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 BA 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 Section O.3.2.2, *Assumptions/Uncertainties*. 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 Section O.3.2.2, *Assumptions/Uncertainties*.

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.3-6 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

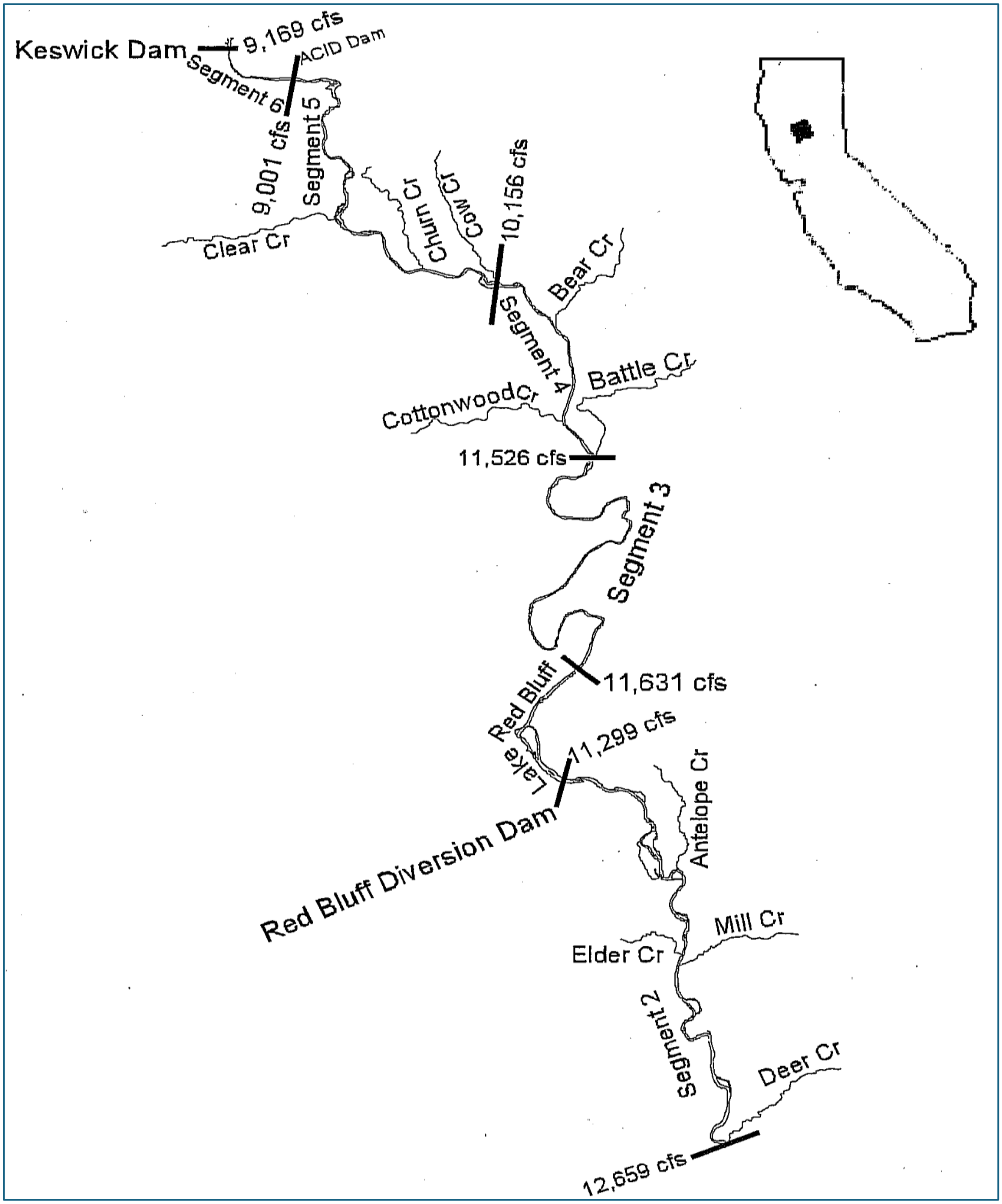
[1] For simplicity, this location is referred to as the Red Bluff Diversion Dam (RBDD) in this document despite dam decommissioning in 2013.

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 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 from 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, and for fall-run the weighting factors were estimated from information in Moyle et al. 2017.

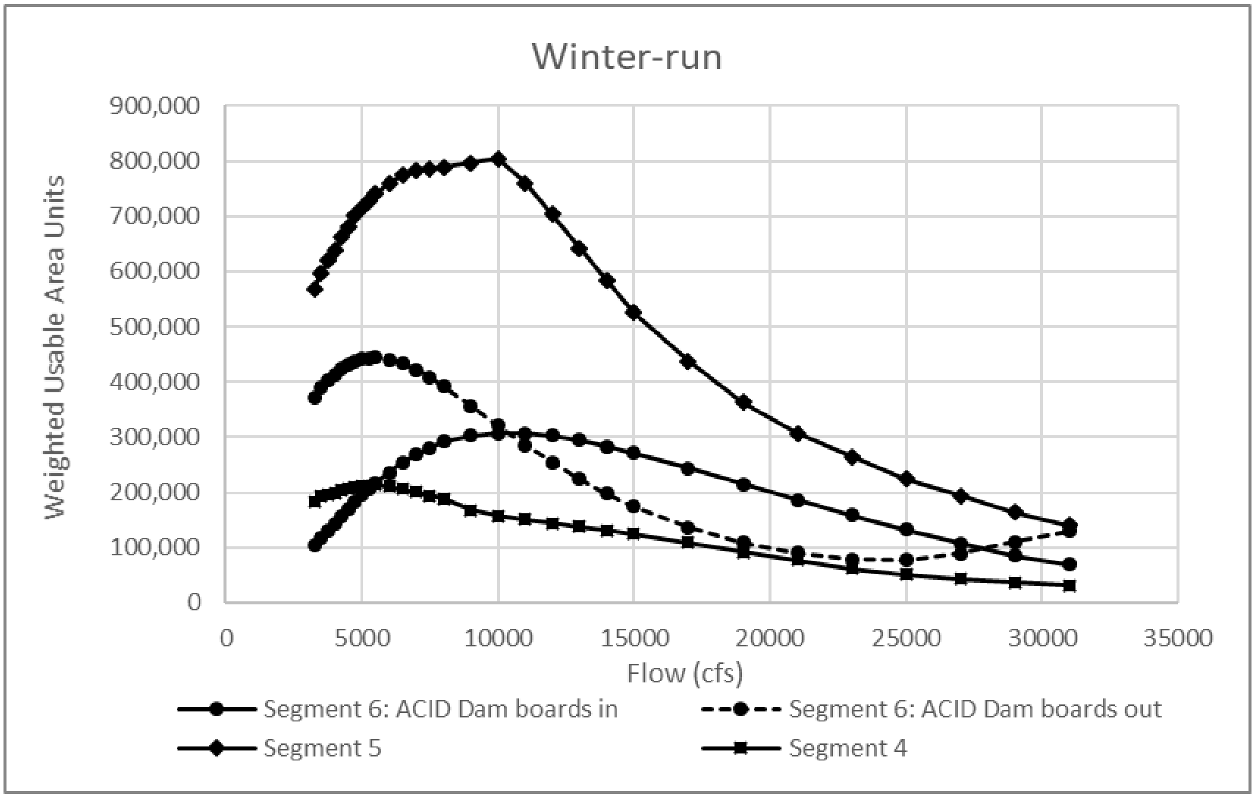
Table O.3-1. Monthly Weighting Factors for Sacramento River Winter-run, Spring-run, Fall-run, Late fall-run, and Steelhead Spawning.

Month	Winter-run	Spring-run	Fall-run	Late fall-run	Steelhead
January	0	0	0	0.4	0.15
February	0	0	0	0.1	0.35
March	0	0	0	0.1	0.35
April	0	0	0	0	0.15
May	0.1	0	0	0	0
June	0.4	0	0	0	0
July	0.4	0	0	0	0
August	0.1	0.1	0	0	0
September	0	0.6	0.1	0	0
October	0	0.3	0.3	0	0
November	0	0	0.4	0	0
December	0	0	0.2	0.4	0



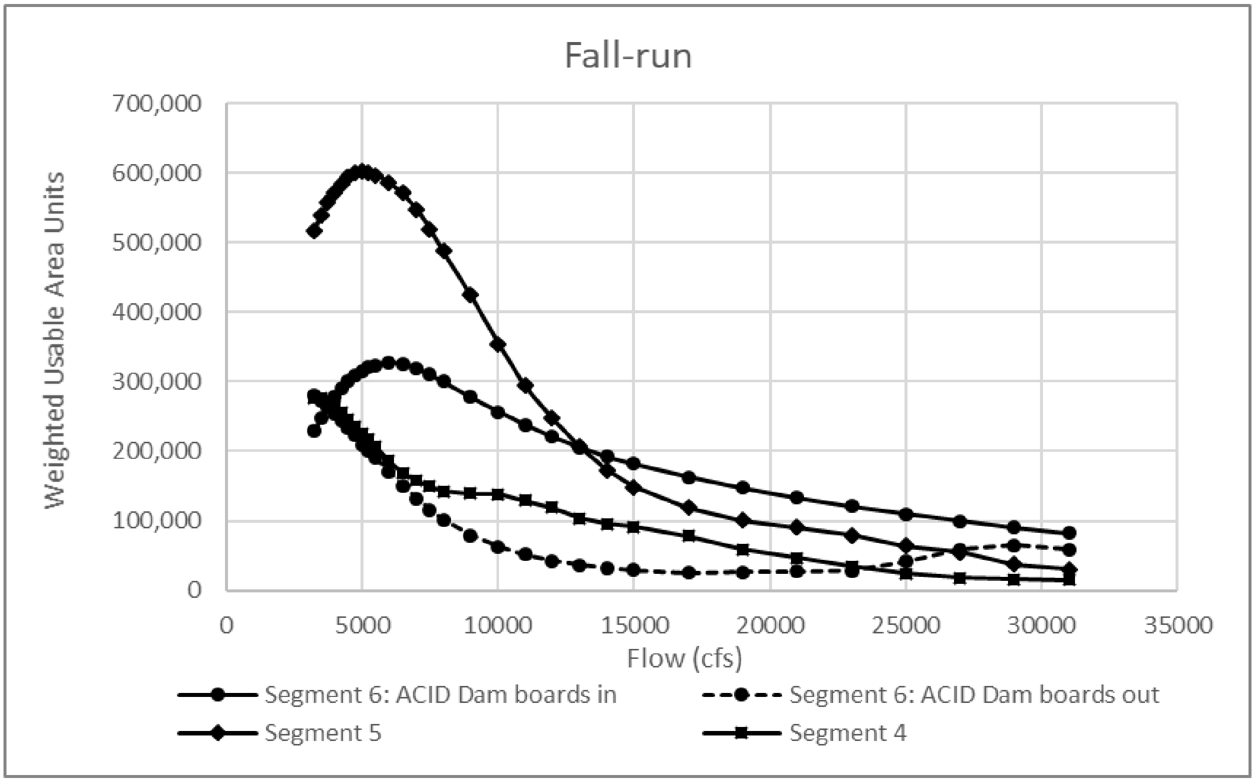
ACID = Anderson-Cottonwood Irrigation District
Source: U.S. Fish and Wildlife Service 2003a.

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).



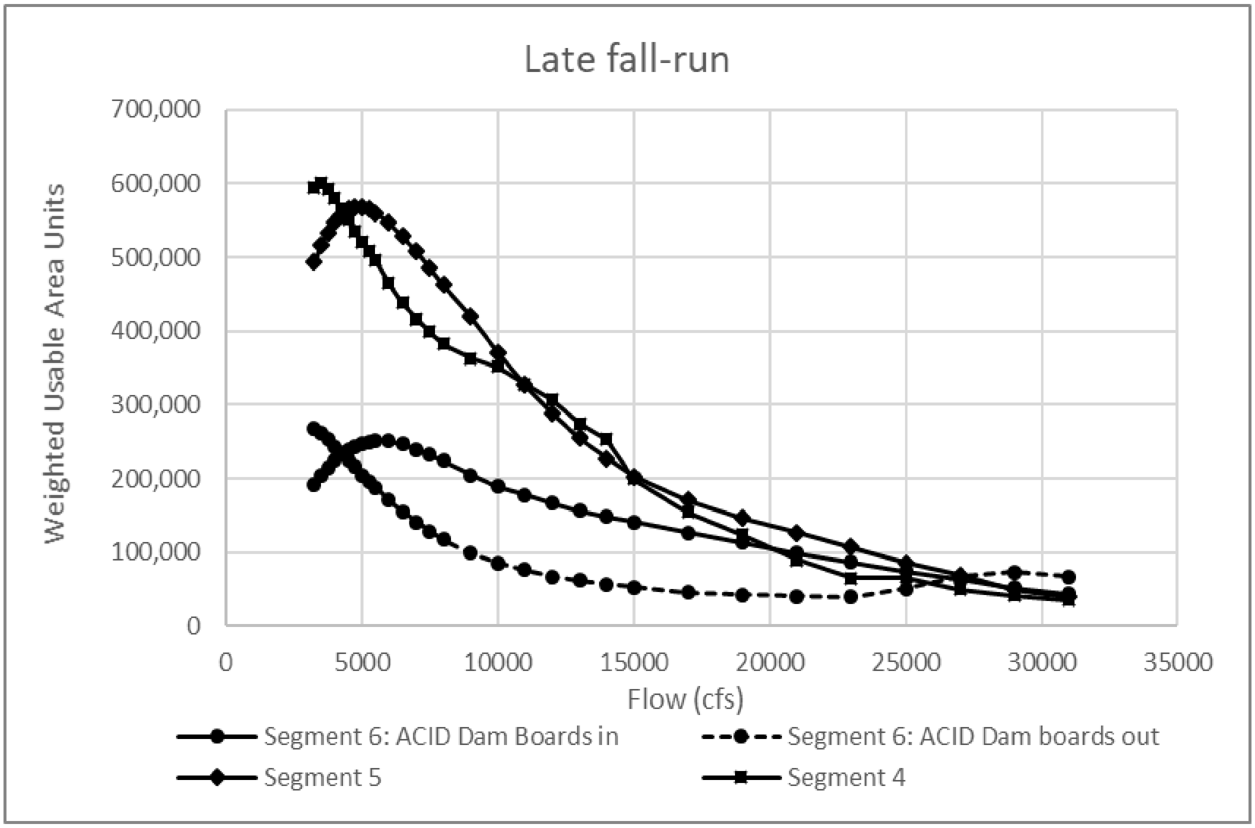
ACID = Anderson-Cottonwood Irrigation District.

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



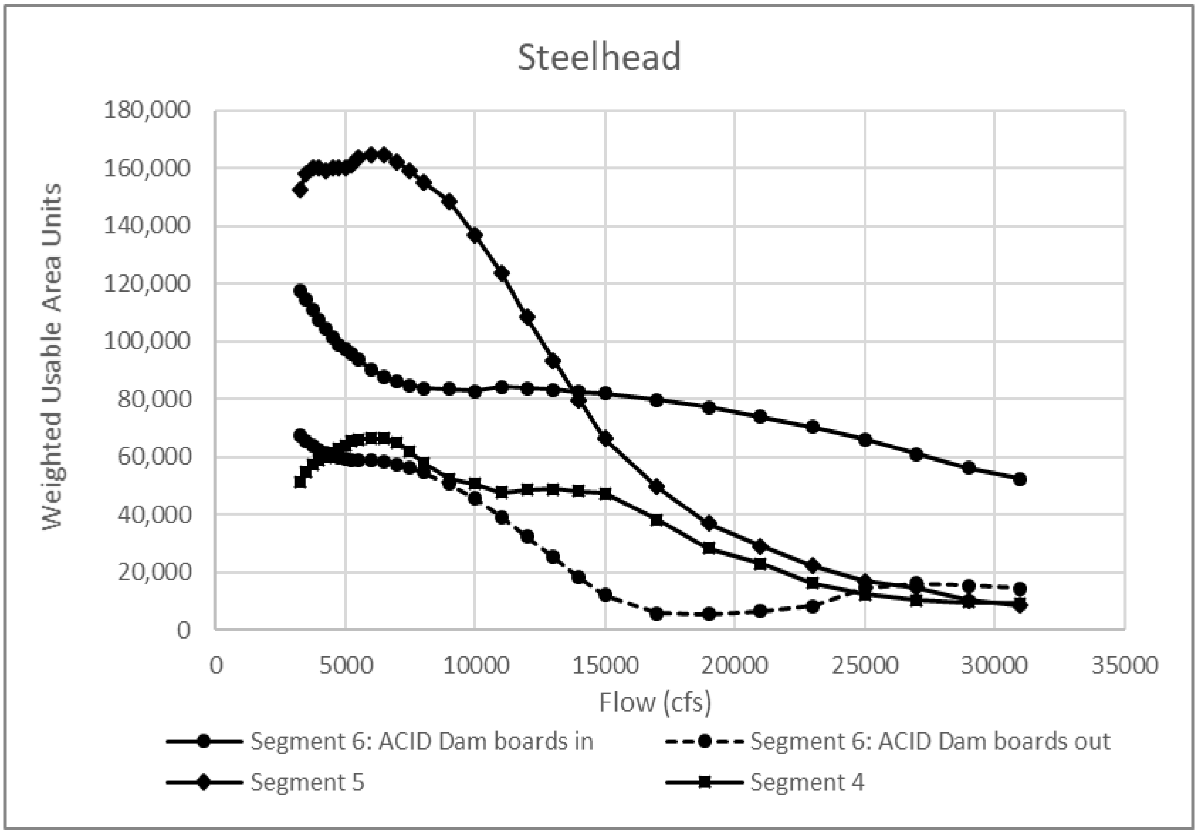
ACID = Anderson-Cottonwood Irrigation District.

