Appendix O, Tributary Habitat Restoration

Attachment O.1 CWP Clear Creek Weighted Usable Area Analysis

O.1.1 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 stream 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 stream 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.1.2 Model Development

O.1.2.1 Methods

For this analysis, spawning and rearing WUA were estimated for spring-run and fall-run Chinook salmon and California Central Valley steelhead in Clear Creek, Shasta County. Spawning and rearing WUA were estimated for the baseline scenarios and management alternatives from CalSim 3 flow data for each month of the 100-year period of record. The WUA analyses are based on a series of U.S. Fish Wildlife (USFWS) field studies conducted from 2004 through 2009 (USFWS 2007, 2011a, 2011b, 2013, 2015).

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 physical habitat 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 stream flow, and the results are combined to develop spawning habitat WUA curves and tables (Bovee et al. 1998). For the USFWS Clear Creek spawning WUA studies, the primary hydraulic model used was RIVER-2D (USFWS 2007, 2011a). The WUA tables are used to look up the amount of spawning WUA available at different flows during the spawning period of the fish. The Clear Creek spawning WUA tables are provided in USFWS 2007 and 2011a.

For development of the rearing WUA curves, the modeling assumptions include that the suitability of physical habitat for salmon and steelhead rearing (fry and juveniles) is largely a function of water depth, flow velocity, adjacent velocity, and the availability of cover. Adjacent velocity is designed to account for microhabitats selected by juveniles in quiet water adjacent to more rapid flow, which provides higher rates of prey encounter. Such microhabitats include heads of pools, behind large boulders, riparian vegetation, and river banks, and (Naman et al. 2019). For the USFWS studies, adjacent velocity was measured within 2 feet on either side of the location where the velocity was the highest (USFWS 2011a, 2013). The race- or species-specific suitability of the rearing habitat with respect to these physical variables is determined by observing the fish's behaviors and is used to develop HSC for each race or species and life stage. 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 rearing habitat WUA curves and tables (Bovee et al. 1998). For USFWS's Clear Creek rearing WUA studies, the primary hydraulic model used was RIVER-2D (USFWS 2011b, 2013). The WUA tables are used to look up the amount of rearing WUA available at different flows during the fry and juvenile rearing periods of the fish. The Clear Creek rearing WUA tables are provided in USFWS 2011b and 2013.

The USFWS studies were conducted between Whiskeytown Reservoir and Clear Creek's confluence with the Sacramento River. For purposes of the studies, the creek was divided into three segments, designated from upstream to downstream as the Upper Alluvial segment, the Canyon segment, and the Lower Alluvial Segment (Figure O.1-1). Spring-run spawn primarily in the upper two segments, fall-run spawn only in the Lower Alluvial segment, and steelhead spawn in all three segments (USFWS 2015). The reports provide spawning WUA tables for spring-run and steelhead in the Upper Alluvial and Canyon segments (USFWS 2007) and fall-run and steelhead in the Lower Alluvial segments (USFWS 2011a). The spawning WUA curves are provided below in Figure O.1-2, Figure O.1-3, and Figure O.1-4.

