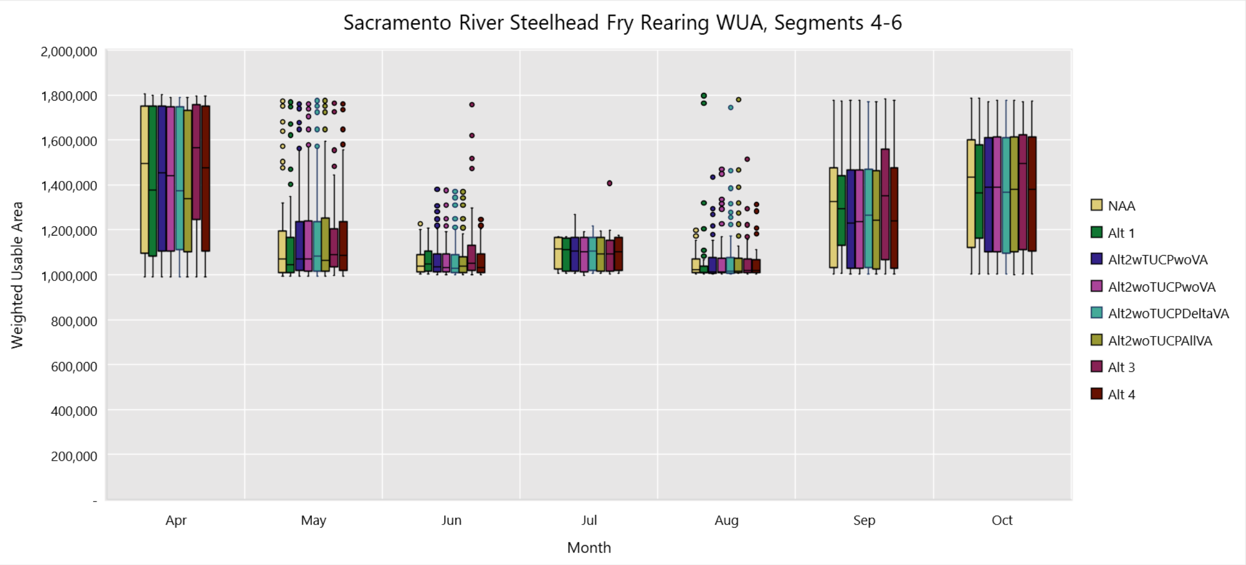


Figure O.3-35. Expected WUA for Steelhead Fry Rearing in the Sacramento River Segments 4-6 for for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Table O.3-24. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Four Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	676,238	682,622	656,455	652,586	652,762	652,251	652,666
AN	692,732	707,925	705,832	696,565	698,414	696,061	696,902
BN	674,842	765,812	752,530	746,194	746,660	744,534	743,520
Dry	705,949	789,567	791,640	782,426	782,493	785,193	783,378
Critical	706,887	830,466	822,469	817,003	813,341	814,024	816,218
All	690,753	749,835	738,999	732,343	732,222	732,122	732,096