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.3-2) 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.3-2). For the salmon races, the mean WUA results for the segments were weighted using the percentage in Table O.3-2 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.3-2) 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 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.

Table O.3-2. 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.3.2.1.2 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 Section O.3.2.2, *Assumptions / Uncertainty*, 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 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.

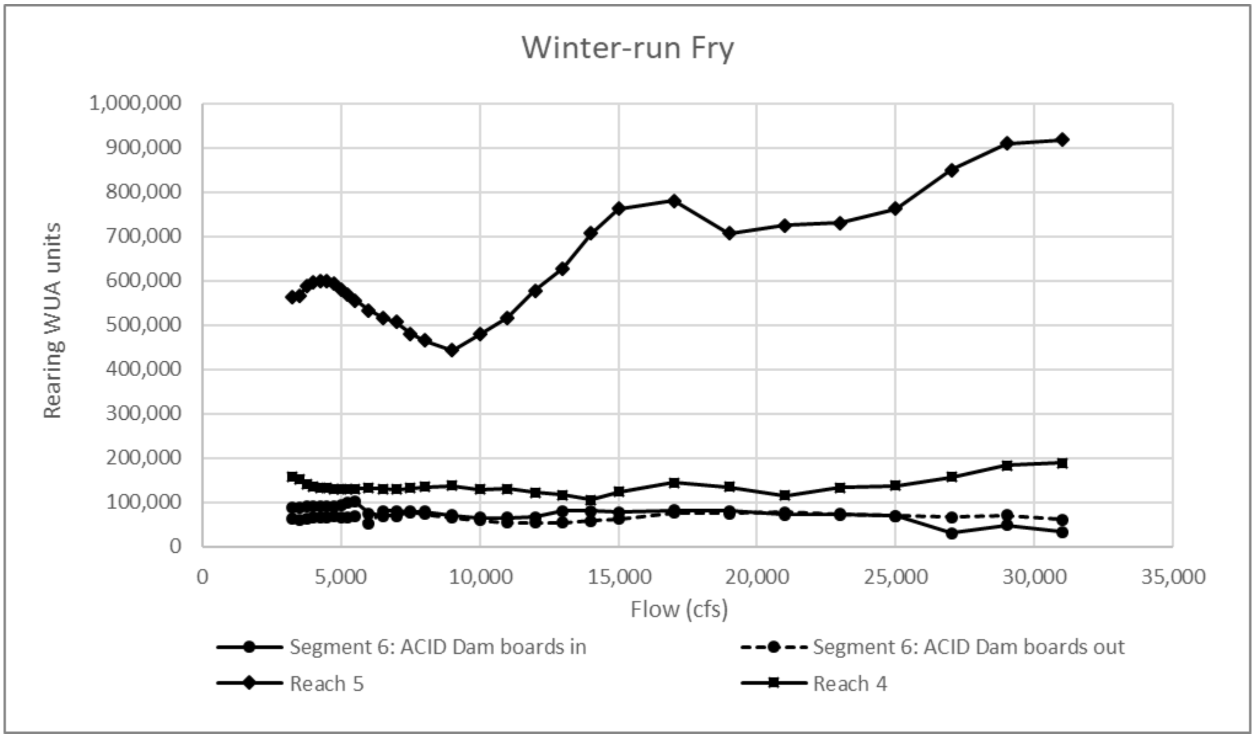
It should be noted that many winter-run fry begin moving downstream shortly after emerging and a majority of the fry may rear primarily downstream of the RBDD (Martin 2001). This may also be true for fry of the other salmon runs and steelhead. Unfortunately, no rearing WUA studies have been conducted 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.3-3) 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.3-3). 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. The primary months of fry rearing for fall-run and late fall-run were obtained in consultations with NMFS for the CWF project. The months of the rearing period for these two races were weighted equally.

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

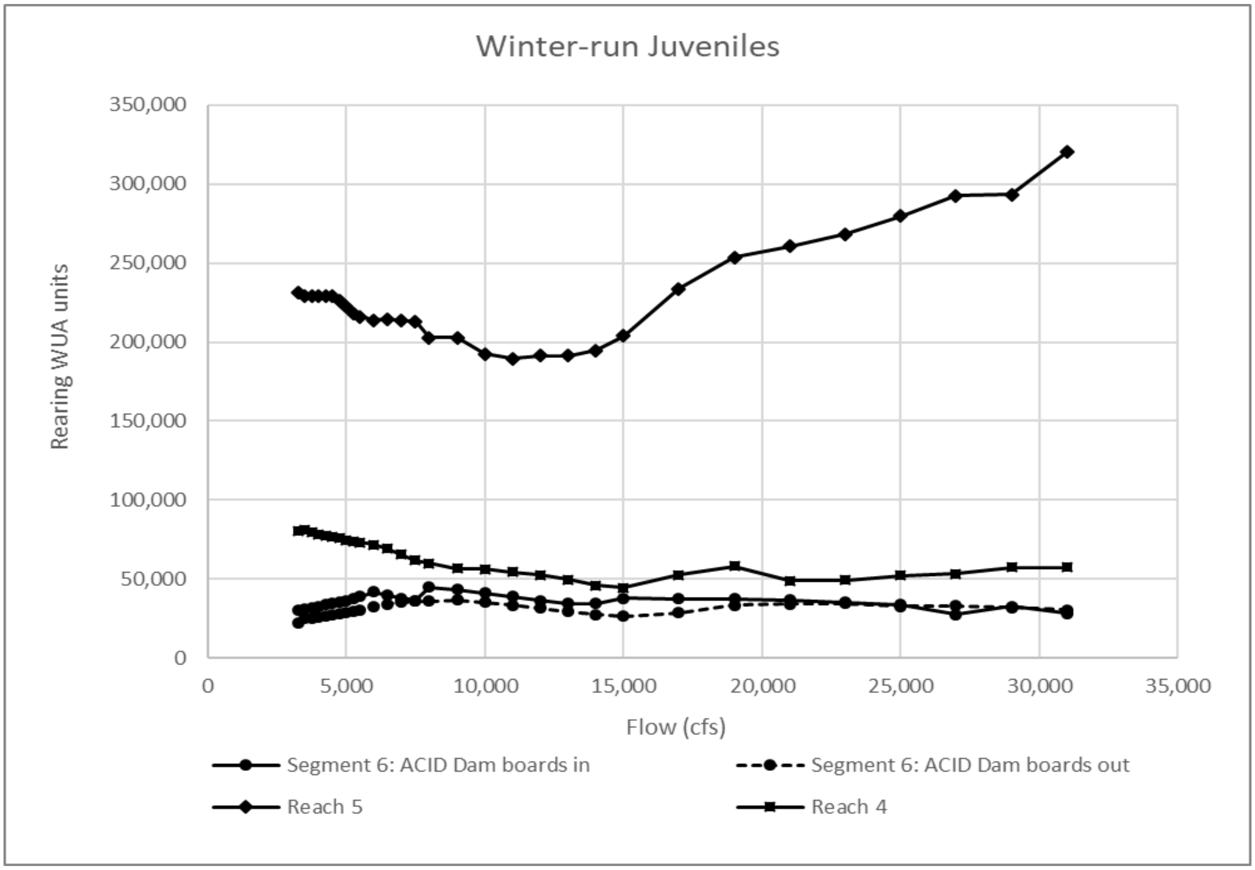
Month	**Winter-run**	**Spring-run**	**Fall-run**	**Late Fall-run**	**Steelhead**
January	0	0.2	0.25	0	0
February	0	0.22	0.25	0	0
March	0	0.2	0.25	0.25	0
April	0	0.18	0	0.25	0.05
May	0	0	0	0.25	0.15
June	0	0	0	0.25	0.2
July	0	0	0	0	0.25
August	0.05	0	0	0	0.2
September	0.35	0	0	0	0.1
October	0.35	0	0	0	0.05
November	0.2	0.05	0	0	0
December	0.05	0.15	0.25	0	0

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, Species Spatial-Temporal Domains). 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 late 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 four phases of Alternative 2 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.



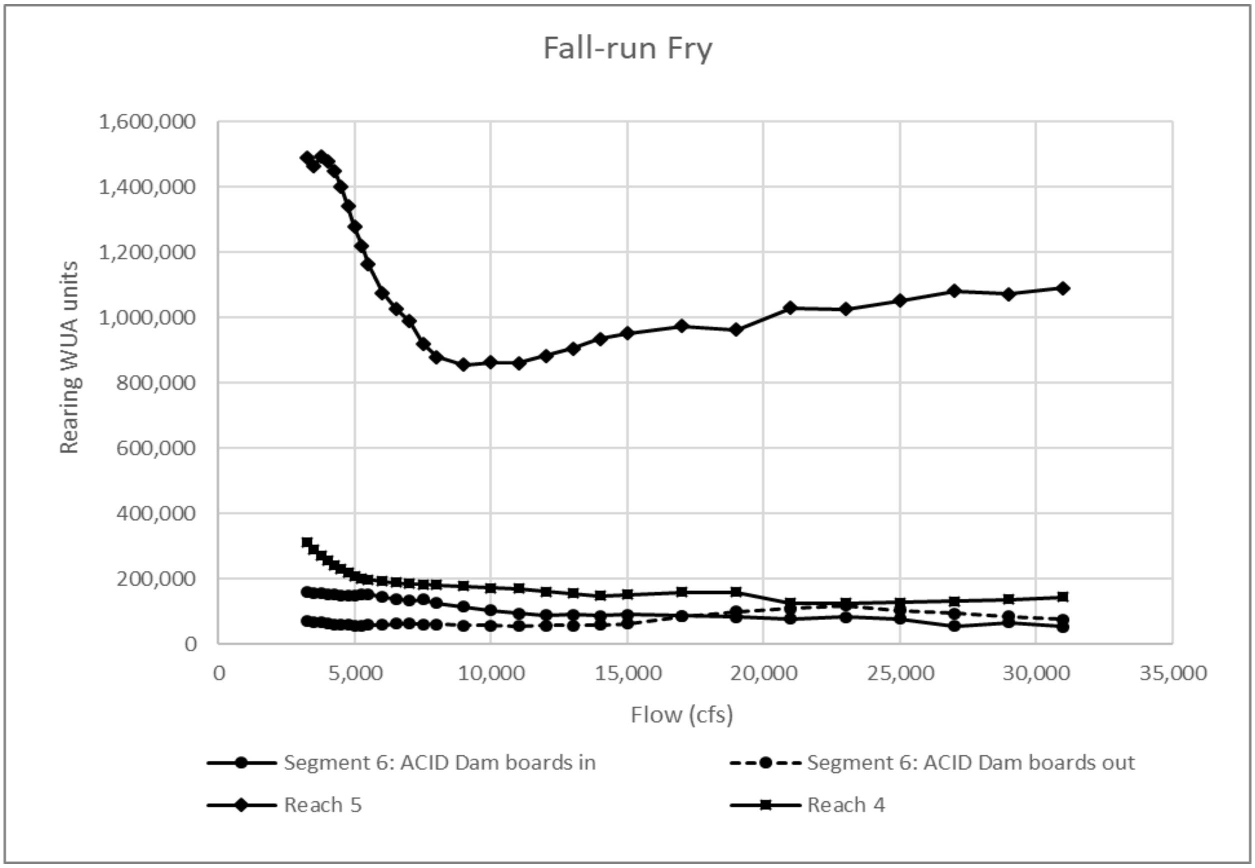
ACID = Anderson-Cottonwood Irrigation District.

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



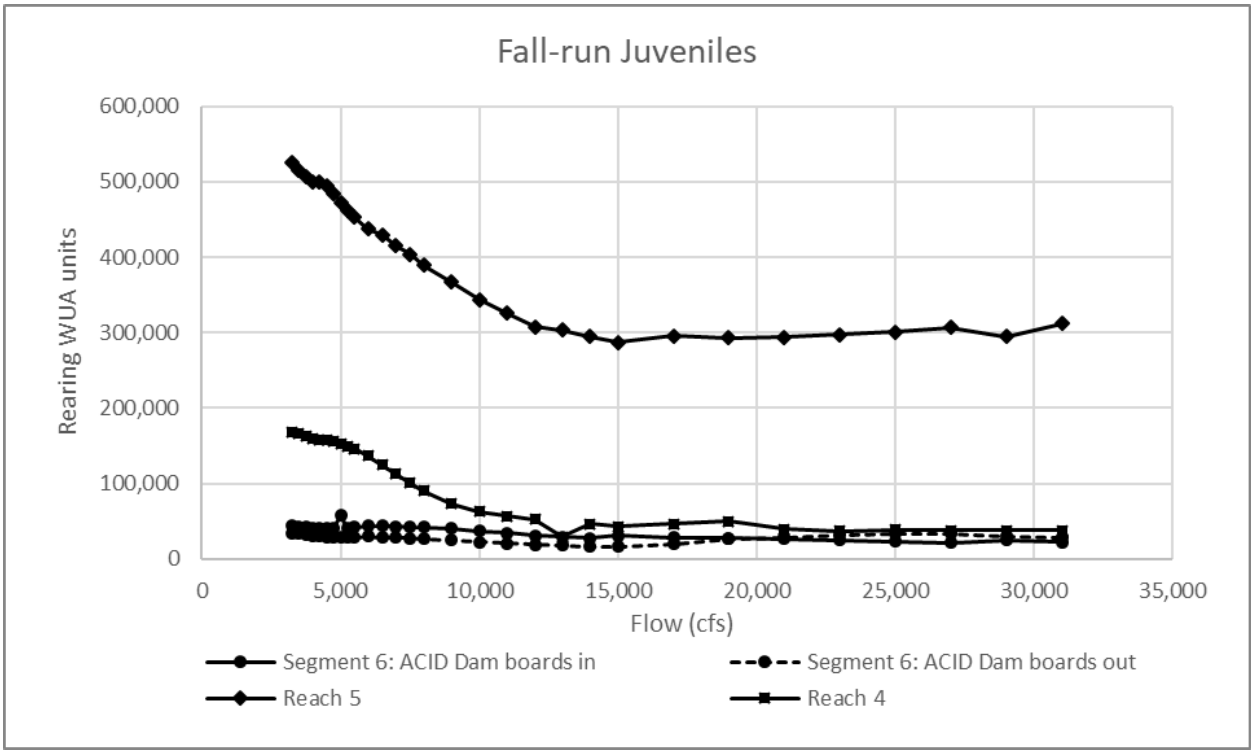
ACID = Anderson-Cottonwood Irrigation District.

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



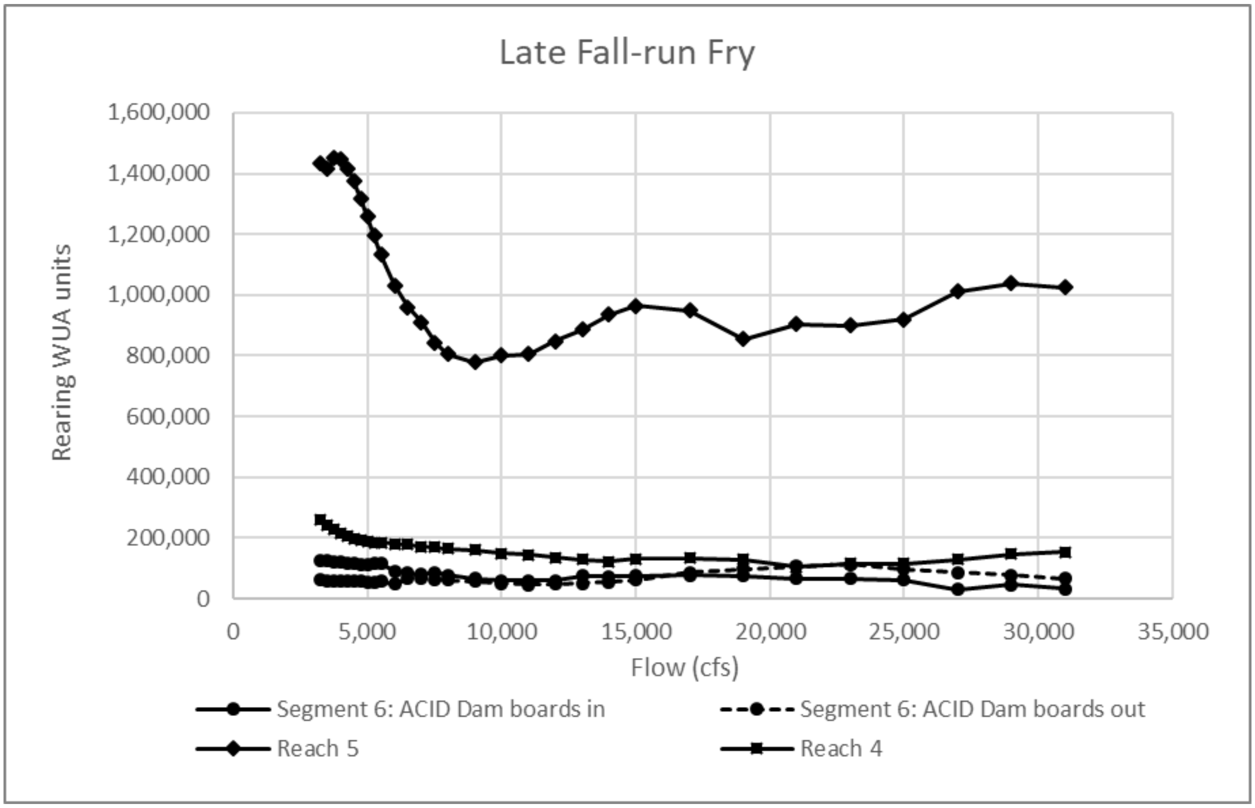
ACID = Anderson-Cottonwood Irrigation District.