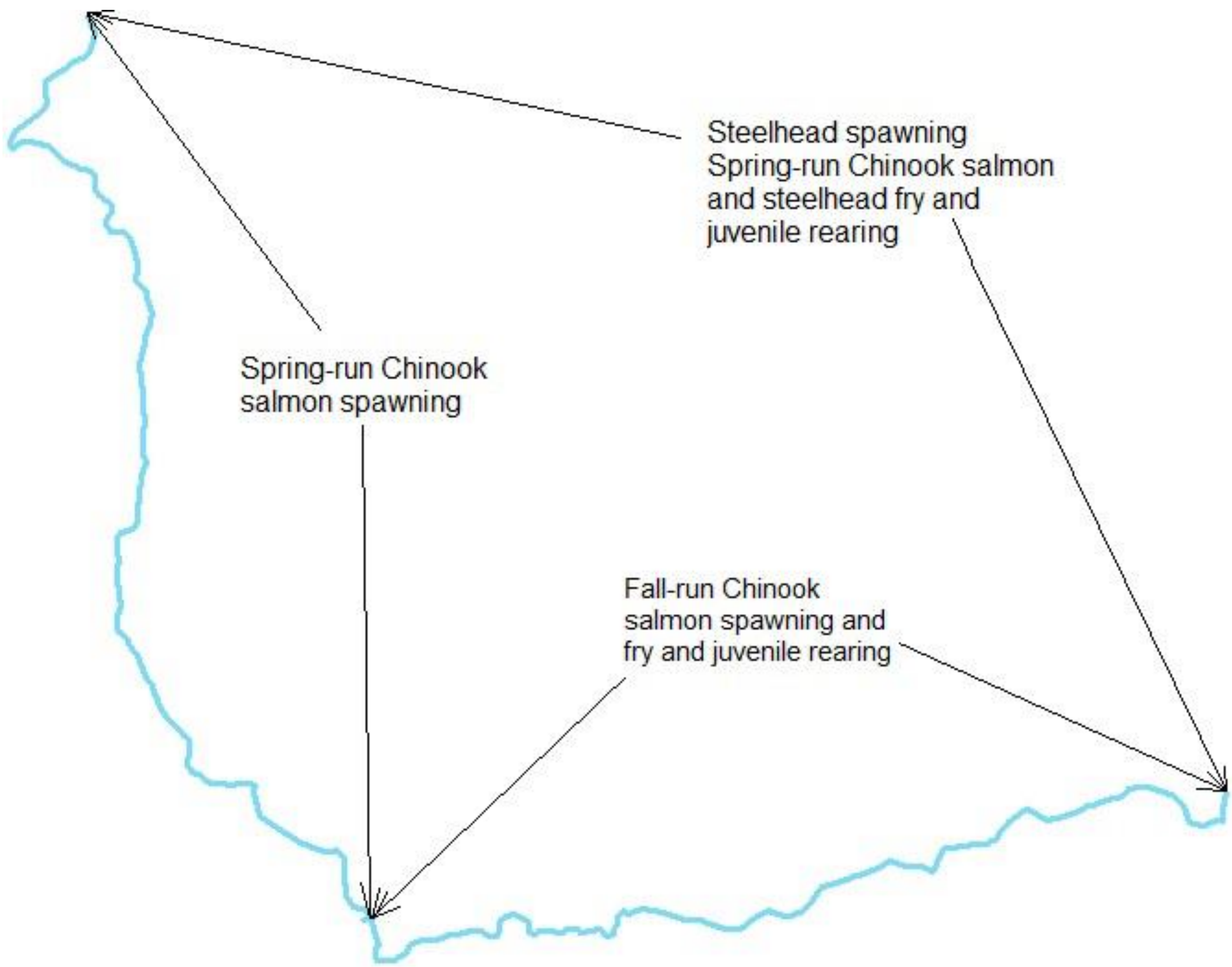

Figure O.1-1. Spatial Distribution of Adult and Juvenile Spring-run and Fall-run Chinook and Steelhead in Clear Creek.

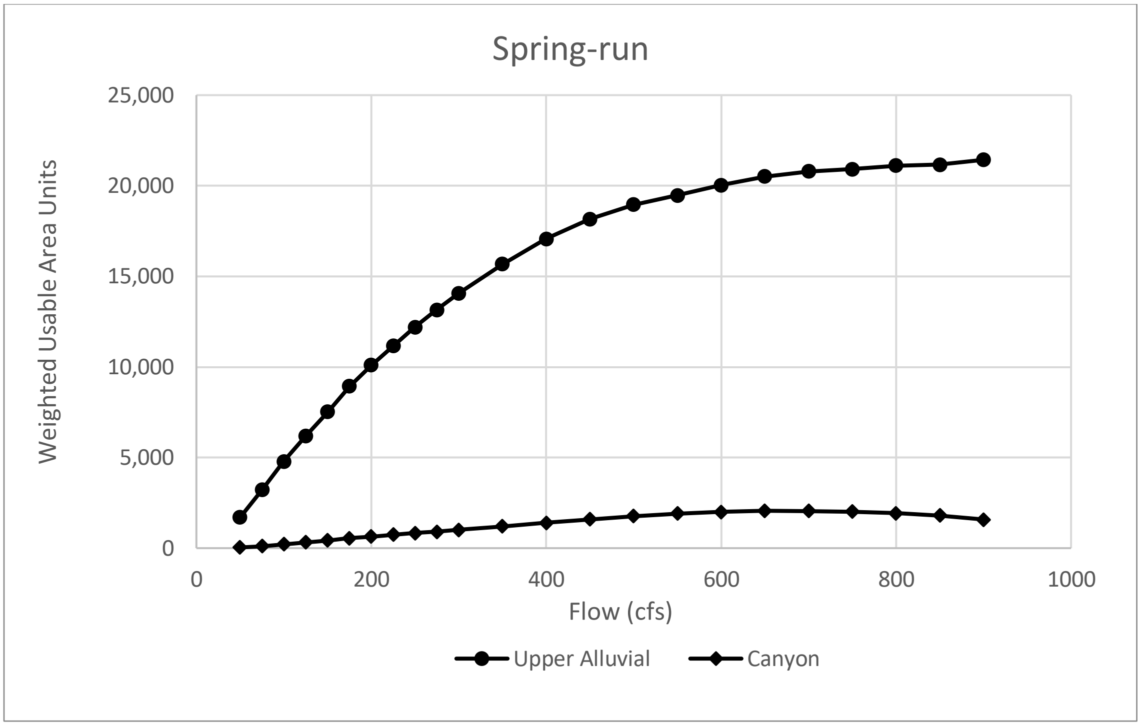

Figure O.1-2. Spawning WUA curves for Spring-Run Salmon in Clear Creek, Upper Alluvial and Canyon Segments.

