Appendix M, Folsom Reservoir Flow and Temperature Management

Attachment M.3 American River Weighted Usable Area Analysis

M.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.

M.3.2 Model Development

M.3.2.1 Methods

For this analysis, spawning WUA was estimated for California Central Valley steelhead and fall-run Chinook salmon in the American River. Fry and juvenile rearing WUA were not estimated because no reliable rearing WUA curves are available for Chinook salmon or steelhead in the American River. The principal study on which this analysis is based, Bratovich et al. 2017, determined spawning WUA in the American River but did not include rearing WUA investigations. The only rearing WUA information found for American River is old and potentially unreliable (U.S. Fish and Wildlife Service 1985).

Bratovich et al. (2017) provide spawning WUA curves for steelhead and fall-run Chinook salmon spawning habitat in the American River in eight sections of the American River. The eight sections lie within the approximately 10-mile river reach from Nimbus Dam downstream to Riverbend Side Channel, where most steelhead and salmon spawning occurs. There are no significant tributaries or diversions within this reach; all the curves are based on flow from Nimbus Dam releases. Figure M.3-1 and Figure M.3-2 show composite spawning WUA curves from Bratovich et al. (2017) that combine the WUA results for the eight sections. For this effects analysis, CalSim 3 flows at Nimbus Dam were used to determine steelhead and fall-run spawning WUA in the American River from the composite WUA curves for each month of the 93-year period of record.

For the Bratovich et al. (2017) study of spawning WUA in the American River, the Habitat Suitability Criteria (HSC) for steelhead and fall-run Chinook spawning were developed using depth, flow velocity, and/or substrate utilization data from previous studies on the American River and other rivers. The HSC were incorporated into a combination of available hydraulic/habitat models (including PHABSIM and RIVER2D) to estimate spawning WUA for different flows (Bratovich et al. 2017).

Mean spawning WUA under the scenarios and the alternatives were estimated for the months of the spawning periods of each species (January through March for steelhead and October through December for fall-run Chinook) under each water year type and all water year types combined. Total spawning WUA for all months were compared after weighting the monthly results by the monthly weighting factors in Table M.3-1. These weighting factors were computed from tables of daily weighting coefficients provided by Bratovich et al. (2017), which were derived from redd survey and carcass survey results. No spatial weighting factors are required because, as noted above, the analyses are based on composite WUA curves that encompass all the spawning sections analyzed.