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 Fry Rearing WUA, as Discussed in the Text.



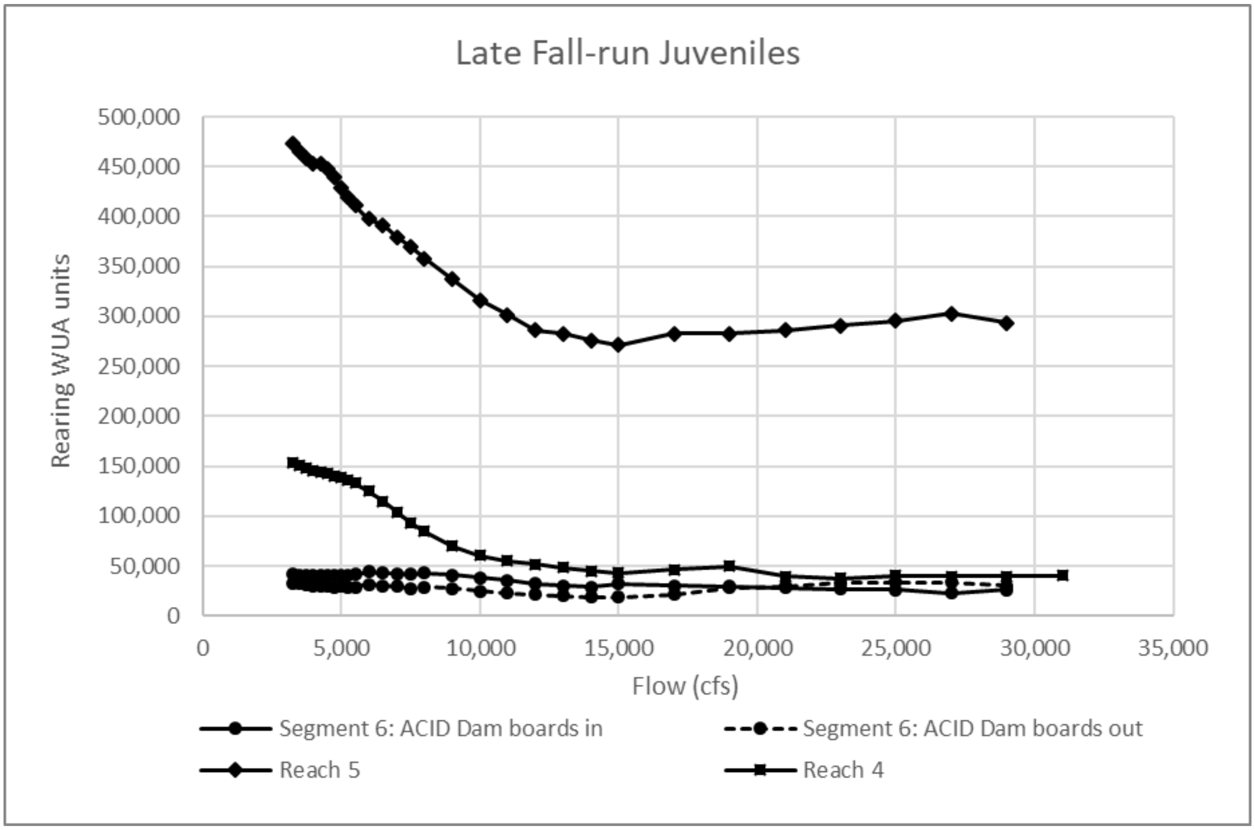
ACID = Anderson-Cottonwood Irrigation District.

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 Spring-run Juvenile 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 Fry 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. These Curves were used to Quantify Steelhead Juvenile Rearing WUA, as Discussed in the Text.

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.3.2.2 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.3.2.2.1 Important Uncertainties and Assumptions of the WUA Analyses Conducted for the Effects Analyses

The CalSim 3 operations model used to estimate spawning and rearing WUA under the phases 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 phases and alternatives conditions. Weighting by the weighting factors in Table O.3-1 and Table O.3-3 ensures that the comparisons account for differences in the amount of spawning occurring in each month, improving the validity of the results.

Fixed monthly spawning and rearing periods, with months weighted by expected occurrences, were used in this analysis for determining effects of changes in flow on spawning and rearing WUA**.** and Table O.3-3). These periods were estimated from a number of literature sources, cited in Attachment O.3, and represent field data collection on spawning and rearing of salmonids in the Sacramento River over many years. They are expected to represent the average spawning and rearing periods of the fish. However, the timing of spawning and rearing by salmon and steelhead may vary somewhat among years depending on flows (Quinn 2005). Timing may be affected by flow volume in spawning and rearing habitats or via flow effects on upstream or downstream migration timing or water temperatures (Sullivan and Hileman 2019; Jennings and Hendrix 2020). The use of fixed spawning and rearing periods for this analysis does not account for these potential variations either in flow from year to year nor for differences in flow regimes between the alternative scenarios, which potentially increases uncertainty in the results. However, variations from the primary spawning and rearing periods are likely to be small, because spawn timing is a conservative, genetically controlled trait in anadromous fish (Quinn 2005) and the timing of spawning directly affects that of rearing.

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.

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).

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 phases and alternatives on rearing habitat in the Sacramento River downstream of Battle Creek.

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.

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.

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.

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).

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.3.2.2.2 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.3.2.3 Code and Data Repository

Data for this analysis are available upon request.

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 BA 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.3-4 and Table O.3-5 provide the spawning WUA results for Sacramento River winter-run Chinook salmon under the BA 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.3-1) and per river segment (Table O.3-2). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-5).

The results for both the BA and EIS modeled scenarios show modest and inconsistent variation in mean spawning WUA with water year type for EXP1 and EXP3, but under the NAA and all BA and EIS modeled scenarios for the 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 is a 5.6% increase for Alt 3 in above normal water years (Table O.3-5). The largest reduction is 1.4% for Alt 1 in above normal water years.

Table O.3-4. Expected WUA for Winter-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, NAA, and four phases of Alternative 2

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	503,647	576,192	545,135	548,572	548,494	548,607	548,848
AN	477,951	594,047	518,502	522,731	522,694	523,507	530,681
BN	469,563	599,138	532,471	538,123	538,253	538,289	546,497
Dry	468,443	601,967	547,915	561,083	560,634	557,712	564,350
Critical	421,055	598,986	582,871	582,443	583,645	578,943	580,022
All	472,251	592,655	545,832	551,495	551,576	550,275	554,590

Table O.3-5. Expected WUA for Winter-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	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
D	547,915	549,027	561,083	560,634	557,712	564,350	552,224	558,365
C	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
W	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
D	547,915	0.20	2.40	2.32	1.79	3.00	0.79	1.91
C	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

Figure O.3-12 and Figure O.3-13 show the full variation in estimated spawning WUA for winter-run under the BA 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 BA 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 produces the lower and more variable spawning WUA results.

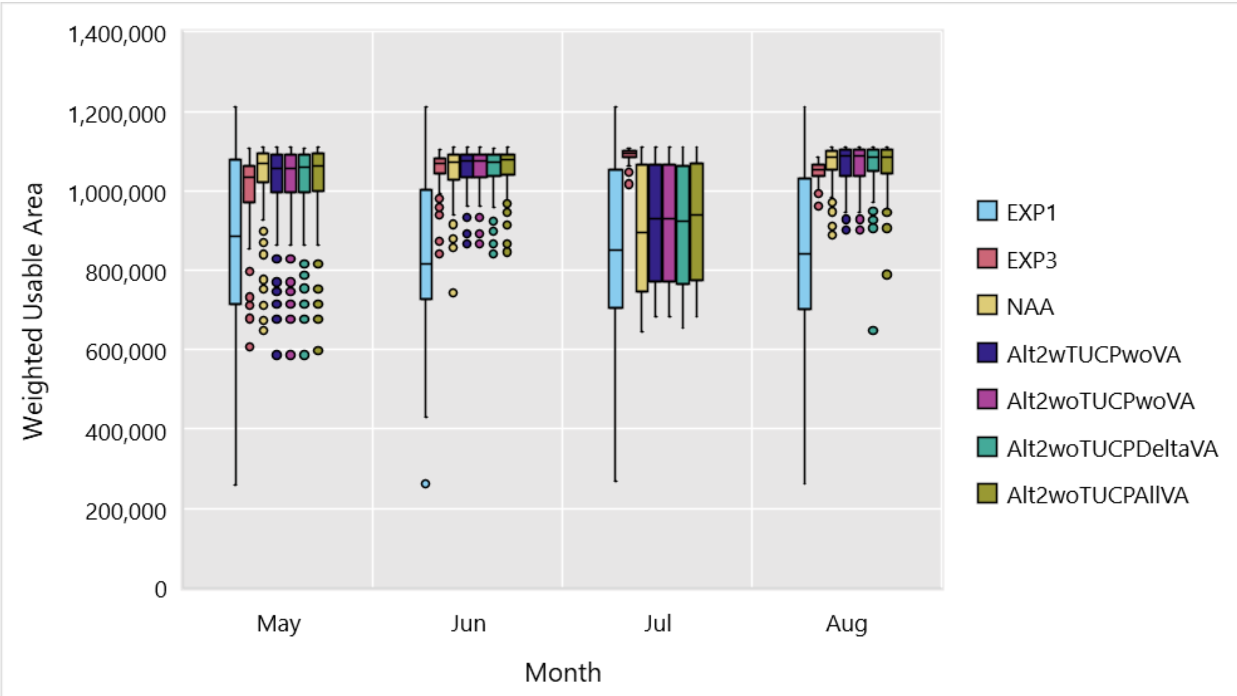


Figure O.3-12. Expected WUA for Winter-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

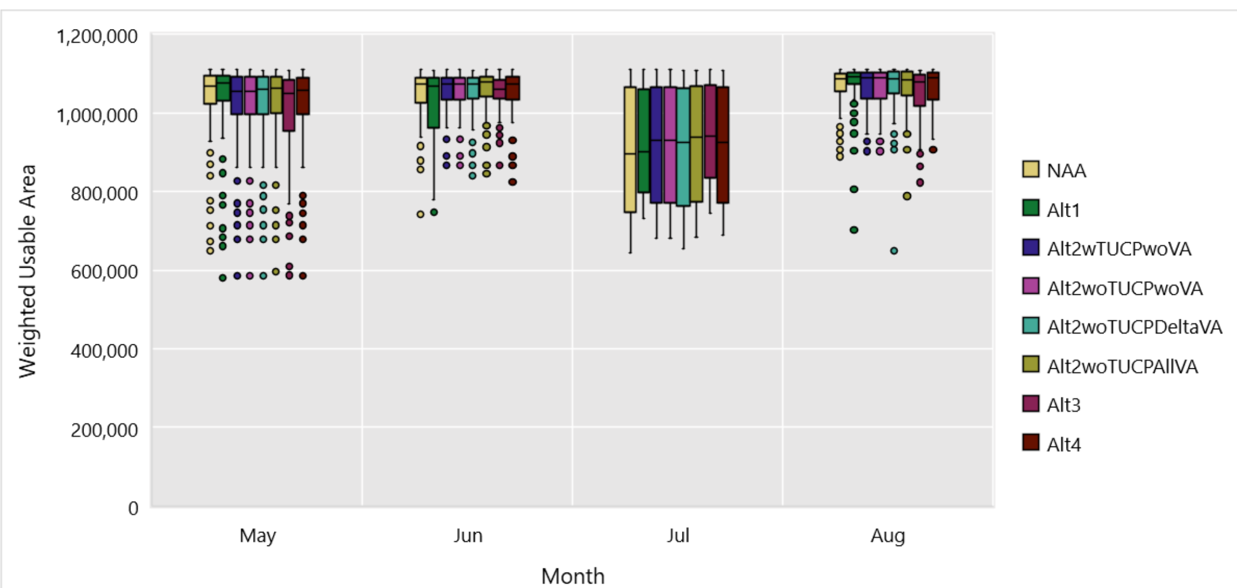


Figure O.3-13. Expected WUA for Winter-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for the NAA and Alternatives 1-4 by Month

O.3.3.1.2 Rearing Weighted Usable Area

Table O.3-6 through Table O.3-9 provide the rearing WUA results for fry and juveniles of Sacramento River winter-run under the BA 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.3-7 and Table O.3-9).

The results for both the BA and EIS modeled scenarios show modest and inconsistent variation in mean fry rearing WUA with water year type for EXP 1 and EXP 3, but under the NAA and both the BA and EIS modeled scenarios for the alternatives, the variation in mean rearing WUA among water year types is generally consistent, with the highest WUA under dry or critically dry water years and lowest in above normal or wet water years (Table O.3-6 and Table O.3-7). 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.3-7). The largest reduction is 1.5% for Alt 1 in critical water years.

Table O.3-6. Expected WUA for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2

WYT	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

Table O.3-7. Expected WUA for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
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
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
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

Figure O.3-14 and Figure O.3-15 show the full variation in estimated fry rearing WUA for winter-run under the BA 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 BA 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.3-7). Winter-run is the only Sacramento River salmonid race or species that shows this pattern.

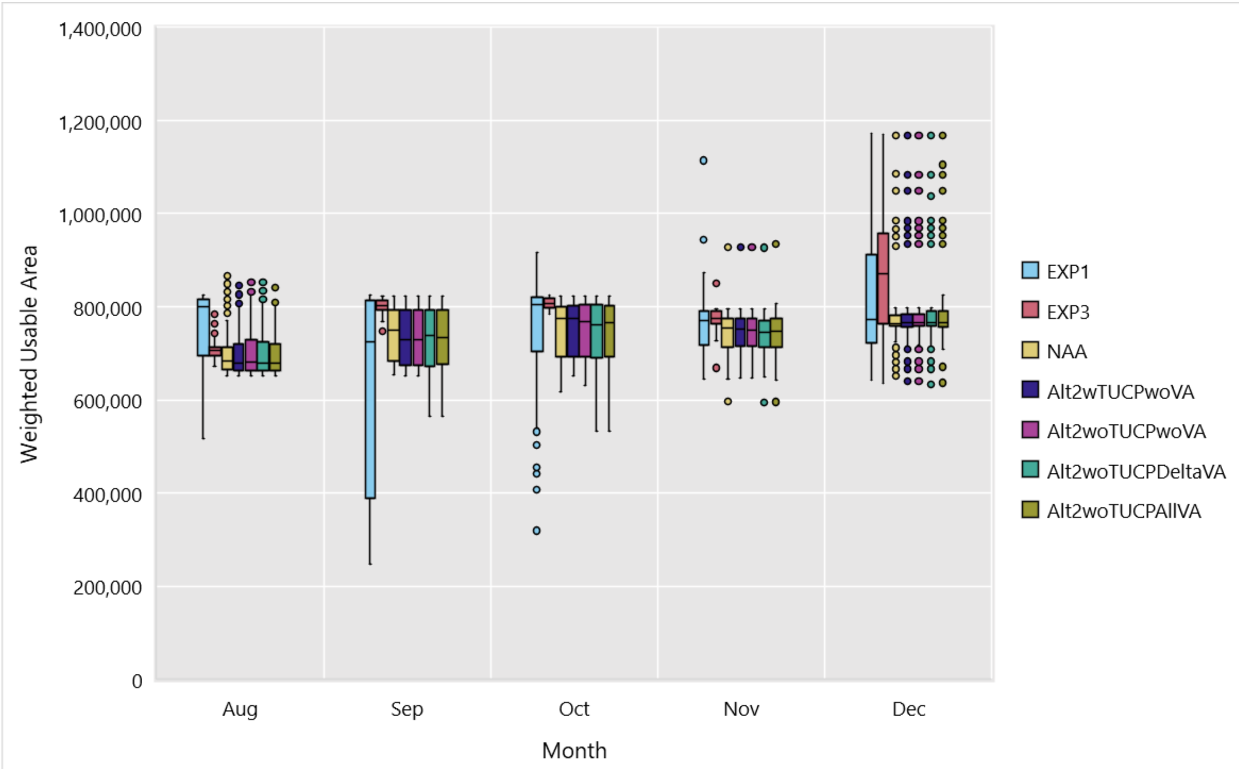


Figure O.3-14. Expected WUA for Winter-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