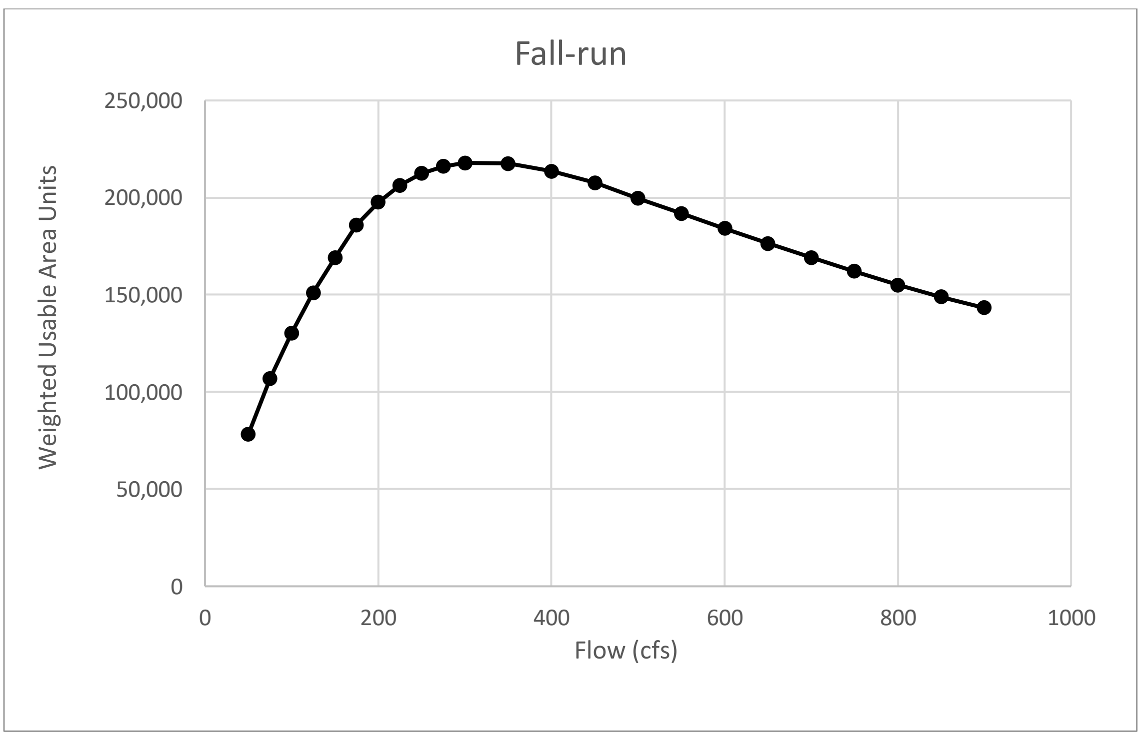

Figure O.1-3. Spawning WUA curve for Fall-Run Salmon in Clear Creek, Lower Alluvial Segment

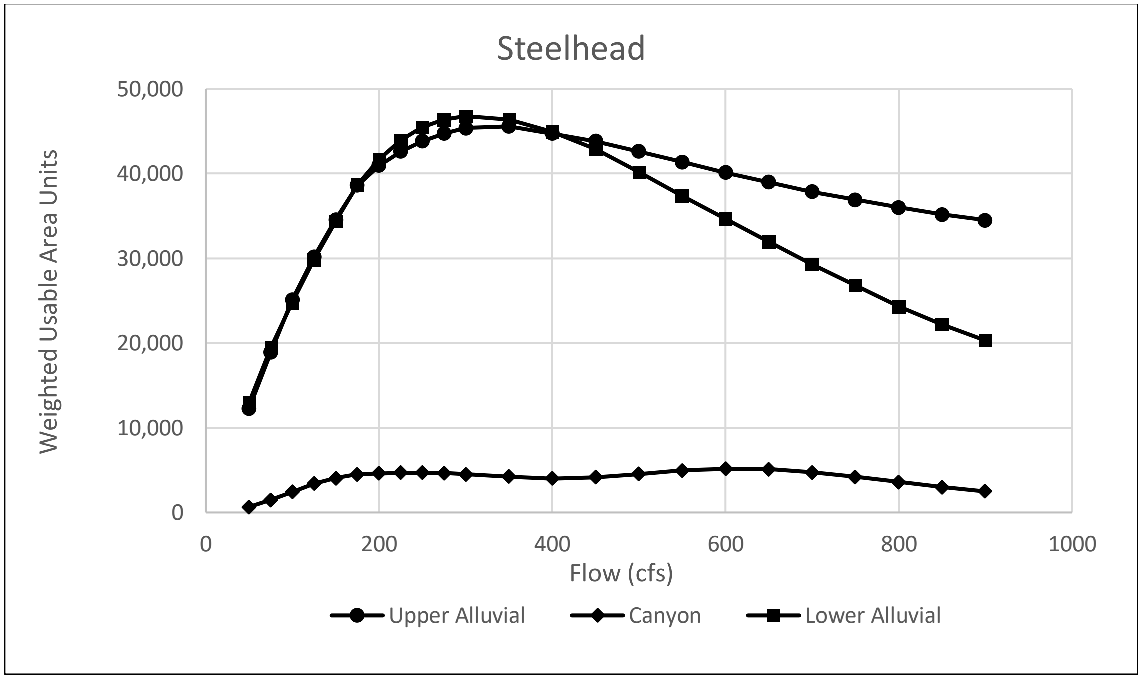

Figure O.1-4. Spawning WUA curves for Steelhead in Clear Creek, Upper Alluvial, Canyon, and Lower Alluvial Segments.

Spring-run and steelhead juveniles rear in the Upper Alluvial, Canyon, and Lower Alluvial stream segments (USFWS 2011b and 2013), whereas fall-run juveniles rear only in the Lower Alluvial segment (USFWS 2013). For the rearing WUA analyses, juvenile steelhead and resident rainbow trout were combined because they could not be differentiated in the field studies. The USFWS reports provide separate WUA curves for fry and juvenile life stages. Based on statistical analyses of differences in habitat use by different sizes of the fish (USFWS 2011b, 2013), a length of 80 mm was used to divide fry from juveniles in the upper two segments and 60 mm was used to divide the two life stages in the Lower Alluvial segment. Based on a lack of statistically significant differences in habitat use, results were lumped for juveniles of spring-run and steelhead (USFWS 2011b and 2013). The reports provide rearing WUA tables for spring-run and steelhead in the Upper Alluvial and Canyon segments (USFWS 2011b) and for both salmon races and steelhead in the Lower Alluvial segment (USFWS 2013). The rearing WUA curves are provided below in Figure O.1-5 through Figure O.1-9.