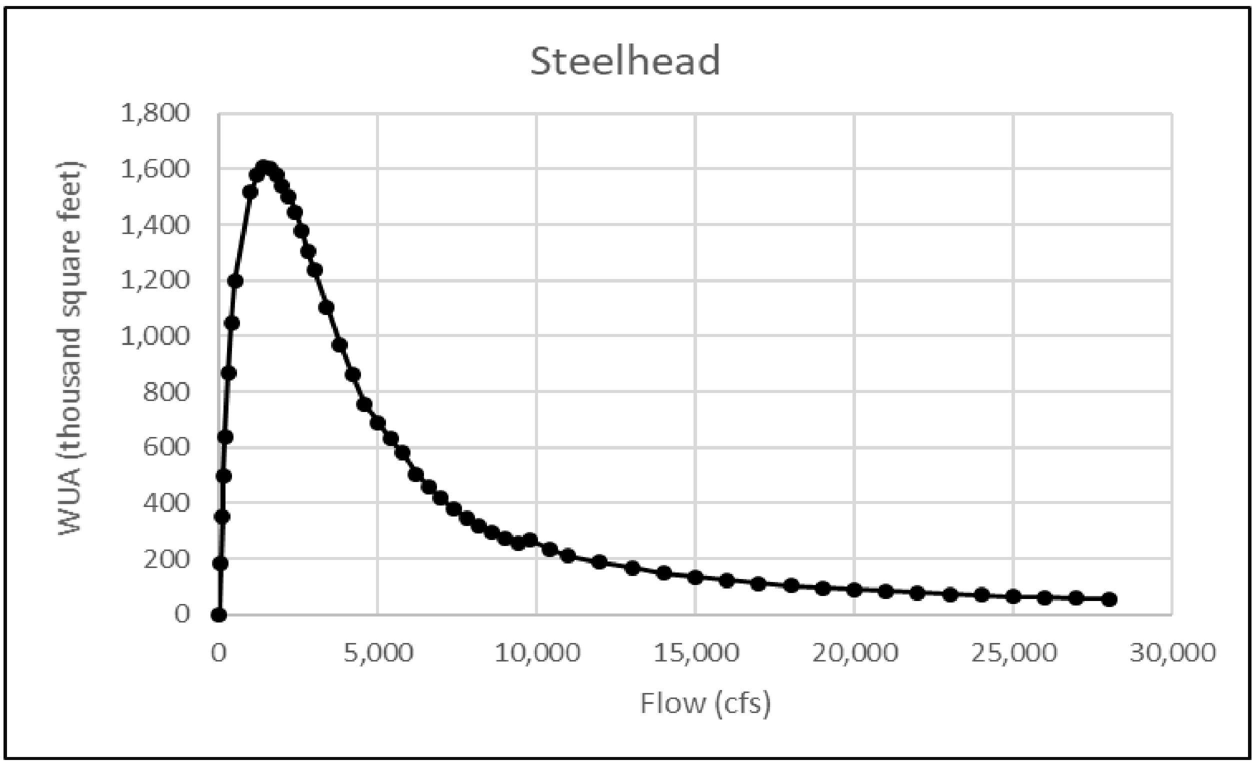

Figure M.3-1. Composite Spawning WUA for Steelhead in the American River.