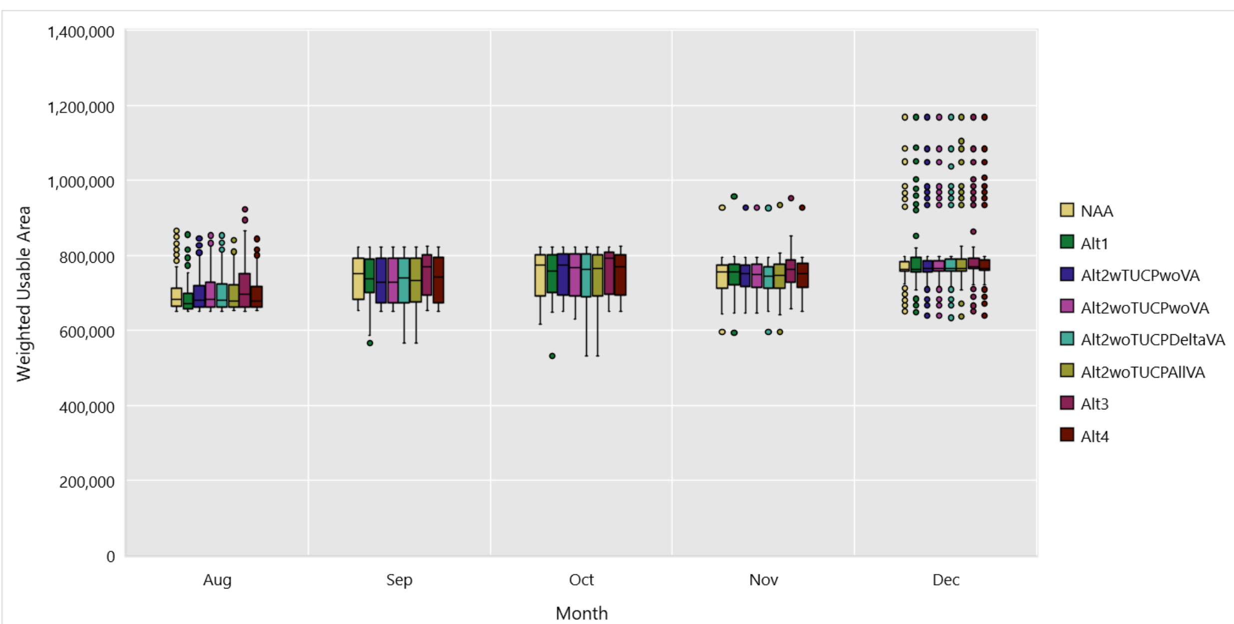


Figure O.3-15. Expected WUA for Winter-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 the NAA and Alternatives 1-4 by Month

The results for both the BA and EIS modeled scenarios show little variation in mean winter-run juvenile rearing WUA with water year type (Table O.3-8 and Table O.3-9). 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.3-9). The largest reduction is 0.5% for Alt2 Without TUCP Systemwide VA in below normal water years.

Table O.3-8. Expected WUA for Winter-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	137,825	141,579	136,563	136,582	136,574	136,480	136,502
AN	136,925	136,994	134,859	134,399	134,439	134,260	134,429
BN	128,529	136,520	133,640	133,217	133,246	133,121	132,936
Dry	129,802	136,889	136,003	135,643	135,658	135,872	135,853
Critical	123,629	137,292	135,317	136,207	135,360	135,209	135,298
All	131,931	138,215	135,453	135,360	135,245	135,200	135,208

Table O.3-9. Expected WUA for Winter-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	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
D	136,003	136,234	135,643	135,658	135,872	135,853	135,789	135,874
C	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
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	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
D	136,003	0.17	-0.26	-0.25	-0.10	-0.11	-0.16	-0.09
C	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

Figure O.3-16 and Figure O.3-17 show the full variation in estimated juvenile rearing WUA for winter-run under the BA 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 BA 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.

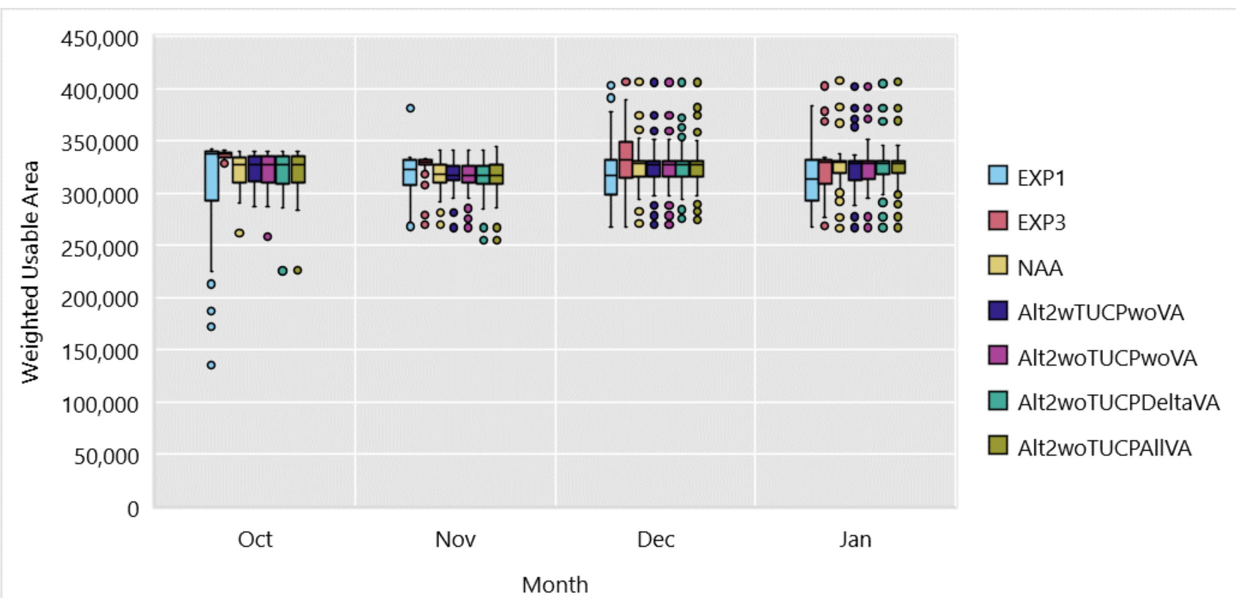


Figure O.3-16. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

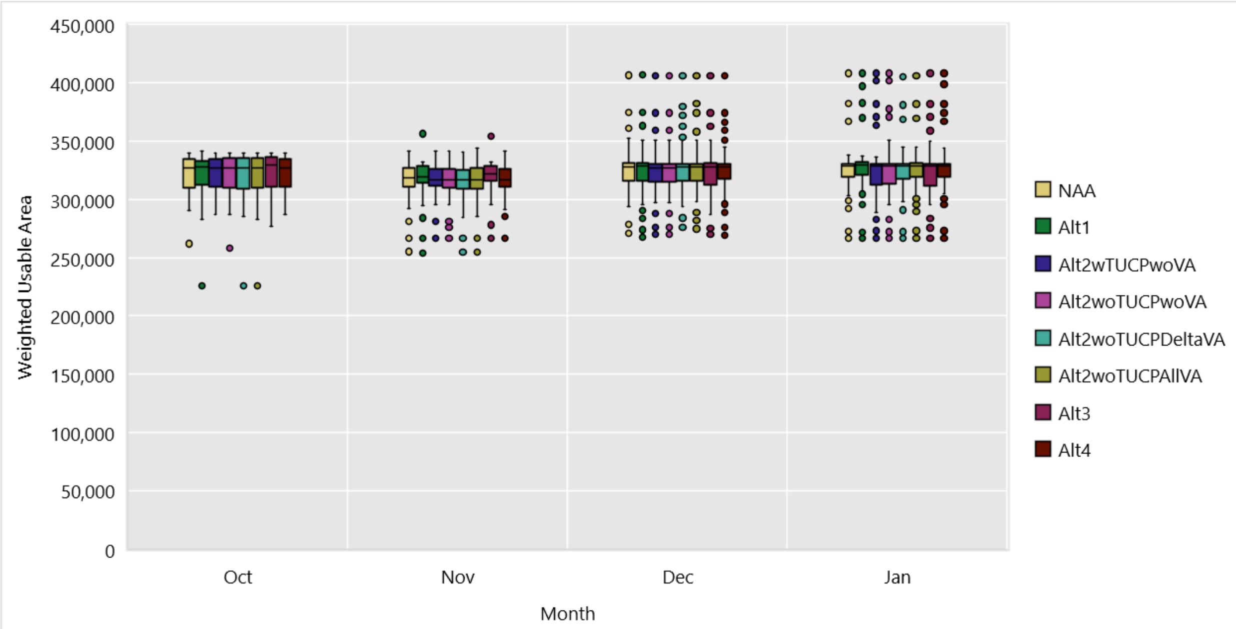


Figure O.3-17. Expected WUA for Winter-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.2 Spring-run Chinook Salmon

O.3.3.2.1 Spawning Weighted Usable Area

Table O.3-10 and Table O.3-11 provide the spawning WUA results for Central Valley spring-run Chinook salmon under the BA modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by their expected distributions among months (Table O.3-1) and river segments (Table O.3-2). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-11).

The results for both the BA and EIS modeled scenarios show modest and inconsistent variation in mean spawning WUA with water year type for EXP 1 and EXP 3, but under the NAA and the BA 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 or wet water years. For the EIS modeled scenarios, the largest difference between the NAA and the scenarios is a 15.5% increase for Alt 1 in above normal water years (Table O.3-7). The largest reduction is 2.7% for Alt 1 in critical water years.

Table O.3-10. Expected WUA for Spring-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	439,130	451,262	340,515	343,188	343,070	342,592	342,214
AN	401,963	453,809	359,947	352,157	352,226	350,776	352,152
BN	330,606	451,585	429,354	427,272	428,824	431,627	430,136
Dry	273,640	452,989	440,725	440,393	440,399	441,154	440,956
Critical	247,091	459,597	443,545	456,308	448,282	435,218	435,186
All	344,395	453,360	399,692	400,832	399,840	398,123	397,909

Table O.3-11. Expected WUA for Spring-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
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

Figure O.3-18 and Figure O.3-19 show the full variation in estimated spawning WUA for spring-run under the BA 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 BA 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 two 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).

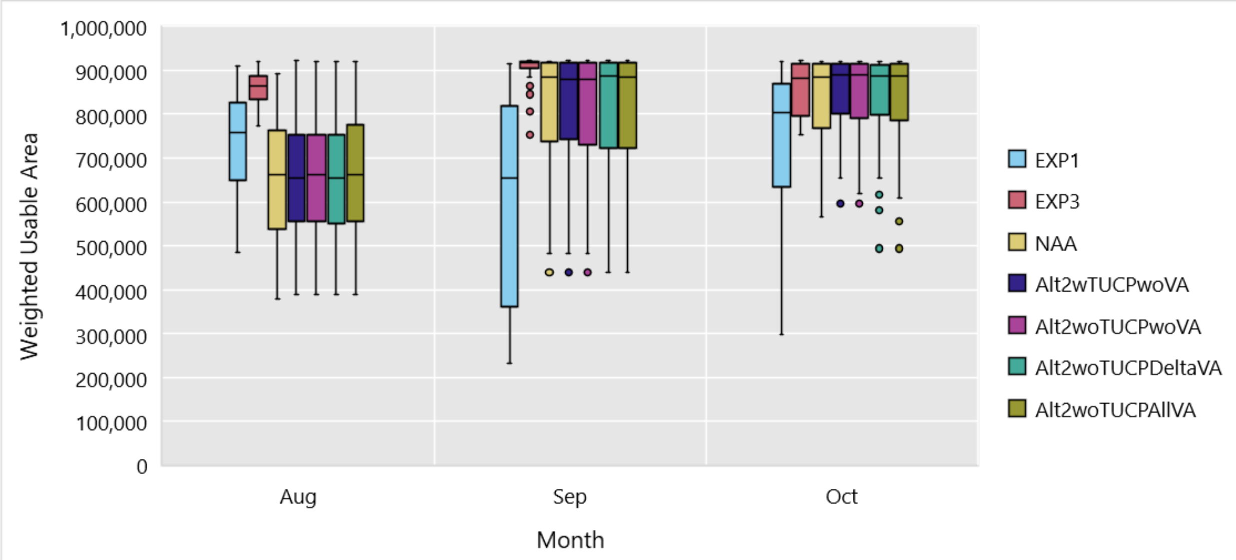


Figure O.3-18. Expected WUA for Spring-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

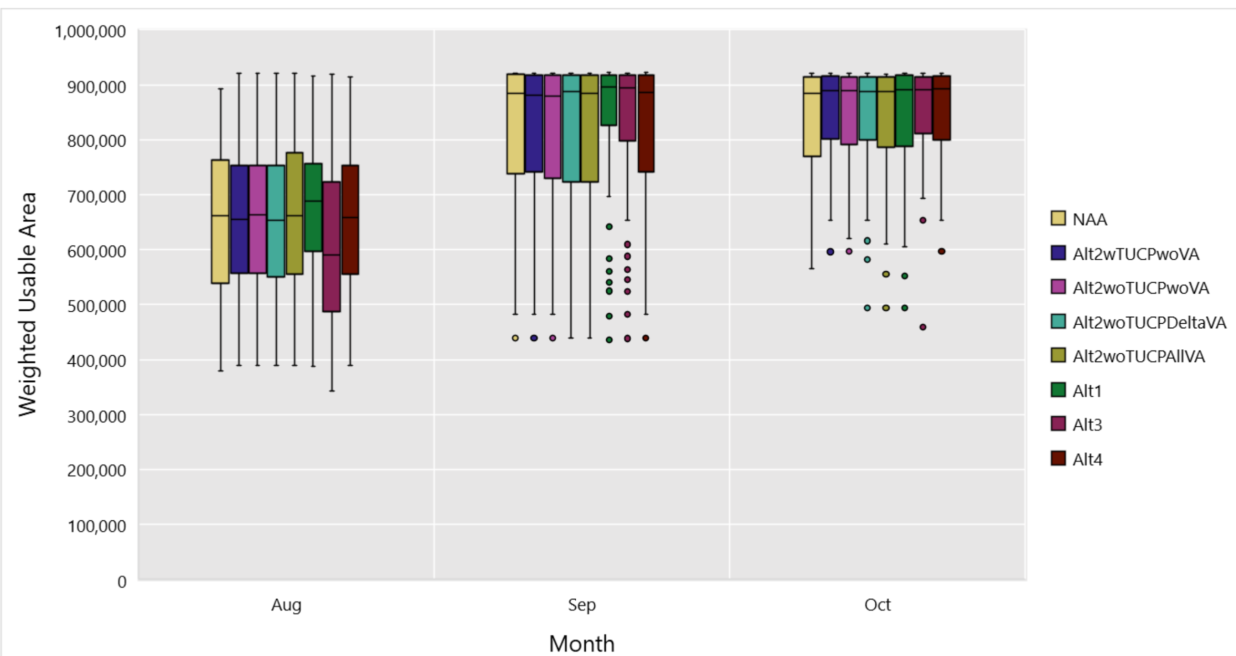


Figure O.3-19. Expected WUA for Spring-run Chinook Salmon Spawning in the Sacramento River Segments 6+5 the NAA and Alternatives 1-4 by Month

O.3.3.2.2 Rearing Weighted Usable Area

Table O.3-12 through Table O.3-13 provide the rearing WUA results for fry and juveniles of Sacramento River spring-run under the BA modeled scenarios and EIS modeled scenarios. 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.3-7 and Table O.3-9).

The results for both the BA and EIS modeled scenarios show consistent variation in mean spring-run fry rearing WUA with water year type for EXP 1, EXP 3, the NAA and all BA and EIS modeled scenarios for alternatives, with the highest WUA under critically dry water years and lowest wet water years (Table O.3-12 and Table O.3-13). EXP 1 is an exception, having the lowest WUA value for above normal water years. 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.3-13).