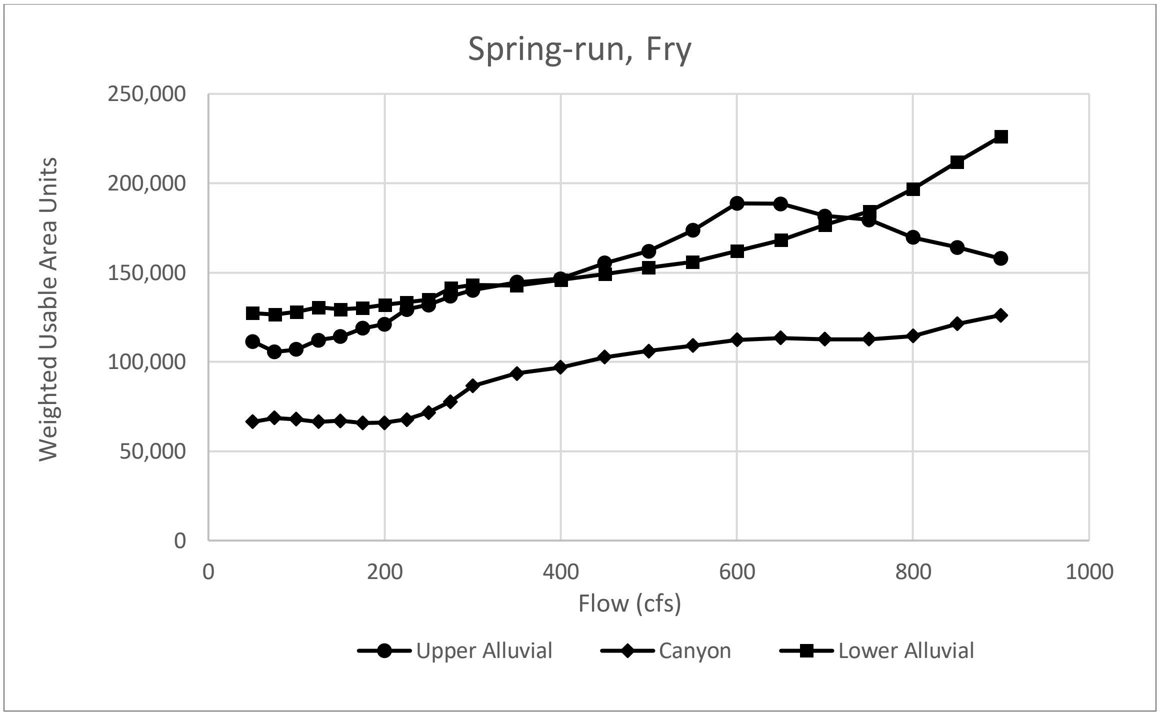

Figure O.1-5. Rearing WUA Curves for Spring-Run Salmon Fry in Clear Creek, Upper Alluvial, Canyon, and Lower Alluvial Segments.

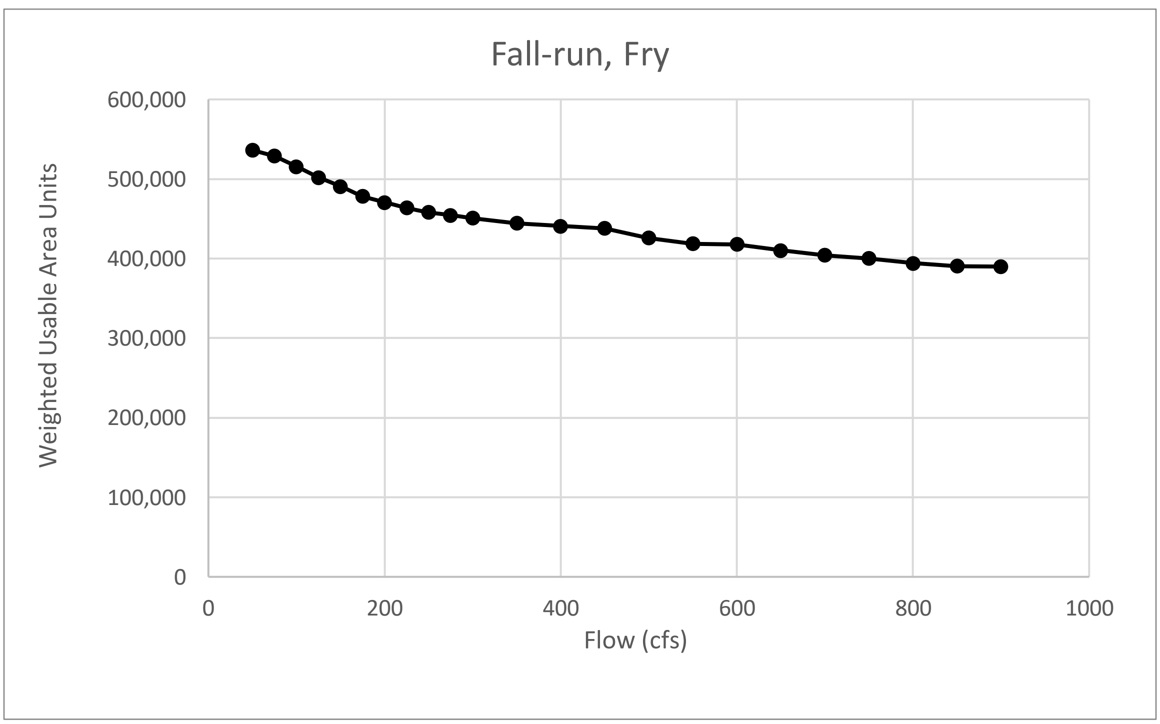

Figure O.1-6. Rearing WUA Curve for Fall-Run Salmon Fry in Clear Creek, Lower Alluvial Segment.