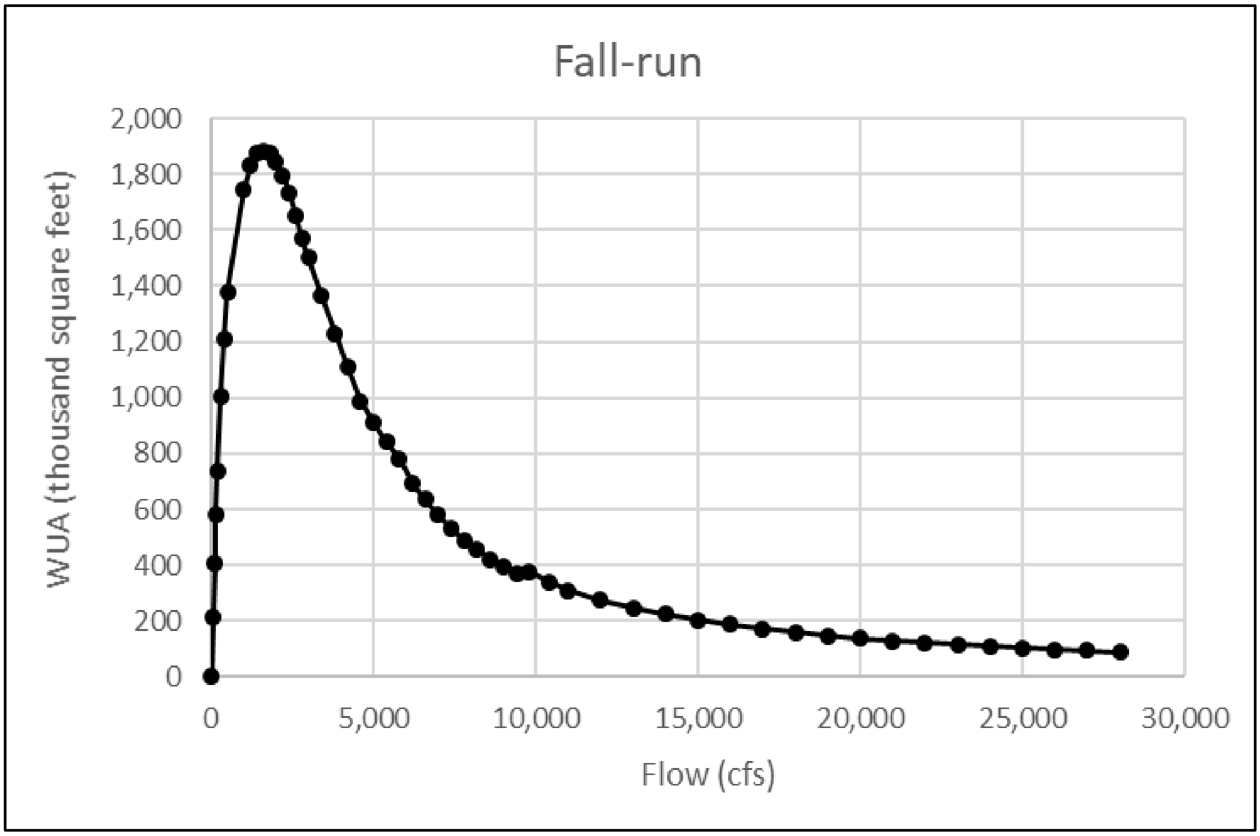

Figure M.3-2. Composite Spawning WUA for Fall-Run Chinook Salmon in the American River.

Table M.3-1. Monthly Weighting Factors for American River Steelhead and Fall-run Spawning

Month	Steelhead	Fall-run
October	0	0.07
November	0	0.85
December	0	0.08
January	0.3	0
February	0.6	0
March	0.1	0

M.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.

M.3.2.2.1 Important Uncertainties and Assumptions of the WUA Analyses Conducted for this Analysis

The CalSim 3 operations model that was used to estimate spawning WUA under scenarios uses 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 scenarios and alternatives conditions. Weighting by the proportions in Table M.3-1 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 periods, with months weighted by expected occurrences, were used in this analysis for determining effects of changes in flow on spawning WUA. These periods were derived from information in Bratovich et al. (2017) based on spawning data for steelhead and fall-run Chinook collected in the lower American River over many years. They are expected to represent the primary spawning periods of the fish. However, the timing of spawning by salmon and steelhead may vary somewhat among years depending on flows (Quinn 2005). The timing of spawning may be directly affected by flow volume in spawning habitats or indirectly affected via flow effects on upstream migration timing or water temperatures (Sullivan and Hileman 2019; Jennings and Hendrix 2020). The use of fixed spawning periods for this analysis does not account for these potential variations either in flow from year to year or for differences in flow regimes between the alternative scenarios, which potentially increases uncertainty in the results. However, variations from the primary spawning periods are likely to be small, because spawn timing is a conservative, genetically controlled trait in anadromous fish (Quinn 2005).

The suitability of physical habitat for salmon and steelhead spawning is assumed to be 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.

Data used to develop the habitat suitability criteria for spawning included information from rivers other than the American River (Bratovich et al. 2017). The use of habitat data from rivers other than the American River adds some uncertainty to the spawning WUA 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).

WUA analyses assume that the channel characteristics of the river, such as proportions of mesohabitat types, during the years of field data collection for the Bratovich et al. 2017 report (1998-1999, 2009, 2011-2016) 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.

M.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. 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. Criticisms addressed in this attachment are primarily those relevant to spawning WUA analysis because, as discussed previously, no rearing WUA analyses were conducted for the American River.

Two frequent criticisms of WUA analysis that are most potentially relevant with regard to the results and conclusions of this analysis are: (1) WUA analysis fails to directly evaluate many factors that are known to be important to fish spawning, including water quality (especially temperature and dissolved oxygen), predation, and competition (including redd superimposition) (Beecher et al. 2010; Railsback 2016), 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). Analysis methods other than PHABSIM are used to evaluate the other factors, which may or may not be affected by flow. Conclusions regarding effects 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 or combined PHABSIM with more powerful tools in recent years, including the RIVER2D hydraulic and habitat model, which was included by Bratovich et al. (2017) in the models used to develop the American River spawning WUA curves used for this WUA analysis. The habitat variables included in hydraulic/habitat modeling have also been expanded and improved (Li et al. 2019). Such methods are promising, but they are not currently available for use in analyzing flow effects on fish populations in the American River.

Some 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 for WUA analyses 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).

M.3.2.3 Code and Data Repository

Data for this analysis are available upon request.

M.3.3 Results

M.3.3.1 Steelhead

Table M.3-2 and Table M.3-3 provide the spawning WUA results for American River steelhead under the BA modeled scenarios and EIS modeled scenarios, respectively. The results are the means for all years analyzed, weighted by monthly spawning use factors as discussed in Section M.3.2.1, *Methods* (Table M.3-1). The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table M.3-3).