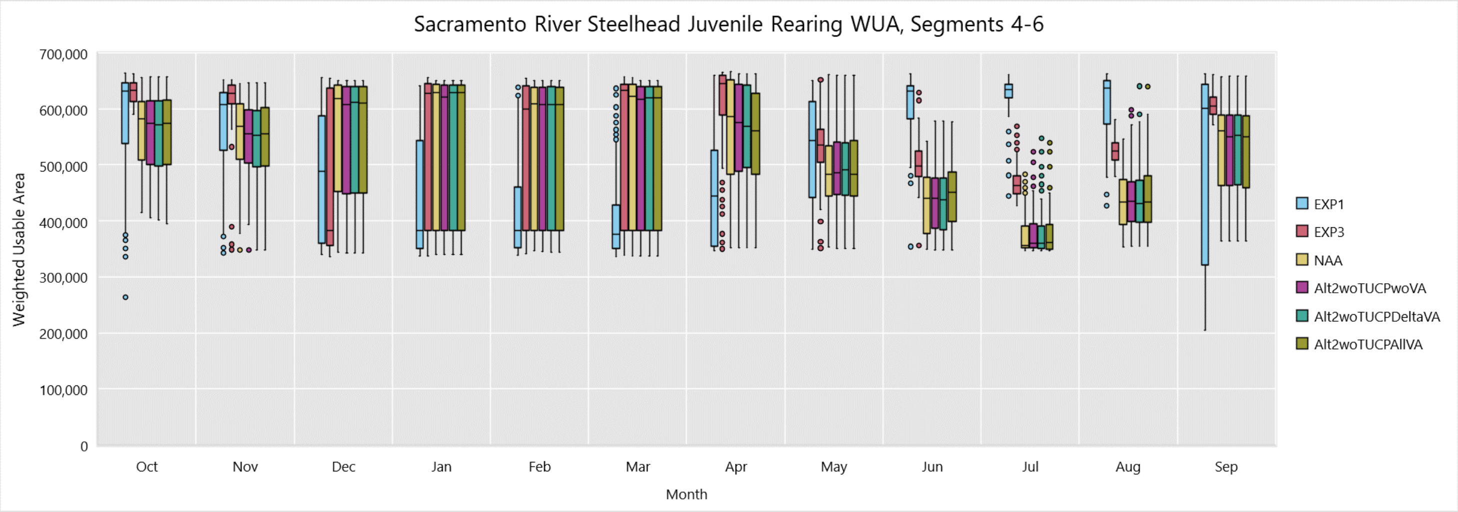


Figure O.3-36. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and three Proposed Action scenarios (Alternative 2) by Month

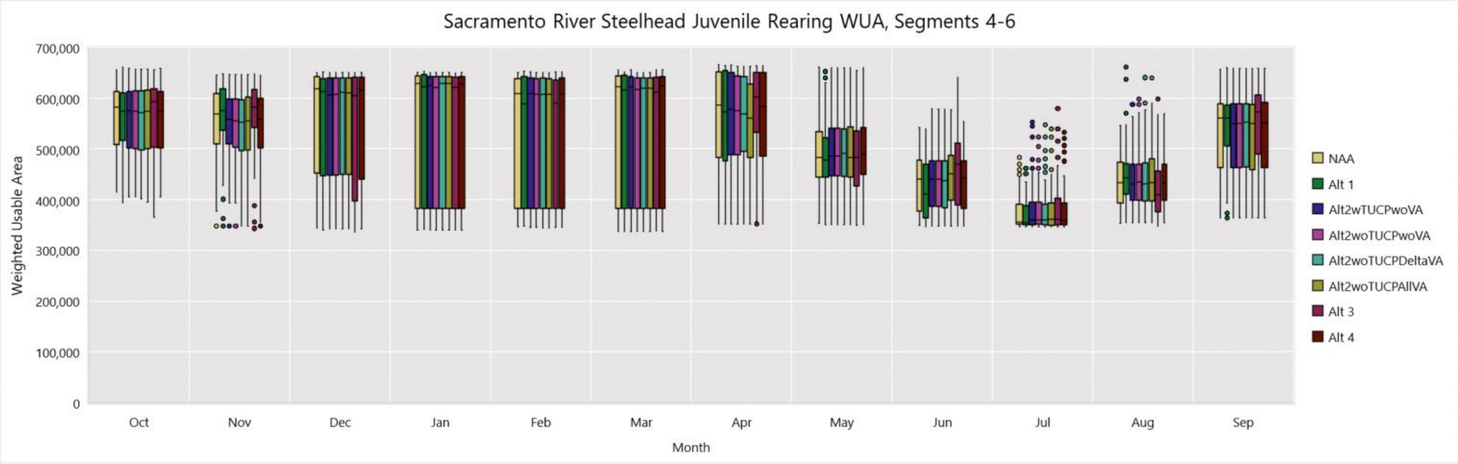


Figure O.3-37. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River Segments 4-6 for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

O.3.4 References

O.3.4.1 Printed References

Bartholow, J. M. 2004. Modeling Chinook Salmon with SALMOD on the Sacramento River, California. *Hydroecologie Applique* 14(1):193–219.

Beecher, H. A. 2017. Comment 1: Why it is Time to Put PHABSIM out to Pasture. *Fisheries* 42(10):508–510.

Beecher, H. A., B. A. Caldwell, S. B. DeMond, D. Seiler, and S. N. Boessow. 2010. An Empirical Assessment of PHABSIM Using Long-Term Monitoring of Coho Salmon Smolt Production in Bingham Creek, Washington. *North American Journal of Fisheries Management* 30:1529–1543.

Bourgeois, G., R. A. Cunjak, D. Caissie, and N. El-Jabi. 1996. A Spatial and Temporal Evaluation of PHABSIM in Relation to Measured Density of Juvenile Atlantic Salmon in a Small Stream. *North American Journal of Fisheries Management* 16:154–166.

Bovee, K. D., B. L. Lamb, J. M. Bartholow, C. B. Stalnaker, J. Taylor, and J. Henriksen. 1998. *Stream Habitat Analysis Using the Instream Flow Incremental Methodology*. USGS/BRD-1998-0004. Fort Collins, CO.