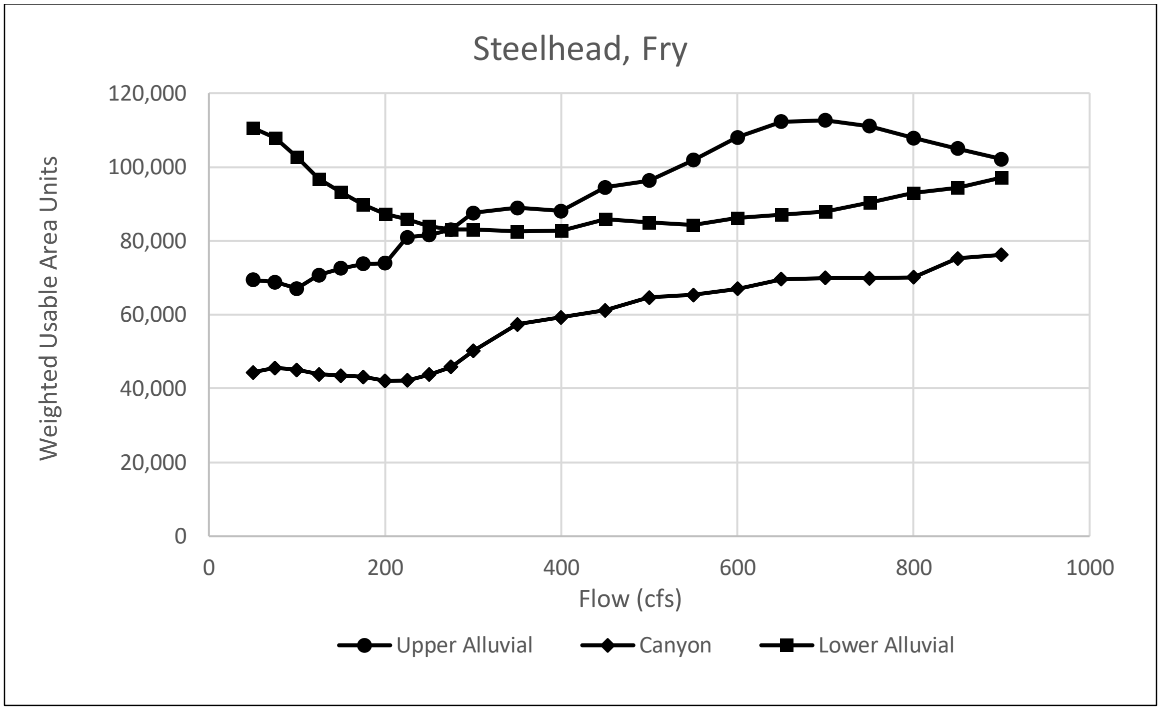

Figure O.1-7. Rearing WUA Curves for Steelhead Fry in Clear Creek, Upper Alluvial, Canyon, and Lower Alluvial Segments.

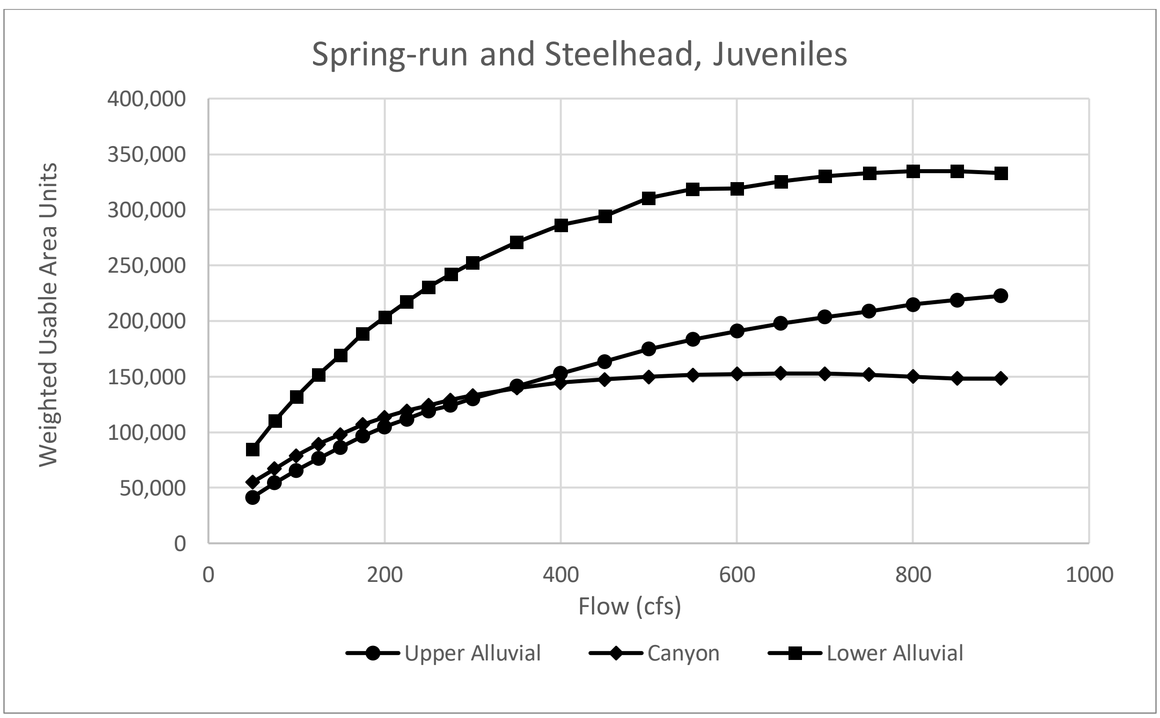

Figure O.1-8. Rearing WUA Curves for Spring-Run Salmon and Steelhead Juveniles in Clear Creek, Upper Alluvial, Canyon, and Lower Alluvial Segments.