The results for both the BA and EIS modeled scenarios show large, consistent increases in mean spawning from wetter to drier water year type among the four phases of Alternative 2 and all BA and EIS modeled scenarios for the alternatives (Table M.3-2 and Table M.3-3. For all EIS modeled scenarios, mean WUA is lower than that for the NAA under almost all water year types (Table M.3-3). The largest difference between the NAA and the scenarios is a 13.3% reduction for Alt 1 in dry water years (Table M.3-3). Alt 1 shows relatively large reductions in WUA for all water year types except wet years. The only increase for all scenario alternatives and water year types is a 1.4% increase for Alt 3 in critical water years (Table M.3-3).

Table M.3-2. Expected WUA for Steelhead Spawning in the American River Downstream of Nimbus Dam for EXP1, EXP3, the NAA, and Four phases of Alternative 2.

Water Year Type	EXP1	EXP3	NAA	Alt2wTUCPwoVA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
Wet	25,901	28,572	29,391	29,246	29,247	29,222	29,291
AN	50,660	54,778	58,460	57,361	57,398	56,892	56,581
BN	81,326	89,033	93,488	91,604	91,796	92,772	93,000
Dry	99,404	105,807	110,795	108,104	108,278	107,496	107,809
Critical	113,433	119,216	120,525	116,689	116,305	115,424	115,178
All	70,990	76,164	79,117	77,323	77,344	77,113	77,165

Table M.3-3. Expected WUA for Steelhead Spawning in the American River Downstream of Nimbus Dam for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt 3	Alt 4
Wet	29,391	28,692	29,246	29,247	29,222	29,291	28,596	29,392
AN	58,460	55,129	57,361	57,398	56,892	56,581	56,888	57,338
BN	93,488	85,702	91,604	91,796	92,772	93,000	92,608	90,881
Dry	110,795	96,053	108,104	108,278	107,496	107,809	110,040	107,547
Critical	120,525	105,814	116,689	116,305	115,424	115,178	122,231	117,633
All	79,117	71,161	77,323	77,344	77,113	77,165	78,607	77,248
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
Wet	29,391	-2.38	-0.49	-0.49	-0.57	-0.34	-2.71	0.00
AN	58,460	-5.70	-1.88	-1.82	-2.68	-3.22	-2.69	-1.92
BN	93,488	-8.33	-2.02	-1.81	-0.77	-0.52	-0.94	-2.79
Dry	110,795	-13.31	-2.43	-2.27	-2.98	-2.70	-0.68	-2.93
Critical	120,525	-12.21	-3.18	-3.50	-4.23	-4.44	1.42	-2.40
All	79,117	-10.06	-2.27	-2.24	-2.53	-2.47	-0.64	-2.36

Figure M.3-3 and Figure M.3-4 show the full variation in estimated spawning WUA for steelhead 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 M.3-1). The median values of the steelhead spawning WUA results under the BA and EIS modeled scenarios are similar for January and March, but somewhat lower for February. This difference results from more frequent high flows (>5,000 cfs) in February and the lower WUA values at higher flows in the steelhead spawning WUA curve (Figure M.3-1). Amongst all of the EIS scenarios, Alternative 1 is consistently the lowest throughout the spawning period (Figure M.3-4).