Table O.3-12. Expected WUA for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2woTUCP 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

Table O.3-13. Expected WUA for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	455,508	459,294	453,553	453,691	454,147	453,937	451,157	455,905
AN	491,821	489,832	488,294	489,252	489,809	485,585	484,558	492,029
BN	528,229	519,813	523,923	523,994	524,594	520,618	530,257	523,900
D	549,399	542,581	541,788	542,669	546,266	544,527	553,984	545,807
C	580,491	568,482	579,203	567,869	565,212	565,304	577,040	576,456
All	516,082	511,765	512,255	510,841	511,587	509,814	514,811	513,976
W	455,508	0.83	-0.43	-0.40	-0.30	-0.34	-0.96	0.09

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
AN	491,821	-0.40	-0.72	-0.52	-0.41	-1.27	-1.48	0.04
BN	528,229	-1.59	-0.82	-0.80	-0.69	-1.44	0.38	-0.82
D	549,399	-1.24	-1.39	-1.23	-0.57	-0.89	0.83	-0.65
C	580,491	-2.07	-0.22	-2.17	-2.63	-2.62	-0.59	-0.70
All	516,082	-0.84	-0.74	-1.02	-0.87	-1.21	-0.25	-0.41

Figure O.3-20 and Figure O.3-21 show the full variation in estimated fry rearing WUA for spring-run under the BA and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the fall-run fry rearing WUA curves from which they are estimated (Figure O.3-8). The estimated fry rearing WUA values under the BA and EIS modeled scenarios are similar for the principal months of spring-run fry rearing, December through March, but they are generally lower for November and April (Figure O.3-16 and Figure O.3-17). Under the EIS modeled alternatives, the December through March period, results show little variation in the third quartile of the WUA distributions, except for Alternative 1. This occurs because the fry rearing WUA curves peak at the lowest flows encountered in the river (Figure O.3-8) and Keswick flow releases are frequently low during these months in critically dry water year types when Shasta Dam is operated to rebuild storage volume. The second quartile is much wider because a greater range of flows affect the fry rearing WUA values below the median. The occurrence of some higher rearing WUA values for April results from the installation of the ACID dam for that month, which results in higher WUA values in Segment 6 of the river (Figure O.3-8).

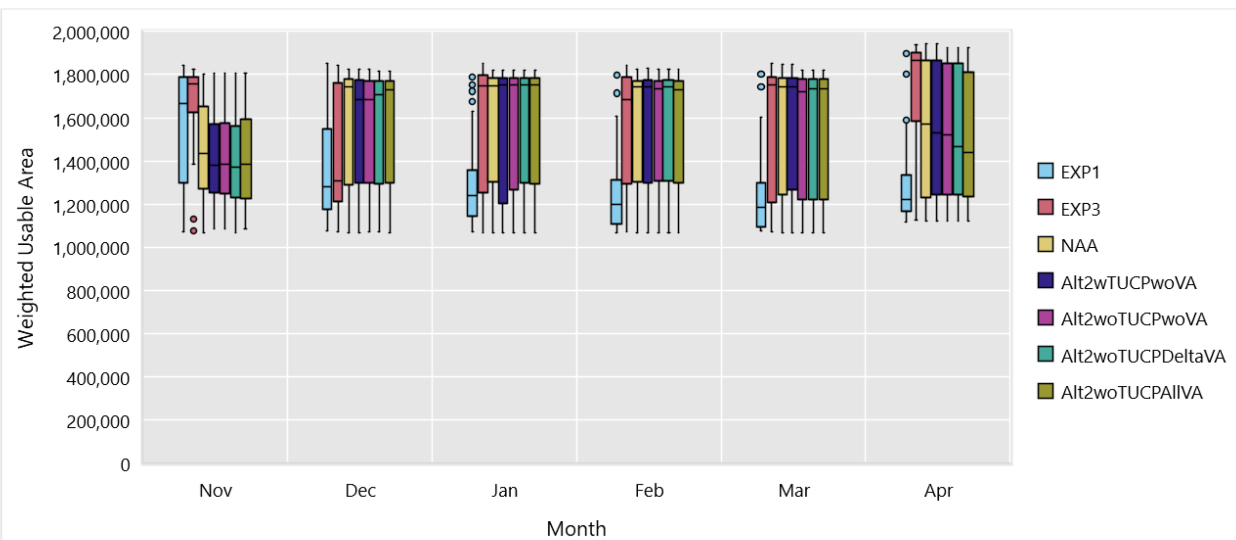


Figure O.3-20. Expected WUA for Spring-run Chinook Salmon Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

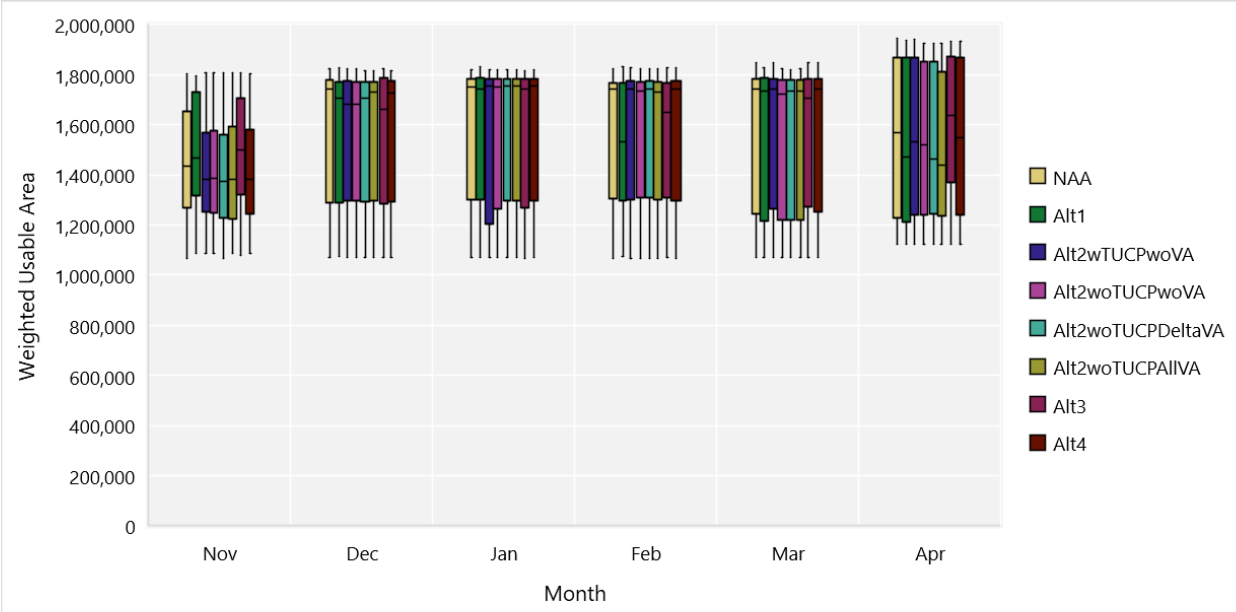
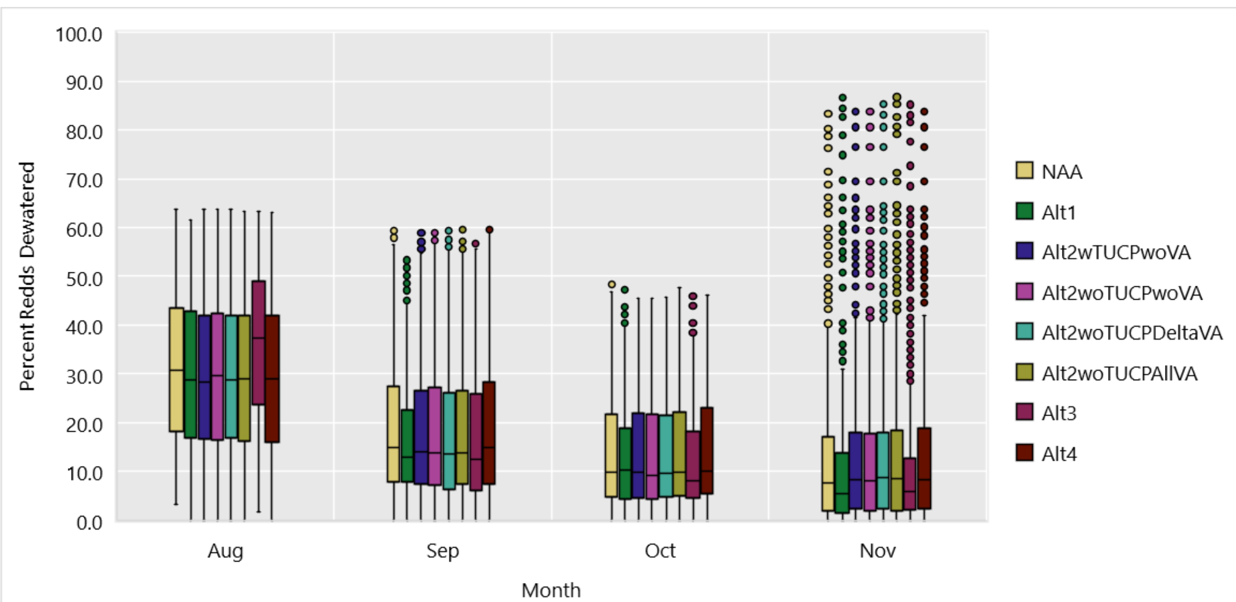


Figure O.3-21. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month



The results for both the BA and EIS modeled scenarios show consistent variation in mean spring-run juvenile rearing WUA with water year type for EXP 1, EXP 3, the NAA and all BA and EIS modeled scenarios for alternatives, with the highest WUA under critically dry water years and lowest under wet water years (Table O.3-12 and Table O.3-13). For the EIS modeled scenarios, the fry rearing WUA results are 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.3-15).

Table O.3-14. Expected WUA for Spring-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	182,154	183,641	176,621	175,420	175,478	175,359	175,491
AN	187,247	192,085	191,772	188,962	189,570	188,849	189,116
BN	182,973	209,016	205,613	203,557	203,723	203,074	202,858
Dry	192,028	216,519	217,257	214,448	214,433	215,220	214,642
Critical	193,690	229,142	226,675	225,044	223,881	224,132	224,786
All	187,336	204,369	201,520	199,471	199,430	199,407	199,410

Table O.3-15. Expected WUA for Spring-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
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
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
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

Figure O.3-22 and Figure O.3-23 show the full variation in estimated juvenile rearing WUA for spring-run under the BA and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the fall-run juvenile rearing WUA curves from which they are estimated (Figure O.3-9). The estimated juvenile rearing WUA values under the BA and EIS modeled scenarios are similar for January through March, but they are generally lower for April and May (Figure O.3-22 and Figure O.3-23). For the January through March period, as described above for spring-run fry rearing WUA, the third quartiles of the WUA distributions have high values and reduced variation. This occurs because, as described for the fry rearing WUA curves, the juvenile rearing WUA curves peak at the lowest flows encountered in the river (Figure O.3-9) and low flows are frequent during January through March when Shasta Dam is operated to rebuild storage.

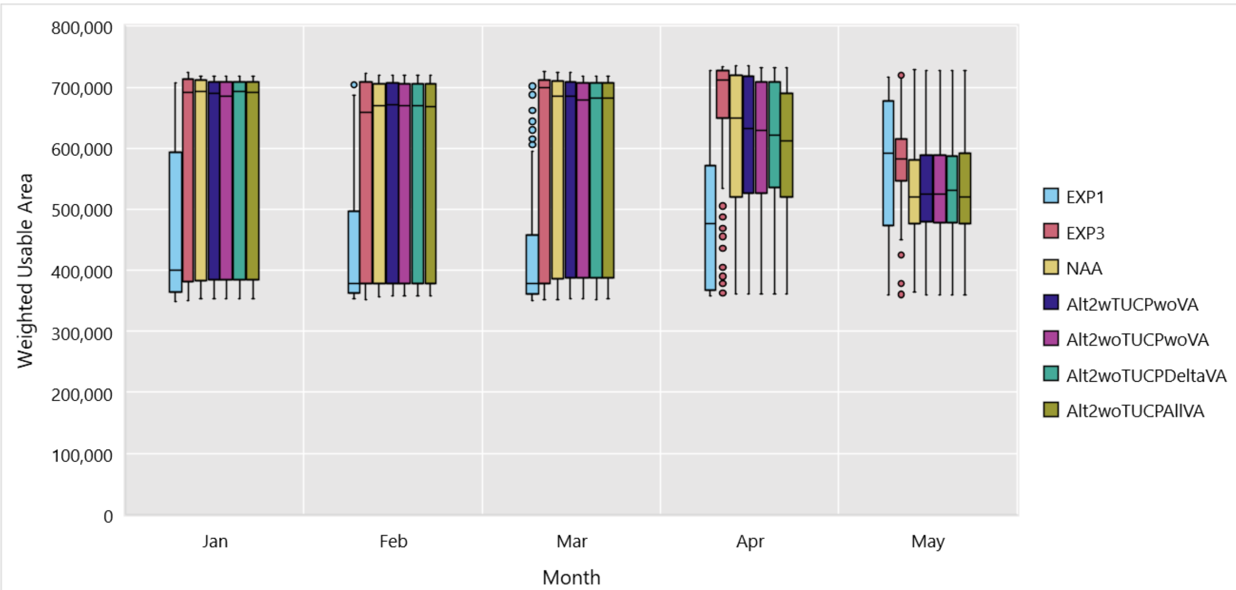


Figure O.3-22. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

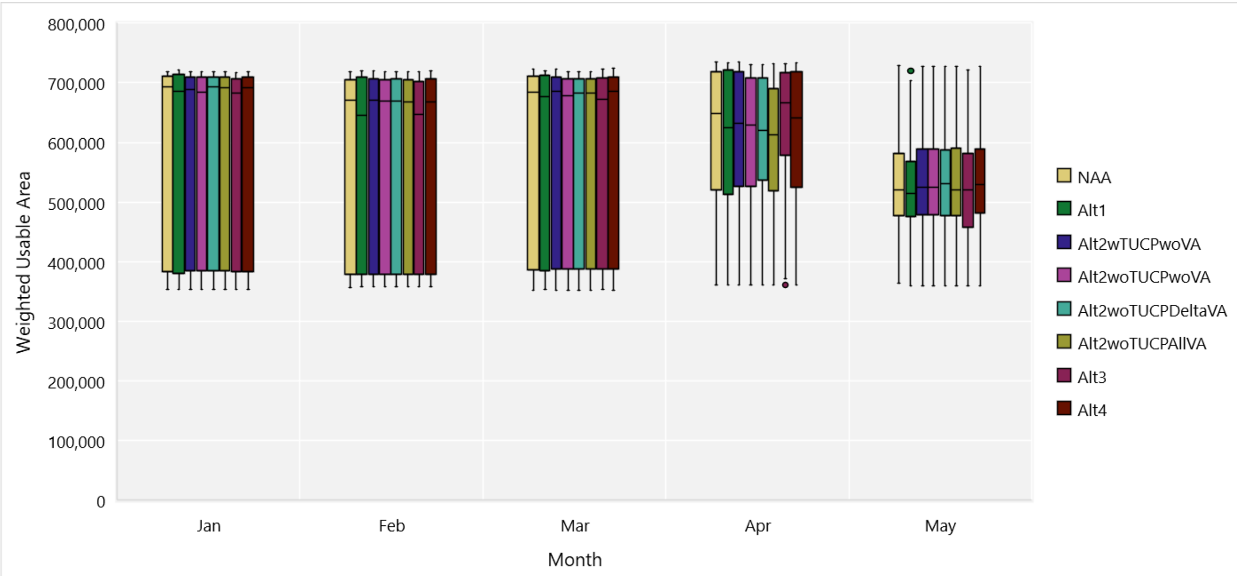


Figure O.3-23. Expected WUA for Spring-run Chinook Salmon Juvenile Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.2.3 Steelhead Spawning Weighted Usable Area

Table O.3-16 and Table O.3-17 provide the spawning WUA results for steelhead under the BA modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by their expected distributions among months (Table O.3-1). As noted earlier, the distribution of steelhead spawning among the river segments is unknown, so WUA results were weighted equally for the three upper river segments. The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-17).

The results for both the BA and EIS modeled scenarios show strong and consistent reductions in the mean spawning WUA from the driest to the wettest water year types (Table O.3-16 and Table O.3-17). This pattern of variation holds for EXP 1, EXP 3, the NAA, and all BA and EIS modeled scenarios of the alternatives. For the EIS modeled scenarios, differences between the NAA and the scenarios are consistently small. The largest difference is a 2.0% reduction for Alt 1 in above normal water years (Table O.3-17). Most other differences are less than 1%.