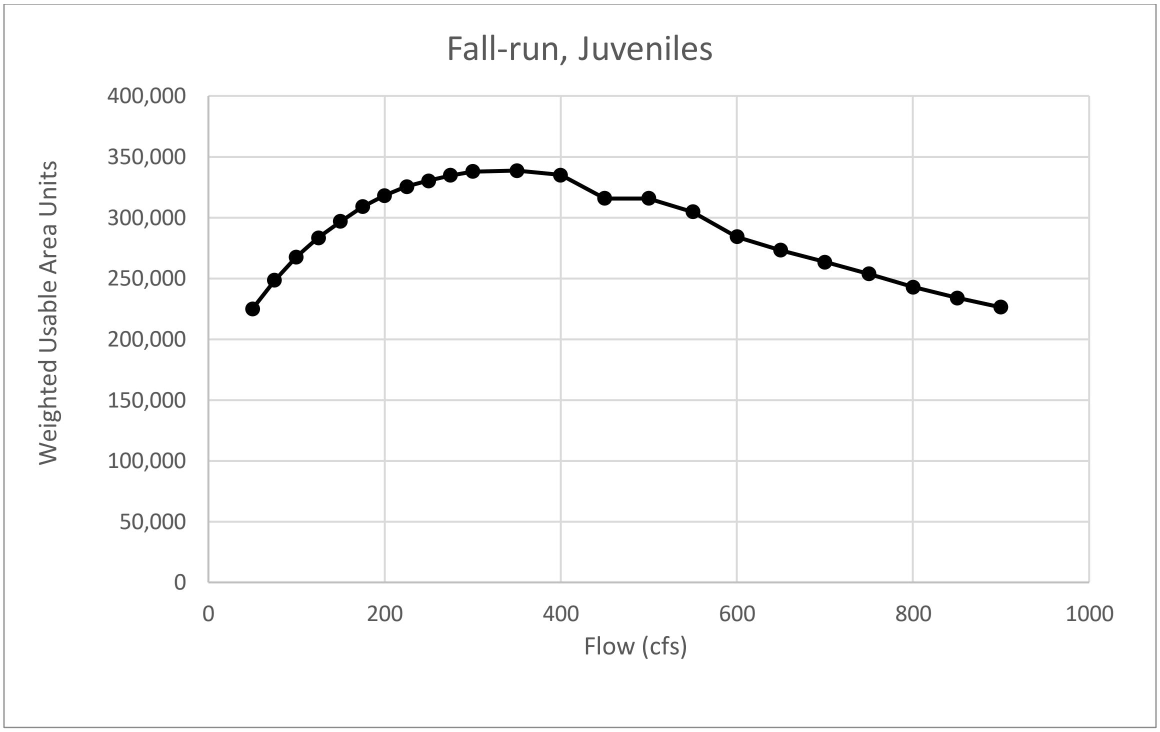

Figure O.1-9. Rearing WUA Curve for Fall-Run Salmon Juveniles in Clear Creek, Lower Alluvial Segment.

In this analysis, spawning and rearing WUA tables in the USFWS reports (USFWS 2007, 2011a, 2011b, and 2013) were used with CalSim 3 flow data for Whiskeytown Lake releases to Clear Creek to estimate spring-run, fall-run, and steelhead spawning and rearing WUA under the baseline scenarios and management alternatives for each month of the 100-year CalSim 3 period of record. Lower Clear Creek has only minor tributaries, so except under high runoff conditions, flow at Whiskeytown Lake adequately represents flow throughout the stream USFWS ?). Spawning and rearing WUAs were determined using flows for the spawning and rearing periods of each run or species (Table O.1-1) under each water year type and all water year types combined. Total weighted means for spawning and rearing WUA that combined the monthly WUA results from all three stream segments were computed using weighting factors for each of the baseline scenarios and management alternatives. The means were computed for each water year type and all water year types combined. The monthly and segment weighting factors for each species or run and life stage are provided in Table O.1-2. Weighting factors for spring-run spawning are from Figures 35 and 36 in Appendix C, *Species Spatial and Temporal Domains*, for spring-run spawning they are from

Table O.1-1. Temporal Distributions of Adult and Juvenile Spring-run, Fall-run and Steelhead in Clear Creek.

Life Stage	Fall-run	Spring-run	Steelhead
Spawning	October-December	September-October	December-April
Fry	January-April	November-March	February-June
Juvenile	May-September	April-August	July-December

Source: USFWS 2015

Table O.1-2. Monthly Weighting Factors for Spawning and Fry and Juvenile Rearing of Spring-run and Fall-run Chinook and Steelhead in Clear Creek.