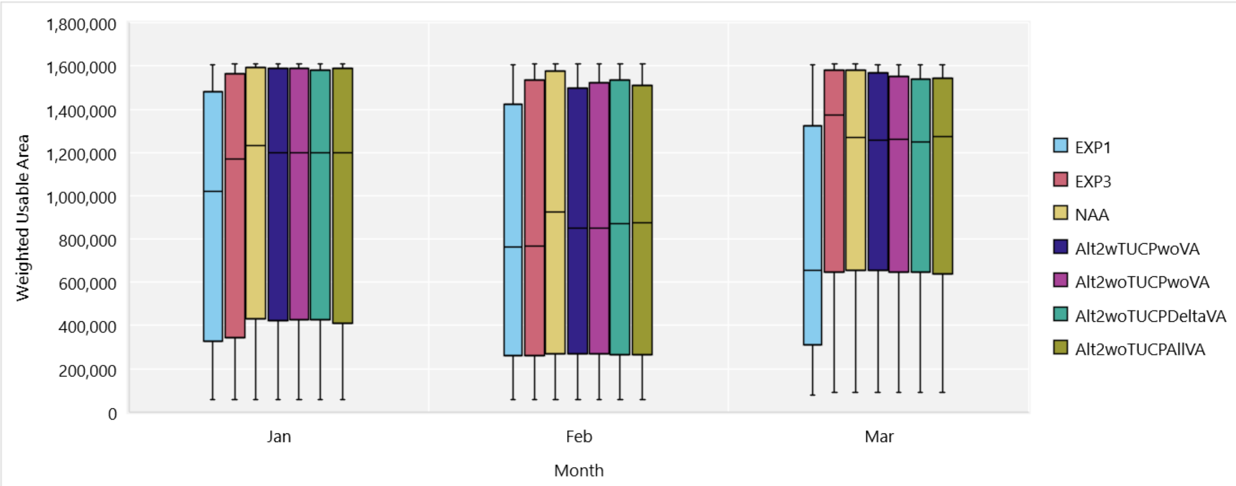

Figure M.3-3. Expected WUA for Steelhead Spawning in the American River Downstream of Nimbus Dam for EXP1, EXP3, NAA, and four phases of Alternative 2 by Month.

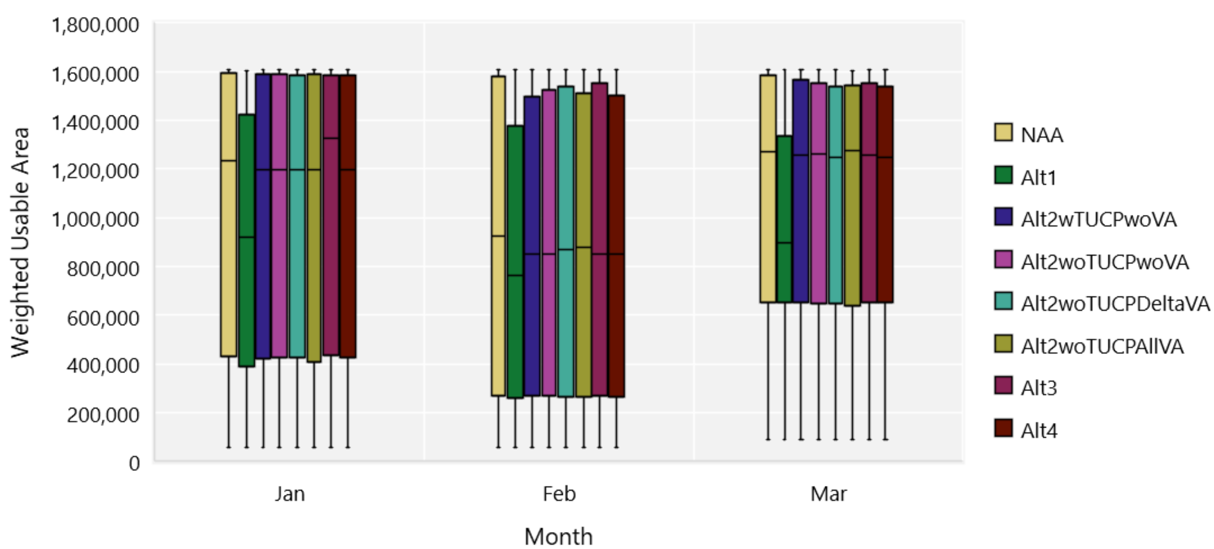

Figure M.3-4. Expected WUA for Steelhead Spawning in the American River Downstream of Nimbus Dam for the NAA and Alternatives 1-4 by Month

Figure M.3-5 and Figure M.3-6 show the full variation in estimated steelhead spawning WUA under the BA and EIS modeled scenarios, respectively, with results grouped by water year type rather than by month. These results are the same as those shown in Table M.3-2 and Table M.3-3 except that they include the variation in WUA results. Above normal (2) and below normal (3) water year types show the greatest levels of variability in WUA values (Figure M.3-5 and Figure M.3-6).