Table O.3-16. Expected WUA for Steelhead Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
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

Table O.3-17. Expected WUA for Steelhead Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	68,940	68,257	68,872	68,889	68,907	68,835	68,905	68,974
AN	85,350	83,628	85,338	86,419	86,071	85,715	85,383	85,113
BN	115,190	113,671	114,540	114,543	114,585	114,042	115,340	114,529
D	118,718	118,760	118,804	118,798	118,827	118,828	119,787	118,762
C	120,314	121,510	119,788	120,229	120,958	120,945	121,177	120,064
All	99,729	99,225	99,528	99,753	99,841	99,671	100,145	99,557
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	68,940	-0.99	-0.10	-0.07	-0.05	-0.15	-0.05	0.05
AN	85,350	-2.02	-0.01	1.25	0.85	0.43	0.04	-0.28
BN	115,190	-1.32	-0.56	-0.56	-0.53	-1.00	0.13	-0.57
D	118,718	0.04	0.07	0.07	0.09	0.09	0.90	0.04
C	120,314	0.99	-0.44	-0.07	0.54	0.52	0.72	-0.21
All	99,729	-0.51	-0.20	0.02	0.11	-0.06	0.42	-0.17

Figure O.3-24 and Figure O.3-25 show the full variation in estimated spawning WUA for steelhead under the BA 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.3-5). The medians of the estimated spawning WUA values under the BA and EIS modeled scenarios are similar for January through March, but they are higher for April (Figure O.3-24 and Figure O.3-25). For all months, the results show little variation in the third quartile of the WUA distributions. This occurs because the steelhead spawning WUA curves peak at low flows (Figure O.3-5) and Keswick flow releases are frequently low during these months when Shasta Dam is operated to rebuild storage volume. The second quartile is much wider because a greater range of flows affect the spawning WUA values below the median. This is especially true for February because flow below Keswick Dam is most variable in this month. The higher spawning WUA values for April result from installation of the ACID dam in that month, which results in much higher WUA values in Segment 6 of the spawning WUA curve (Figure O.3-5).

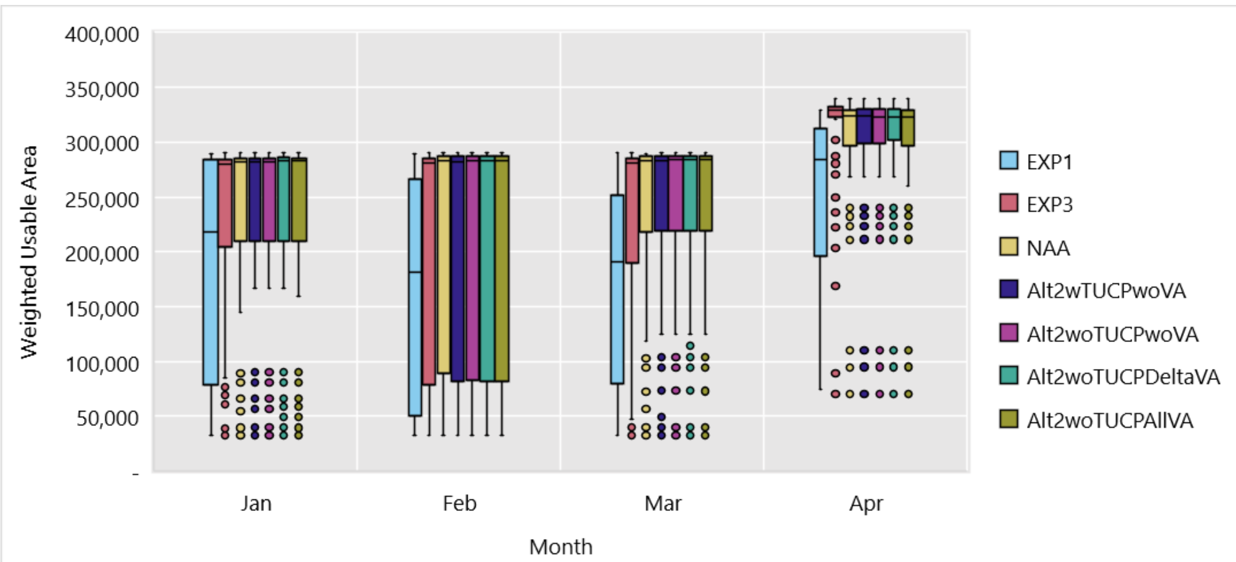


Figure O.3-24. Expected WUA for Steelhead Spawning in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

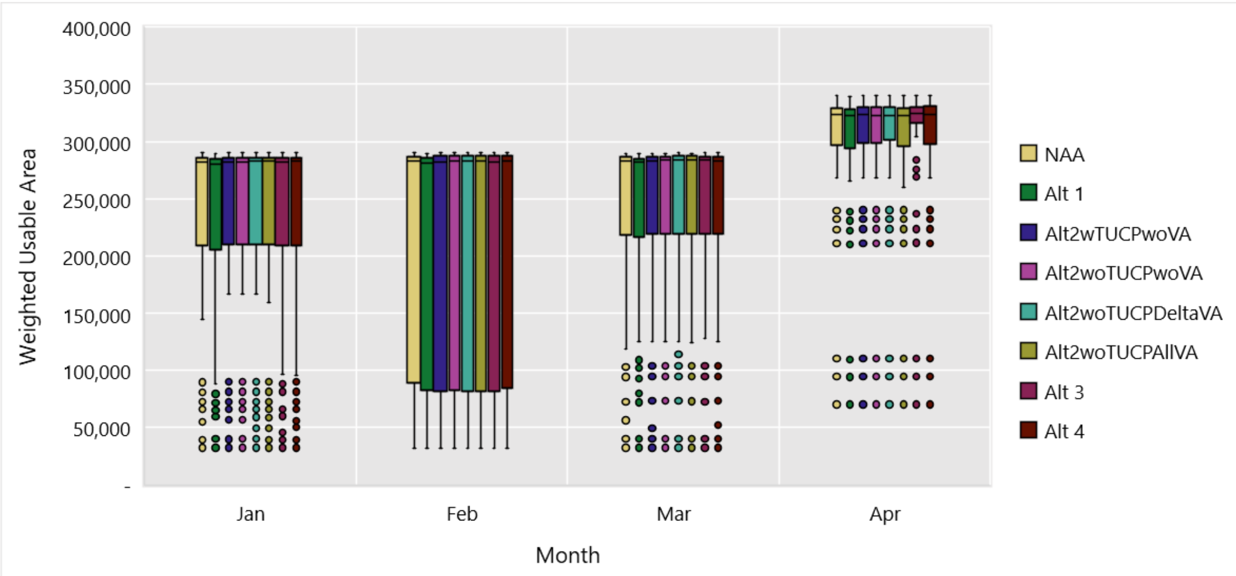


Figure O.3-25. Expected WUA for Steelhead Spawning in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.2.5 Rearing Weighted Usable Area

Table O.3-18 through Table O.3-21 provide the rearing WUA results for fry and juveniles of Sacramento River steelhead under the BA 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.3-19 and Table O.3-21).

The results for both the BA and EIS modeled scenarios show inconsistent variation in mean steelhead fry rearing WUA with water year type for EXP 1 and EXP 3, but generally consistent, moderate reductions in rearing WUA from drier to wetter water years for the NAA and all BA and EIS modeled scenarios alternatives (Table O.3-18 and Table O.3-19). For the EIS modeled scenarios, the fry rearing WUA results are generally similar or slightly lower under the EIS modeled scenarios than under the NAA, except during critical water years for which rearing WUA was up to 5.8% higher under Alternative 2 With TUCP Without VA (Table O.3-19). Alt 1 was an exception, with essentially no change from the NAA in critical water years.

Table O.3-18. Expected WUA for Steelhead Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	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

Table O.3-19. Expected WUA for Steelhead Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	369,731	369,951	369,257	369,270	369,217	369,514	376,385	369,261
AN	370,176	377,065	370,059	370,052	369,569	368,182	371,535	370,069
BN	379,819	375,275	376,446	377,485	378,388	375,573	382,589	376,785
D	383,413	380,264	380,896	381,072	382,286	383,068	388,407	380,574
C	395,872	395,783	418,908	415,011	412,754	411,061	418,050	411,478
All	379,021	378,472	381,336	380,946	380,961	380,262	386,317	380,136
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	369,731	0.06	-0.13	-0.12	-0.14	-0.06	1.80	-0.13
AN	370,176	1.86	-0.03	-0.03	-0.16	-0.54	0.37	-0.03
BN	379,819	-1.20	-0.89	-0.61	-0.38	-1.12	0.73	-0.80
D	383,413	-0.82	-0.66	-0.61	-0.29	-0.09	1.30	-0.74
C	395,872	-0.02	5.82	4.83	4.26	3.84	5.60	3.94
All	379,021	-0.14	0.61	0.51	0.51	0.33	1.92	0.29

Figure O.3-26 and Figure O.3-27 show the full variation in estimated fry rearing WUA for spring-run under the BA and EIS modeled scenarios, respectively. The upper and lower limits of the range in WUA values are determined by the ranges of the late fall-run fry rearing WUA curves from which they are estimated (Figure O.3-10). The estimated fry rearing WUA values under the BA and EIS modeled scenarios are highly variable among the months, April through October, of the fry rearing period (Figure O.3-26 and Figure O.3-27). WUA values of the fry rearing WUA curve are lowest in the range of 6,000 cfs to 27,000 cfs (Figure O.3-10) and flows in this range are almost twice as frequent during May through August as in April, September, or October. The April, September, and October results show much more variability in the WUA values than the May through August results, reflecting greater variability in flows during those three months.

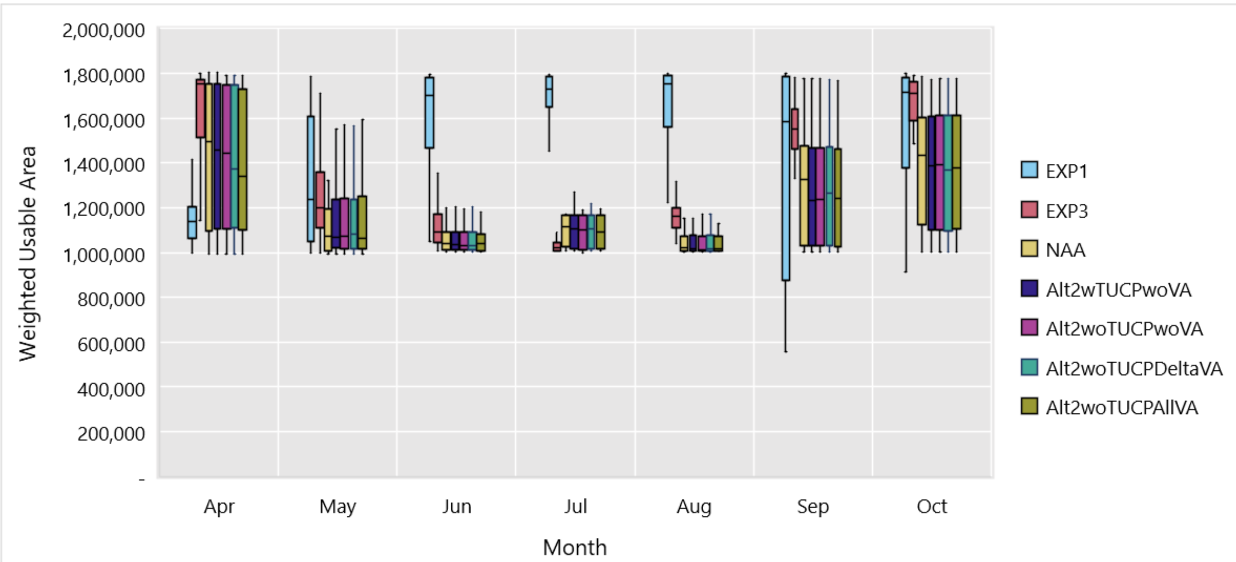


Figure O.3-26. Expected WUA for Steelhead Fry Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

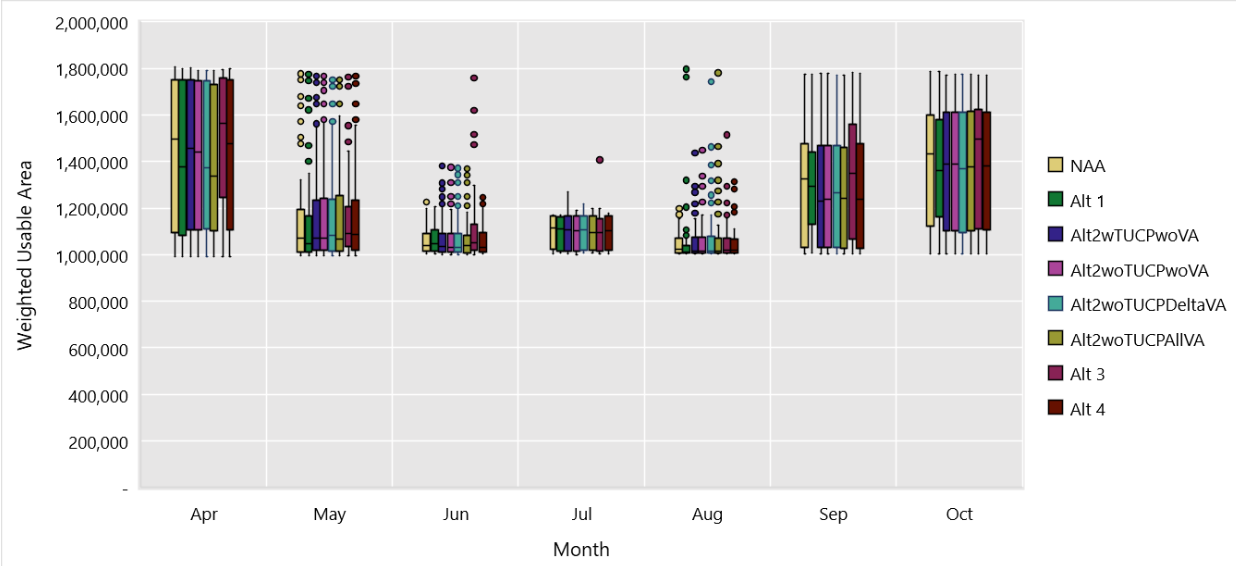


Figure O.3-27. Expected WUA for Steelhead Fry Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

The results for both the BA and EIS modeled scenarios show consistent variation in mean steelhead juvenile rearing WUA with water year type for EXP 1, EXP 3, the NAA, and all BA and EIS modeled scenarios for alternatives, with the highest WUA under critically dry water years and lowest wet water years (Table O.3-20 and Table O.3-21). The only exception to this pattern of variation is for EXP1, which has lower rearing WUA under below normal years than in above normal or wet year water years. For the EIS modeled scenarios, the fry rearing WUA results were generally moderately lower under the EIS modeled scenarios than under the NAA, with a maximum reduction of 1.6% for Alt 3 in critical water years (Table O.3-21).

Table O.3-20. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	169,059	170,656	164,114	163,146	163,190	163,063	163,166
AN	173,183	176,981	176,458	174,141	174,604	174,015	174,225
BN	168,711	191,453	188,133	186,549	186,665	186,134	185,880
Dry	176,487	197,392	197,910	195,606	195,623	196,298	195,845
Critical	176,722	207,617	205,617	204,251	203,335	203,506	204,054
All	172,688	187,459	184,750	183,086	183,055	183,030	183,024

Table O.3-21. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	164,114	164,551	163,146	163,190	163,063	163,166	165,783	163,881
AN	176,458	177,999	174,141	174,604	174,015	174,225	176,511	175,097
BN	188,133	188,009	186,549	186,665	186,134	185,880	186,435	185,951
D	197,910	197,849	195,606	195,623	196,298	195,845	195,894	196,900
C	205,617	204,775	204,251	203,335	203,506	204,054	202,427	204,063
All	184,750	184,946	183,086	183,055	183,030	183,024	183,952	183,610
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	164,114	0.27	-0.59	-0.56	-0.64	-0.58	1.02	-0.14
AN	176,458	0.87	-1.31	-1.05	-1.38	-1.27	0.03	-0.77
BN	188,133	-0.07	-0.84	-0.78	-1.06	-1.20	-0.90	-1.16
D	197,910	-0.03	-1.16	-1.16	-0.81	-1.04	-1.02	-0.51
C	205,617	-0.41	-0.66	-1.11	-1.03	-0.76	-1.55	-0.76
All	184,750	0.11	-0.90	-0.92	-0.93	-0.93	-0.43	-0.62

Figure O.3-28 and Figure O.3-29 show the full variation in estimated juvenile rearing WUA for steelhead under the BA 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 for late fall-run from which they are estimated (Figure O.3-11). The analysis for steelhead juvenile includes all months because steelhead juveniles may reside in freshwater for a year or more before emigrating to the sea. The estimated juvenile rearing WUA values under the BA and EIS modeled scenarios are similar for December through March, and they are lower for May through August (Figure O.3-28 and Figure O.3-29). As discussed previously for spring-run rearing WUA and steelhead spawning WUA, the high WUA values with low variability in the third quartile for December through March result from the peaking of the WUA curve at the lowest flows (Figure O.3-11) and frequent low Keswick Dam flow releases during these months to build Shasta storage. The wide range of values in the second quartile of these months reflects the high frequency and variability of higher flows in these wet months. The low juvenile rearing WUA values during June through August result from relatively frequent flows above about 10,000 cfs during those months and the low WUA values in the juvenile rearing WUA curves at flows greater than about 10,000 cfs.