	Spring-run Chinook			Steelhead			Fall-run Chinook		
Month	Spawn	Fry	Juv.	Spawn	Fry	Juv.	Spawn	Fry	Juv.
January				0.35					
February				0.4					
March				0.05					
April									
May									
June									
July									
August									
September									
October	0.8						0.3		
November	0.2						0.4		
December				0.2			0.3		

O.1.2.2 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 effects 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.1.2.2.1 Important Uncertainties and Assumptions of the WUA Analyses Conducted for this Analysis

1. The CALSIM III operations model used to estimate spawning WUA under the baseline and the alternatives uses a monthly timestep. Therefore, the WUA results should be treated as monthly averages. Using monthly averages to compare spawning and rearing WUA results is suitable for showing differences in effects of the different flow regimes under baseline and alternatives conditions. Monthly average WUA results faithfully represent the average conditions affecting the fish.
2. 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, competition, water quality, etc.) could influence habitat suitability, contributing to uncertainty in the results.
3. 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, competition, water quality, etc.) could influence habitat suitability, contributing to uncertainty in the results.
4. The output of the WUA analysis is an index of habitat suitability, not an absolute measure of habitat surface area. In the literature, including in the USFWS reports on which this analysis is based (USFWS 2007, 2011a, 2011b, 2013), Weighted Usable Area may be 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).
5. Fixed spawning periods were used in this analysis for determining effects of changes in flow on spawning WUA (Table O.1-1). These periods are provided by USFWS (2015), which has collected data on spawning of salmonids in Clear Creek 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 nor for differences in flow regimes between the baseline and 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).
6. WUA analyses assume that the channel characteristics of the river, such as proportions of mesohabitat types, during the time of field data collection by USFWS (2004-2009) 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.1.2.2.2 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). Effects of flows on critical processes such channel maintenance, floodplain inundation, and riparian regeneration are also beyond the scope of WUA analyses (Poff et al. 1997; Petts 2009), 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 related hydraulic habitat models such as RIVER-2D (Beecher 2017). Analysis methods other than PHABSIM are used to evaluate the other factors, which may or may not be affected by flow. These methods typically include evaluation tools for assessing effects on water temperatures, redd dewatering, adult migration passage, emigrating juvenile salmonid survival, water diversion entrainment, and other factors. 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 or combined PHABSIM with more powerful tools in recent years, including the RIVER2D hydraulic and habitat model, which was the principal hydraulic habitat model used in the USFWS analyses (USFWS 2007, 2011a, 2011b, 2013) to develop the Clear Creek WUA curves used in this analysis. The habitat variables included in the hydraulic/habitat modeling have also been expanded and improved (Li et al. 2019). 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). Many of these improvements were incorporated in the USFWS Clear Creek WUA analyses (USFWS 2007, 2011a, 2011b, 2013). 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 Clear Creek.

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.1.2.3 Code and Data Repository

Code, input, and output files for this analysis can be found at: [TBD].

O.1.3 Results

Table O.1-3. Expected WUA for Spring-run Chinook Spawning in Clear Creek for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	2,540	5,714	5,752	5,064	5,064	5,064
AN	2,494	5,875	5,643	5,048	5,048	5,048
BN	764	4,170	5,459	4,540	4,561	4,530
Dry	773	3,287	5,719	5,051	5,051	5,051
Critical	563	2,926	5,069	4,141	4,215	4,123
All	1,473	4,430	5,567	4,817	4,832	4,812

Table O.1-4. Expected WUA for Spring-run Chinook Spawning in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	5,752	1,200	5,064	5,064	5,064	5,064	4,532	5,046
AN	5,643	1,191	5,048	5,048	5,048	5,048	4,525	5,030
BN	5,459	1,134	4,993	4,540	4,561	4,530	4,457	4,766
D	5,719	1,200	5,051	5,051	5,051	5,051	4,526	5,033
C	5,069	1,017	4,577	4,141	4,215	4,123	4,184	4,516
All	5,567	1,158	4,968	4,817	4,832	4,812	4,461	4,905

Table O.1-5. Expected WUA for Spring-run Chinook Spawning in Clear Creek for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	35,270	35,662	41,196	43,452	43,452	43,452
AN	35,517	36,262	41,305	43,489	43,489	43,489
BN	32,763	35,167	40,891	43,288	43,295	43,289
Dry	34,675	37,190	39,588	42,470	42,470	42,470
Critical	28,227	30,931	36,610	38,618	38,618	38,618
All	33,584	35,267	40,037	42,418	42,420	42,419

Table O.1-6. Expected WUA for Steelhead Spawning in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	41,196	15,690	43,452	43,452	43,452	43,452	43,515	43,451
AN	41,305	14,393	43,489	43,489	43,489	43,489	43,572	43,489
BN	40,891	14,338	43,611	43,288	43,295	43,289	43,688	43,589
D	39,588	14,479	42,470	42,470	42,470	42,470	42,512	42,469
C	36,610	13,957	38,610	38,618	38,618	38,618	38,594	38,610
All	40,037	14,697	42,475	42,418	42,420	42,419	42,526	42,471

Table O.1-7. Expected WUA for Fall-run Chinook Spawning in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	197,705	114,579	201,120	201,120	201,120	201,120	196,781	201,120
AN	197,705	114,579	201,120	201,120	201,120	201,120	196,781	201,120
BN	192,524	112,033	201,120	197,831	198,023	198,289	196,781	200,941
D	197,705	114,579	201,120	201,120	201,120	201,120	196,781	201,120
C	136,527	81,290	145,932	142,095	143,601	141,779	154,459	143,347
All	187,596	109,128	192,841	191,674	191,935	191,709	190,432	192,422