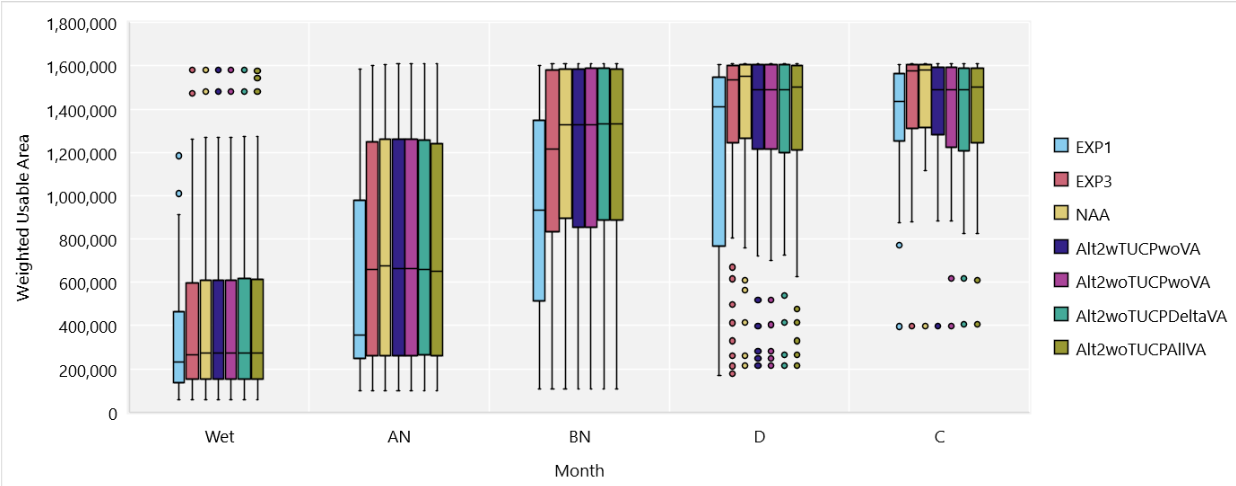

Figure M.3-5. Expected WUA for Steelhead Spawning in the American River Downstream of Nimbus Dam for EXP1, EXP3, NAA, and four phases of Alternative 2 by Water Year Type.

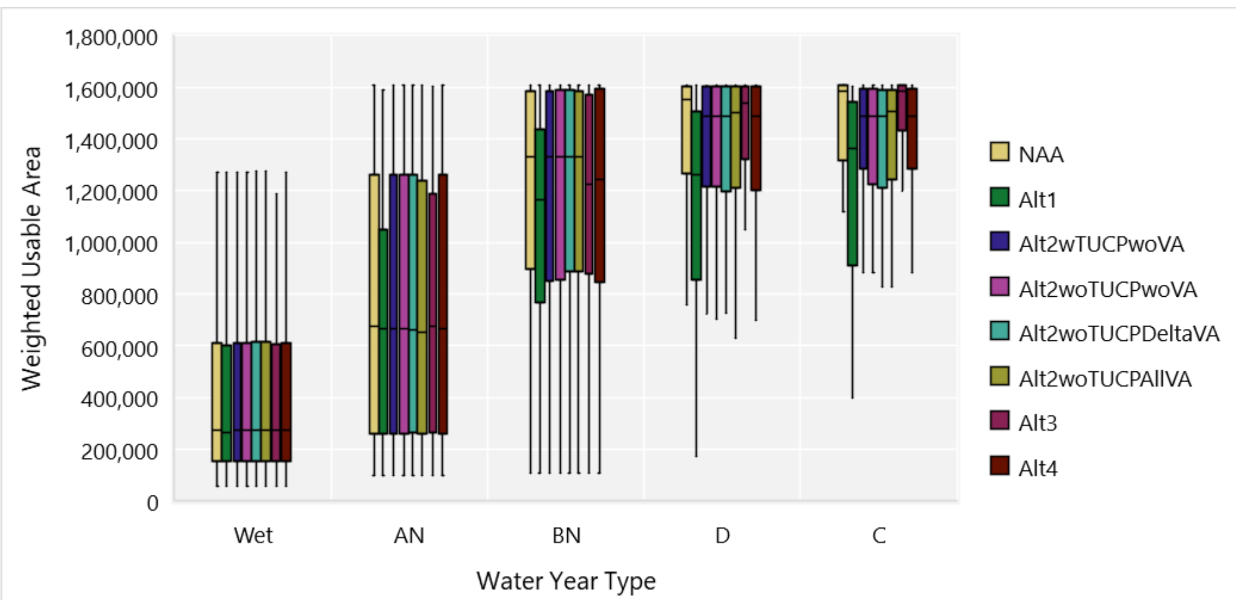

Figure M.3-6. Expected WUA for Steelhead Spawning in the American River Downstream of Nimbus Dam for the NAA and Alternatives 1-4 by Water Year Type.