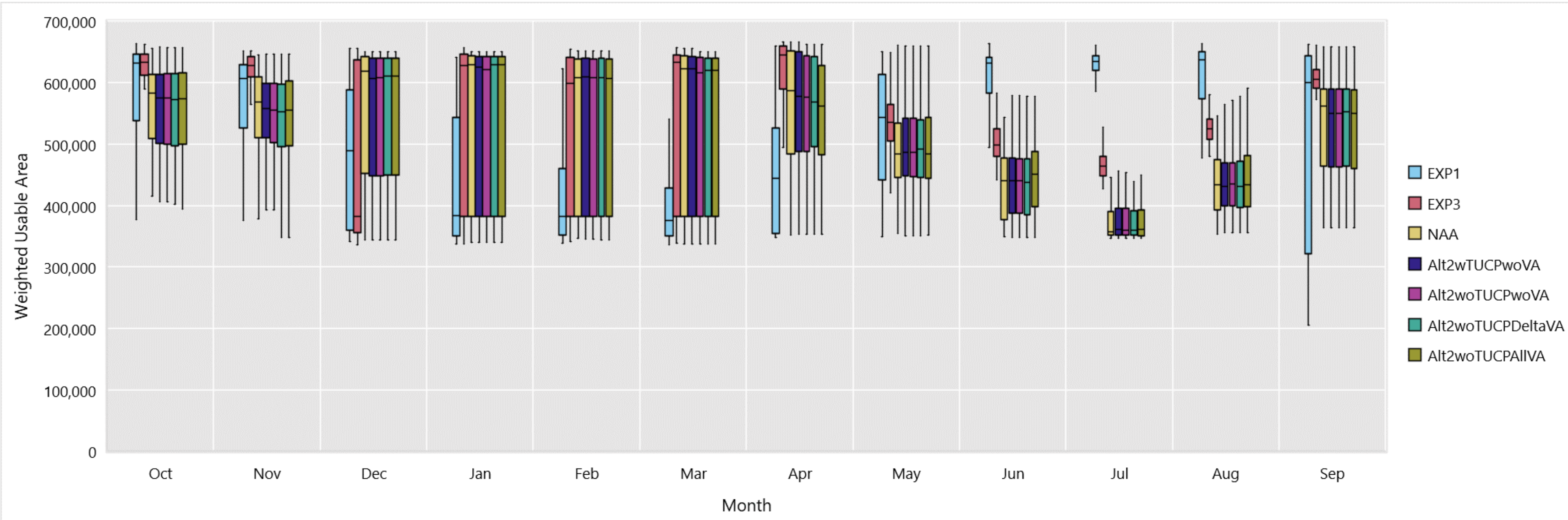


Figure O.3-28. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River Segments 4-6 for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month

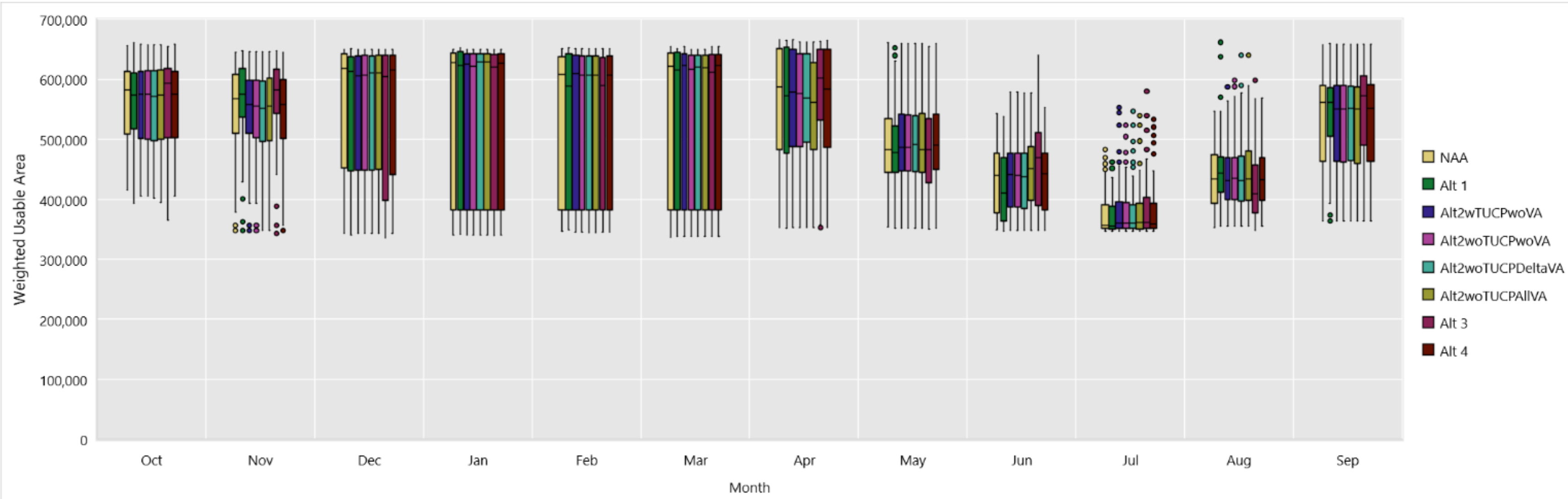


Figure O.3-29. Expected WUA for Steelhead Juvenile Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.3 Fall-run Chinook Salmon

O.3.3.3.1 Spawning Weighted Usable Area

Table O.3-22 provides the spawning WUA results for Central Valley fall-run Chinook salmon under the BA modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by their expected distributions among months (Table O.3-1) and river segments (Table O.3-2). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-17).

The results for the EIS modeled scenarios show modest and inconsistent variation in mean spawning WUA with water year type among the NAA, but under the 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 wet water years. For the EIS modeled scenarios, the largest difference between the NAA and the scenarios is a 4.2% increase for Alternative 1 in above normal water years (Table O.3-22). The largest reduction is 2.5% for Alternative 3 in below normal water years.

Table O.3-22. Expected WUA for Fall-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	248,609	251,195	247,735	247,665	246,597	246,813	253,861	248,051
AN	260,323	271,327	257,015	257,011	254,853	255,899	266,848	257,479
BN	279,409	278,724	277,187	277,477	275,880	274,523	272,376	275,650
D	282,535	282,309	281,169	281,218	281,931	279,807	281,449	281,806
C	295,535	293,889	299,876	295,655	293,366	293,615	300,890	298,829
All	271,162	273,059	270,353	269,760	268,670	268,172	272,874	270,231
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	248,609	1.04	-0.35	-0.38	-0.81	-0.72	2.11	-0.22
AN	260,323	4.23	-1.27	-1.27	-2.10	-1.70	2.51	-1.09
BN	279,409	-0.25	-0.79	-0.69	-1.26	-1.75	-2.52	-1.35
D	282,535	-0.08	-0.48	-0.47	-0.21	-0.97	-0.38	-0.26
C	295,535	-0.56	1.47	0.04	-0.73	-0.65	1.81	1.11
All	271,162	0.70	-0.30	-0.52	-0.92	-1.10	0.63	-0.34

Figure O.3-30 shows the full variation in estimated spawning WUA for fall-run Chinook salmon under the EIS modeled scenarios. 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.3-4). The medians of the estimated spawning WUA values under the EIS modeled scenarios are similar throughout the spawning period (Figure O.3-30). October and September have less variation in WUA values in comparison to November and December, which is due to more variable flows expected with winter storms during the latter period.

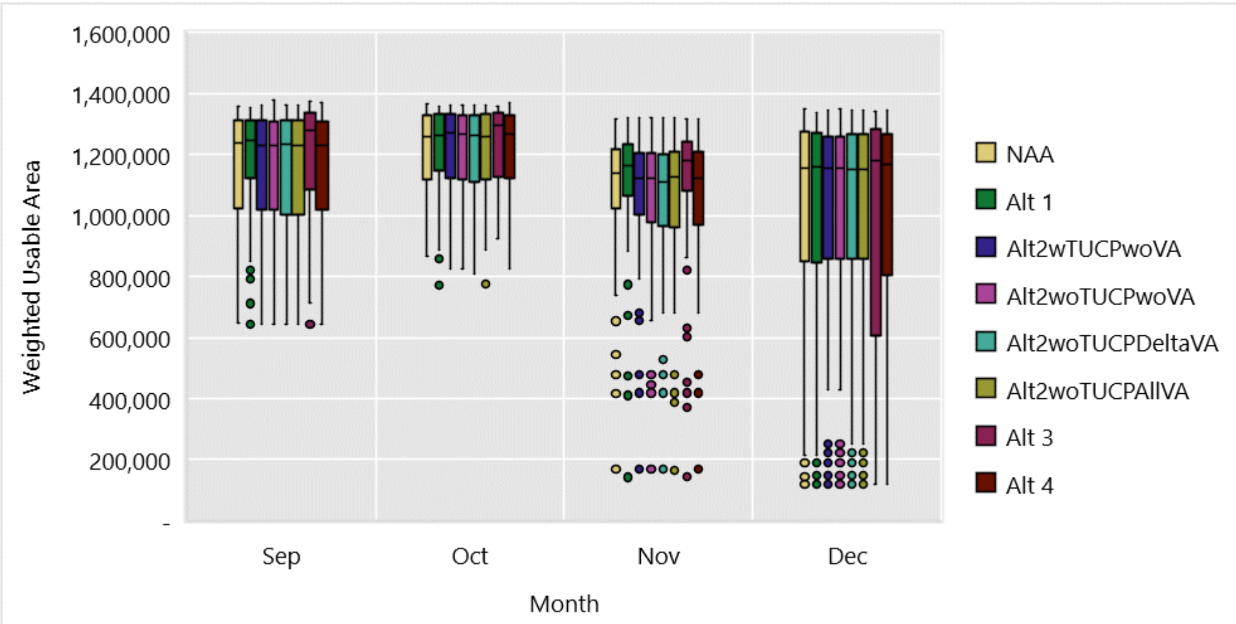


Figure O.3-30. Expected WUA for Fall-run Spawning in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.3.2 Rearing Weighted Usable Area

Table O.3-23 and Table O.3-24 provide the rearing WUA results for fry and juveniles of Sacramento River fall-run under the 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 include the percent differences between the results of the NAA and the alternatives (Table O.3-23 and Table O.3-24).

The results show consistent, moderate variation in mean fall-run fry rearing WUA with water year type among the modeled scenarios, with the highest WUA under critically dry water years and lowest in wet water years (Table O.3-23). The fry rearing WUA results were mostly lower under the alternatives than under the NAA. The largest reductions between the NAA and the scenarios is a 2.6% reductions for Alternative 1 under above normal water years (Table O.3-12).

As was the case for the fall-run fry rearing WUA results, the results for fall-run juvenile rearing WUA show consistent variation in mean WUA with water year type among the NAA and Alternatives 1-4, with the highest WUA under critically dry water years and lowest in wet water years (Table O.3-24). The amount of reduction in juvenile rearing WUA is less than that found for fry rearing WUA (Table O.3-23). For the EIS modeled scenarios, most of the juvenile rearing WUA values are similar between the EIS modeled scenarios and the NAA. The largest difference is a 3.5% increase for Alternative 3 in critical water years and the largest reduction is 2.0% under Alternative 1 in critical water years (Table O.3-24).

Table O.3-23. Expected WUA for Fall-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	455,637	456,054	453,202	453,400	454,319	454,268	451,341	457,165
AN	492,038	479,274	487,823	489,015	490,027	489,168	480,803	492,697
BN	529,011	521,447	525,728	525,803	524,628	525,443	523,459	525,898
D	559,189	554,150	549,214	550,013	553,842	551,796	551,581	554,237
C	577,817	571,987	579,332	571,973	575,261	576,727	573,246	575,565
All	518,209	512,937	514,211	513,464	515,085	514,836	511,882	516,668
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	455,637	0.09	-0.53	-0.49	-0.29	-0.30	-0.94	0.34
AN	492,038	-2.59	-0.86	-0.61	-0.41	-0.58	-2.28	0.13
BN	529,011	-1.43	-0.62	-0.61	-0.83	-0.67	-1.05	-0.59
D	559,189	-0.90	-1.78	-1.64	-0.96	-1.32	-1.36	-0.89
C	577,817	-1.01	0.26	-1.01	-0.44	-0.19	-0.79	-0.39
All	518,209	-1.02	-0.77	-0.92	-0.60	-0.65	-1.22	-0.30

Table O.3-24. Expected WUA for Fall-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	167,061	165,808	166,997	166,986	167,013	167,070	164,405	166,980
AN	173,315	171,758	173,451	173,471	173,501	172,640	171,616	173,477
BN	188,565	185,016	187,349	187,747	188,449	187,141	192,391	187,171
D	192,553	190,916	192,941	193,236	193,811	194,576	197,892	192,681
C	207,891	203,702	213,653	209,372	207,499	206,366	215,240	211,970
All	184,459	182,188	185,256	184,713	184,689	184,351	186,623	184,891

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	167,061	-0.75	-0.04	-0.05	-0.03	0.00	-1.59	-0.05
AN	173,315	-0.90	0.08	0.09	0.11	-0.39	-0.98	0.09
BN	188,565	-1.88	-0.64	-0.43	-0.06	-0.76	2.03	-0.74
D	192,553	-0.85	0.20	0.35	0.65	1.05	2.77	0.07
C	207,891	-2.02	2.77	0.71	-0.19	-0.73	3.54	1.96
All	184,459	-1.23	0.43	0.14	0.13	-0.06	1.17	0.23

Figure O.3-31 and Figure O.3-32 show the full variation in estimated fry and juvenile rearing WUA for fall-run under the EIS modeled scenarios. The upper and lower limits of the range in WUA values are determined by the ranges of the fall-run fry and juvenile rearing WUA curves from which they are estimated (Figure O.3-8 and Figure O.3-9). The estimated fry rearing WUA values under the EIS modeled scenarios are highly variable among the months, December through March (Figure O.3-31). However, the median values for fry rearing are relatively similar across all months for the NAA and Alternatives 2 and 4, with some reductions under Alternative 1 and 3 in comparison to the NAA. During the juvenile rearing period, the median values are similar amongst Alternatives 1-4 and the NAA between February and March but show differences April through June (Figure O.3-32). In April, Alternative 3 has the highest median value and Alternative 2 without TUCP Systemwide VA has the lowest median value. In June, when flows tend to be lowest during the juvenile rearing period, Alternative 3 has the highest median value and Alternative 1 has the lowest median value.

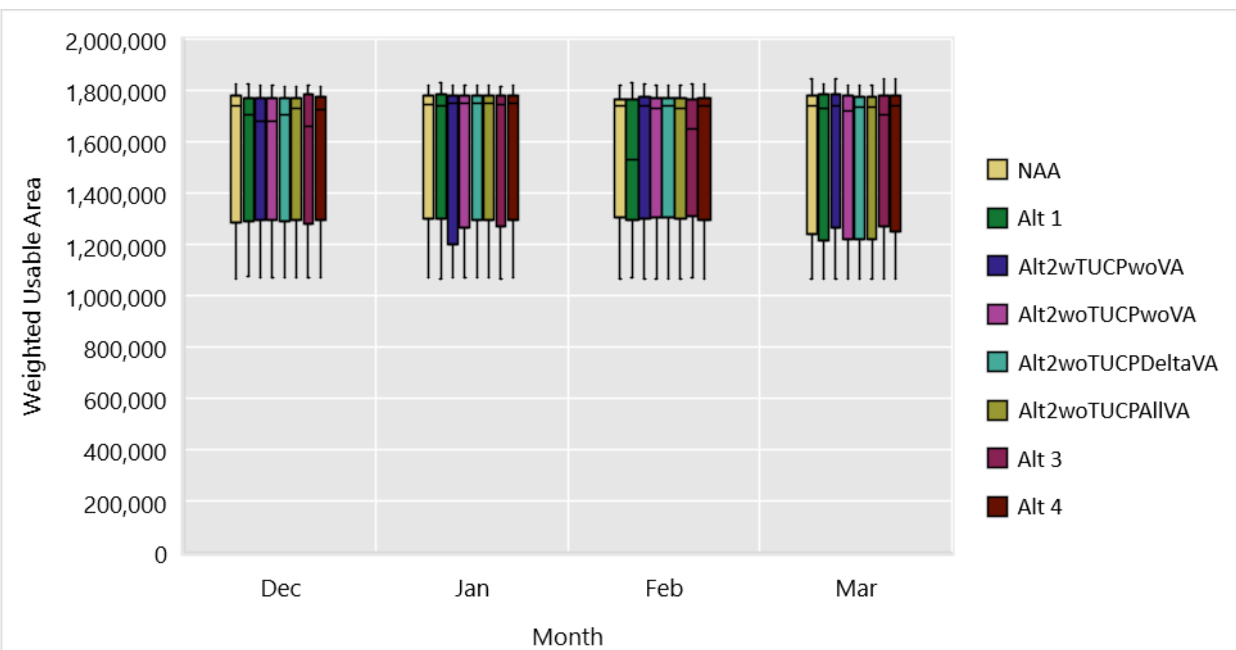


Figure O.3-31. Expected WUA for Fall-run Fry Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

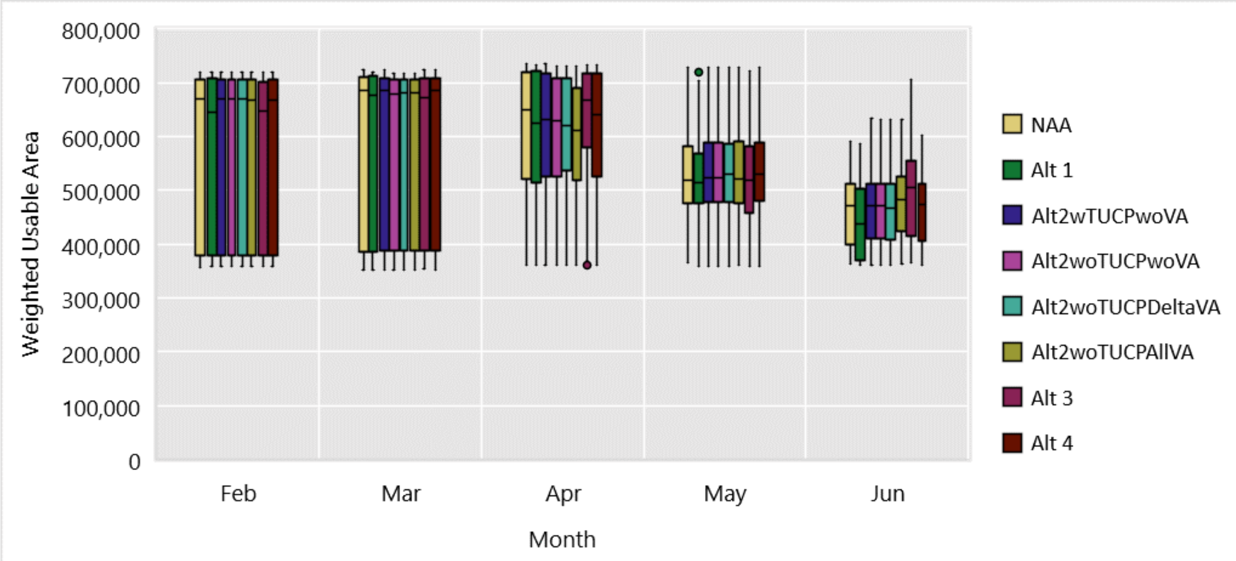


Figure O.3-32. Expected WUA for Fall-run Juvenile Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.4 Late Fall-run Chinook Salmon

O.3.3.4.1 Spawning Weighted Usable Area

Table O.3-25 provides the spawning WUA results for late fall-run Chinook salmon under the EIS modeled scenarios. The results are the means for all years analyzed, weighted by their expected distributions among months (Table O.3-1) and river segments (Table O.3-2). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table O.3-25).