ESSA Technologies Ltd. 2011. Sacramento River Ecological Flows Tool (SacEFT): Record of Design. Version 2.00. Vancouver, BC. Prepared for The Nature Conservancy, Chico, CA.

Geist, D. R., C. S. Abernathy, K. D. Hand, V. I. Cullinan, J. A. Chander, and P. A. Groves. 2016. Survival, development, and growth of fall Chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. *Transactions of the American Fisheries Society* 135:1462–1477.

Healey, M. C. 1991. *Life History of Chinook Salmon (*Oncorhynchus tshawytscha*)*. pp. 312-393 in C. Groot and L. Margolis, eds. Pacific Salmon Life Histories. UBC Press. Vancouver, Canada. 564pp.

ICF International 2016

Martin, C. D., P. D. Gaines, and R. R. Johnson. 2001. *Estimating the Abundance of Sacramento River Juvenile Winter Chinook Salmon with Comparisons to Adult Escapement.* Red Bluff Research Pumping Plant Report Series, Volume 5. U. S. Fish and Wildlife Service, Red Bluff, CA.

McMichael, G. A., C. L. Rakowski, B. B. James, and J. A. Lukas. 2005. Estimated fall chinook salmon survival to emergence in dewatered redds in a shallow side channel of the Columbia River. *North American Journal of Fisheries Management* 25:876–884.

Naman, S. M., J. S. Rosenfeld, J. R. Neuswanger, E. C. Enders, and B. C. Eaton. 2019. Comparing, Correlative and Bioenergetics-based Habitat Suitability Models for Drift-feeding Fishes. *Freshwater Biology* 64:1613–1626.

Naman, S. M., J. S. Rosenfeld, J. R. Neuswanger, E. C. Enders, J. W. Hayes, E. O. Goodwin, I. G. Jowett, and B. C. Eaton. 2020. Bioenergetic Habitat Suitability Curves for Instream Flow Modeling: Introducing User-Friendly Software and its Potential Application. *Fisheries* 45:605–613.

Payne, T. R. 2003. The Concept of Weighted Usable Area as Relative Suitability Index. In IFIM Users Workshop, June 1–5, 2003, Fort Collins, Colorado.

Railsback, S. F. 2016. Why it is Time to Put PHABSIM Out to Pasture. *Fisheries* 41:720-725.

Reiser, D. W., and P. J. Hilgert. 2018. A Practitioner's Perspective on the Continuing Technical Merits of PHABSIM. *Fisheries* 43:278-283.

Stalnaker, C. B., I. Chisholm, A. Paul. 2017. Don't Throw out the Baby (PHABSIM) with the Bathwater; Bringing Scientific Credibility to Use of Hydraulic Models, Specifically PHABSIM. *Fisheries* 42(10):510–516.

U.S. Fish and Wildlife Service. 2003a. *Flow-Habitat Relationships for steelhead and fall, late-fall, and winter-run Chinook salmon spawning in the Sacramento River between Keswick Dam and Battle Creek.* February 4, 2003. Sacramento, CA.

U.S. Fish and Wildlife Service. 2003b. *Comparison of PHABSIM and 2-D Modeling of Habitat for Steelhead and Fall-run Chinook Salmon Spawning in the Lower American River.* February 4, 2003. Sacramento, CA.

U.S. Fish and Wildlife Service. 2005a. *Flow-Habitat Relationships for Fall-run Chinook Salmon Spawning in the Sacramento River between Battle Creek and Deer Creek.* August 10, 2005. Sacramento, CA.

U.S. Fish and Wildlife Service. 2005b. *Flow-Habitat Relationships for Chinook Salmon Rearing in the Sacramento River between Keswick Dam and Battle Creek.* August 2, 2005. Sacramento, CA.

U.S. Fish and Wildlife Service. 2006. *Sacramento River (Keswick Dam to Battle Creek) Redd Dewatering and Juvenile Stranding Final Report.* June 22, 2006. Sacramento, CA.

Williams 2006

O.3.4.2 Personal Communications

Gard, Mark. Fish and Wildlife Biologist. U.S. Fish and Wildlife Service. July 5, 2015—Email to Sophie Unger, Senior Fish Biologist, ICF, Sacramento, CA.

Robinson, Donald. Senior Systems Ecologist. ESSA Technologies, Vancouver, BC. June 16, 2015—Email to Clint Alexander, President, ESSA Technologies, Vancouver, BC.