M.3.3.2 Fall-run Chinook Salmon

Table M.3-4 provides the spawning WUA results for American River fall-run Chinook under the EIS modeled scenarios. The results are the means for all years analyzed, weighted by monthly spawning use factors as discussed in Section M.3.2.1, *Methods* (Table M.3-1). The table includes the percent differences between the results of the NAA and the alternatives (Table M.3-4).

The results show little consistency in variations of spawning WUA with water year type for the EIS modeled scenarios for the alternatives, except that wet water years consistently have the lowest WUA values. The reduction in WUA values for wet years likely results from the fact that wet years on average have more frequent high flows and the fall-run spawning WUA curve peaks at relatively low flows and falls sharply at flows greater than about 2,000 cfs (Figure M.3-2). As described above for steelhead, mean spawning WUA for fall-run is lower under all EIS modeled scenarios and almost all water year types than under the NAA (Table M.3-4). The largest differences between the NAA and the scenarios are 14.6% reduction for Alt 1 in below normal water years and a 12.1% reduction for Alt 1 in above normal water years (Table M.3-4). Alt 1 shows relatively large reductions in WUA for all water year types. Except under Alt 1 and Alt 3, most of the largest reductions occurred for critical water years. The largest increase for all scenario alternatives and water year types is 1.4% increase for Alt 3 in dry water years (Table M.3-4).

Table M.3-4. Expected WUA for Fall-run Chinook Spawning in the American River Downstream of Nimbus Dam for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA.

WYT	NAA	Alt 1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt 3	Alt 4
Wet	110,031	104,927	109,091	109,186	108,538	108,806	109,743	109,148
AN	140,579	123,537	139,812	139,838	139,380	139,640	137,001	139,916
BN	136,602	116,729	134,816	134,092	133,095	132,691	137,595	135,800
Dry	126,078	115,099	125,677	125,258	126,034	123,862	127,786	124,645
Critical	134,075	123,463	126,791	123,661	124,507	125,010	131,242	126,721
All	126,854	115,064	124,965	124,295	124,179	123,774	126,400	124,916
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
Wet	110,031	-4.64	-0.85	-0.77	-1.36	-1.11	-0.26	-0.80
AN	140,579	-12.12	-0.55	-0.53	-0.85	-0.67	-2.54	-0.47
BN	136,602	-14.55	-1.31	-1.84	-2.57	-2.86	0.73	-0.59
Dry	126,078	-8.71	-0.32	-0.65	-0.04	-1.76	1.35	-1.14
Critical	134,075	-7.92	-5.43	-7.77	-7.14	-6.76	-2.11	-5.49
All	126,854	-9.29	-1.49	-2.02	-2.11	-2.43	-0.36	-1.53

Figure M.3-7 and Figure M.3-8 show the full variation in estimated spawning WUA for fall-run under the EIS modeled scenarios, with results grouped by spawning month and water year type, 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 M.3-2). The median values of the fall-run spawning WUA results are similar for November and December but are somewhat higher for October. This difference results from less frequent high flows (>5,000 cfs) in October and the higher WUA values at lower flows in the fall-run spawning WUA curve (Figure M.3-1). Figure M.3-8 shows the results of fall-run spawning WUA grouped by water year type. The results are the same as those shown in Table M.3-4 except that they include the variation in WUA results.