The results for the EIS modeled scenarios show large and consistent variation in mean late fall-run spawning WUA with water year type for the NAA and Alternatives 1-4, with the highest WUA under critically dry water years and lowest in wet water years (Table O.3-25). Mean WUA values are lower under Alternatives 1-4 than the NAA for almost all water year types. The largest reduction was 7.4% for Alternative 1 in above normal water years.

Table O.3-25. Expected WUA for Late Fall-run Chinook Spawning in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	173,702	170,866	171,746	172,176	172,601	172,584	170,001	174,201
AN	226,884	210,084	223,076	226,599	226,173	225,212	213,486	226,719
BN	257,048	253,693	255,025	255,026	254,051	253,848	249,880	254,618
D	280,192	277,702	274,627	274,857	276,405	275,625	276,762	277,845
C	308,625	306,270	304,982	304,394	308,616	309,708	302,470	304,190
All	243,156	238,310	239,795	240,372	241,296	241,106	237,085	241,600
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	173,702	-1.63	-1.13	-0.88	-0.63	-0.64	-2.13	0.29
AN	226,884	-7.40	-1.68	-0.13	-0.31	-0.74	-5.91	-0.07
BN	257,048	-1.31	-0.79	-0.79	-1.17	-1.24	-2.79	-0.95
D	280,192	-0.89	-1.99	-1.90	-1.35	-1.63	-1.22	-0.84
C	308,625	-0.76	-1.18	-1.37	0.00	0.35	-1.99	-1.44
All	243,156	-1.99	-1.38	-1.14	-0.76	-0.84	-2.50	-0.64

Figure O.3-33 shows the full variation in estimated spawning WUA for late fall-run under the EIS modeled scenarios. 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.3-5). The median values of the estimated spawning WUA under the EIS modeled scenarios are similar throughout the spawning period of January through March (Figure O.3-33).

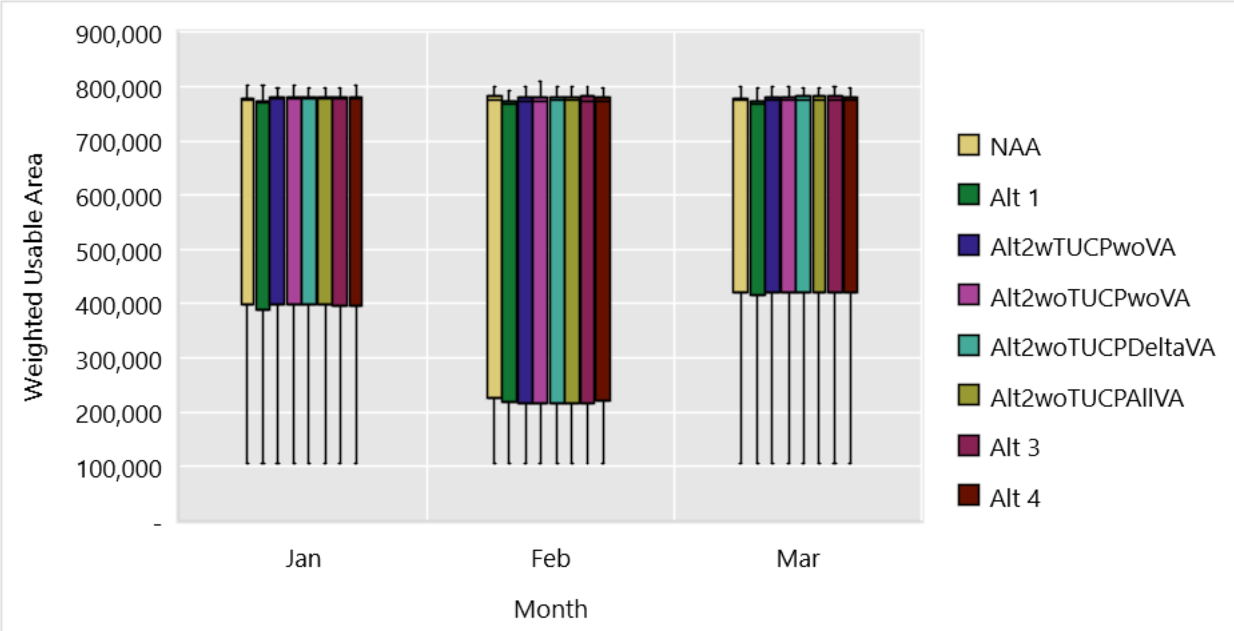


Figure O.3-33. Expected WUA for Late Fall-run Spawning in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

O.3.3.4.2 Rearing Weighted Usable Area

Table O.3-26 and Table O.3-27 provide the rearing WUA results for fry and juveniles of late fall-run under the EIS modeled scenarios. 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.

The results for the EIS modeled scenarios show moderate, consistent variation in mean late fall-run fry rearing WUA with water year type among Alternatives 1-4 and the NAA, with the highest WUA under critically dry water years and lowest under wet water years (Table O.3-26). The fry rearing WUA results are mostly similar between Alternatives 1-4 and the NAA. The largest difference between the NAA and the scenarios is a 5.6% increase for Alternative 3 under critical water years and the largest reduction is 3.5% for Alternative 1 in critical water years (Table O.3-26).

The results for late fall-run juvenile rearing WUA for the EIS modeled scenarios show little variation in mean WUA with water year type among the NAA and Alternatives 1-4 (Table O.3-27). The juvenile rearing WUA values for Alternatives 1-4 were generally higher than those of the NAA. The largest increase was a 6.7% for Alternative 2 With TUCP Without VA in critical water years (Table O.3-27). The largest reduction was 2.1% under Alternative 1 in critical water years.

Table O.3-26. Expected WUA for Late Fall-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	408,175	409,503	407,911	407,907	407,868	407,993	404,002	407,950
AN	413,558	418,974	414,442	413,850	414,305	409,047	413,311	414,684
BN	424,557	423,266	423,934	424,582	426,992	419,988	438,344	423,485
D	432,209	425,394	431,906	432,163	433,380	435,731	448,418	431,687
C	466,993	450,647	483,744	472,641	463,016	458,930	493,127	475,630
All	427,057	423,703	429,602	427,919	427,158	425,107	436,407	428,215
WYT	**NAA**	**Alt 1**	**Alt2wTUCP woVA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**	**Alt 3**	**Alt 4**
W	408,175	0.33	-0.06	-0.07	-0.08	-0.04	-1.02	-0.06
AN	413,558	1.31	0.21	0.07	0.18	-1.09	-0.06	0.27
BN	424,557	-0.30	-0.15	0.01	0.57	-1.08	3.25	-0.25
D	432,209	-1.58	-0.07	-0.01	0.27	0.81	3.75	-0.12
C	466,993	-3.50	3.59	1.21	-0.85	-1.73	5.60	1.85
All	427,057	-0.79	0.60	0.20	0.02	-0.46	2.19	0.27

Table O.3-27. Expected WUA for Late Fall-run Chinook Juvenile Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	146,115	145,066	146,404	146,382	146,289	146,525	146,985	146,362
AN	138,604	138,055	138,927	139,000	138,957	140,412	140,532	139,121
BN	136,531	137,398	136,858	137,706	138,187	139,757	139,595	136,582
D	141,755	141,398	143,677	143,664	143,393	145,519	140,093	142,919
C	158,342	154,956	168,956	165,568	164,259	163,625	165,254	167,397
All	144,248	143,406	146,593	146,204	145,984	146,945	146,020	146,127

WYT	NAA	Alt 1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt 3	Alt 4
W	146,115	-0.72	0.20	0.18	0.12	0.28	0.60	0.17
AN	138,604	-0.40	0.23	0.29	0.25	1.30	1.39	0.37
BN	136,531	0.63	0.24	0.86	1.21	2.36	2.24	0.04
D	141,755	-0.25	1.36	1.35	1.16	2.65	-1.17	0.82
C	158,342	-2.14	6.70	4.56	3.74	3.34	4.37	5.72
All	144,248	-0.58	1.63	1.36	1.20	1.87	1.23	1.30

Figure O.3-34 and Figure O.3-35 show the full variation in estimated fry and juvenile rearing WUA for late fall-run under the EIS modeled scenarios. The upper and lower limits of the range in WUA values are determined by the ranges of the late fall-run fry and juvenile rearing WUA curves from which they are estimated (Figure O.3-10 and Figure O.3-11). The estimated fry rearing WUA values under the EIS modeled scenarios are variable among the months, March through June (Figure O.3-34). The median values for fry rearing vary to a lesser degree, with the most variation in April amongst the NAA and Alternatives 1-4. Between the months of the fry rearing period, May and June have the lowest expected WUA median values. During the juvenile rearing period, the median WUA values steadily decline from March to the lowest median WUA values in July, and rise to the highest median WUA values in September (Figure O.3-35).

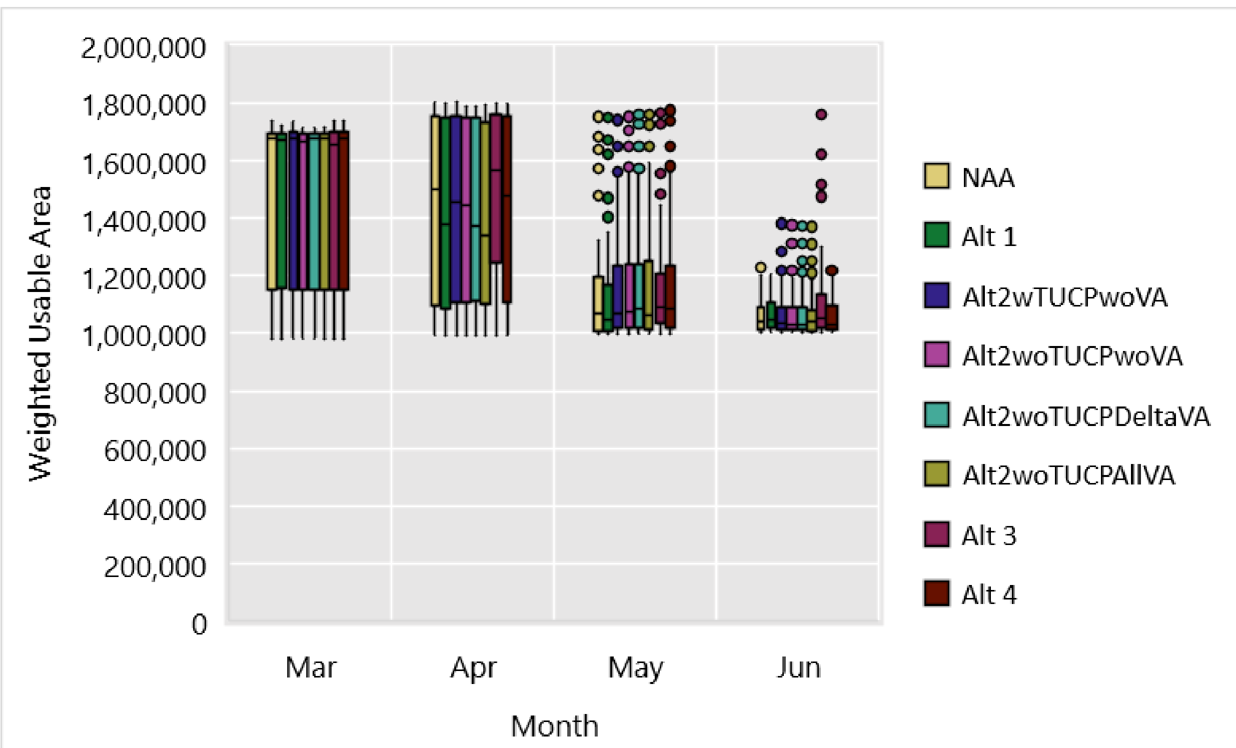


Figure O.3-34. Expected WUA for Late Fall-run Fry Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

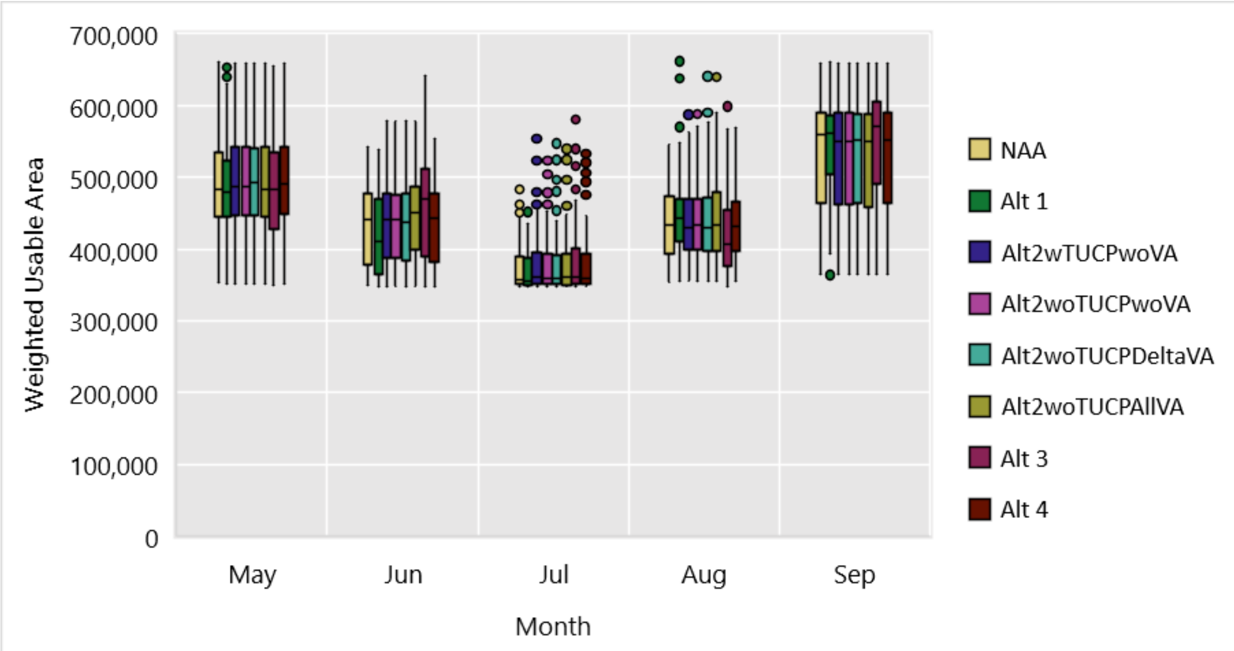


Figure O.3-35. Expected WUA for Late Fall-run Juvenile Rearing in the Sacramento River Segments 4-6 for the NAA and Alternatives 1-4 by Month

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