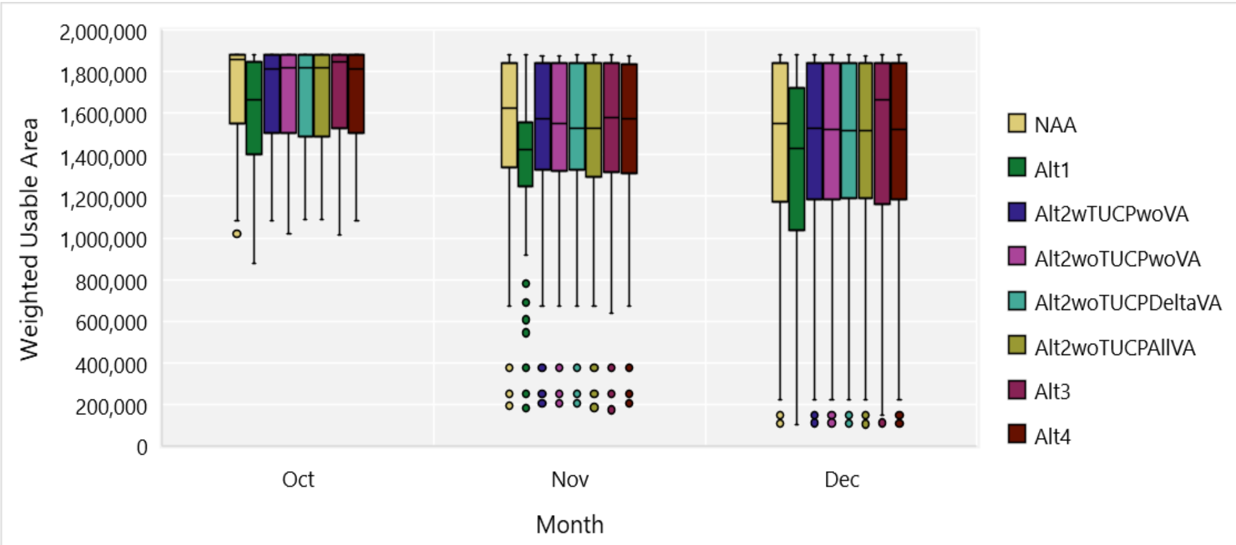

Figure M.3-7. Expected WUA for Fall-run Spawning in the American River Downstream of Nimbus Dam for the NAA and Alternatives 1-4 by Month

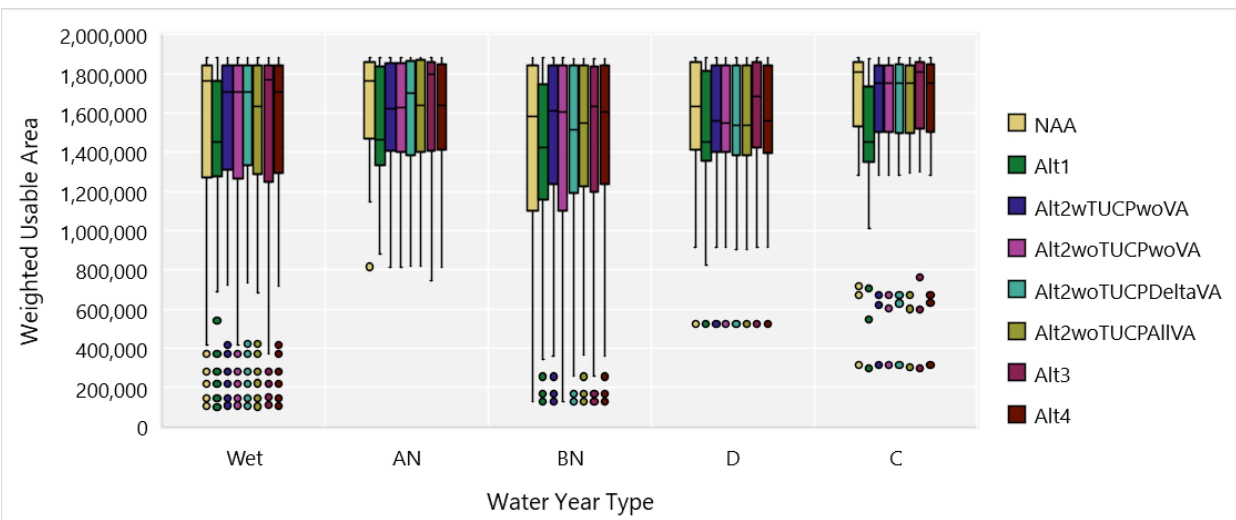

Figure M.3-8. Expected WUA for Fall-run Spawning in the American River Downstream of Nimbus Dam for the NAA and Alternatives 1-4 by Water Year Type.

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