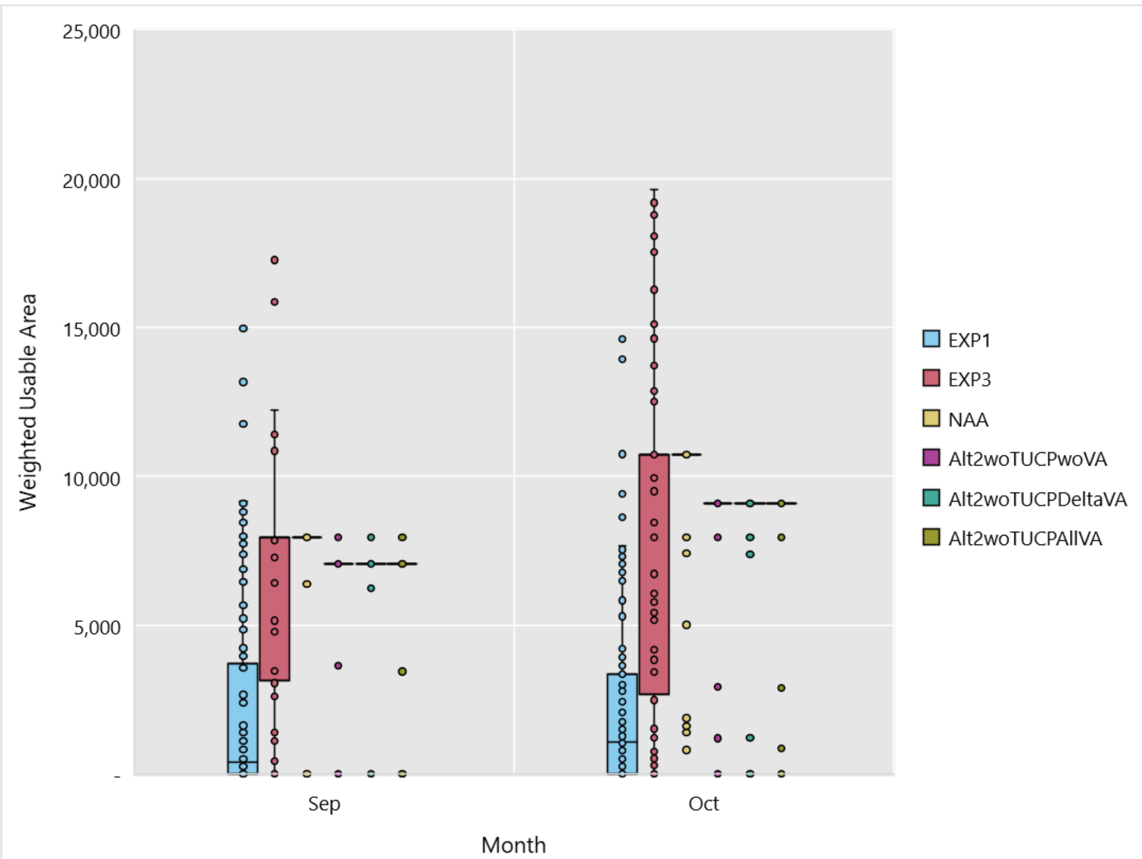

Figure O.1-10. Expected WUA for Spring-run Chinook Salmon Spawning in Clear Creek for EXP1, EXP3, NAA, and three Alternative 2 components by Month

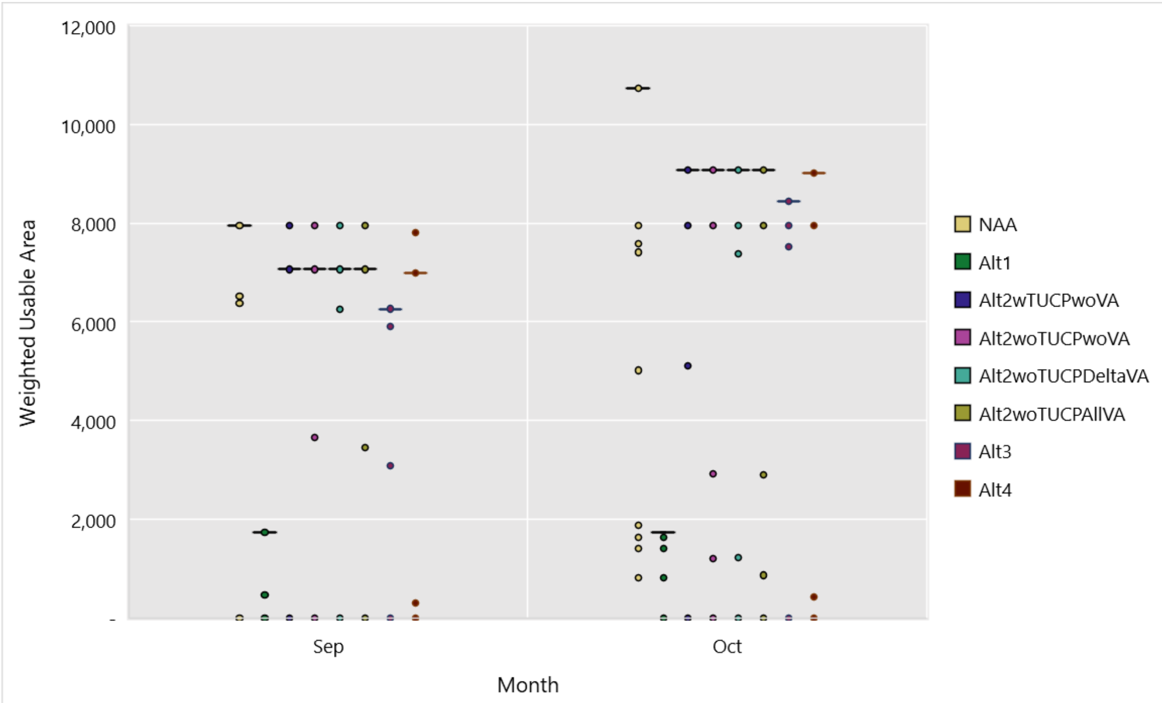

Figure O.1-11. Expected WUA for Spring-run Chinook Salmon Spawning in Clear Creek for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

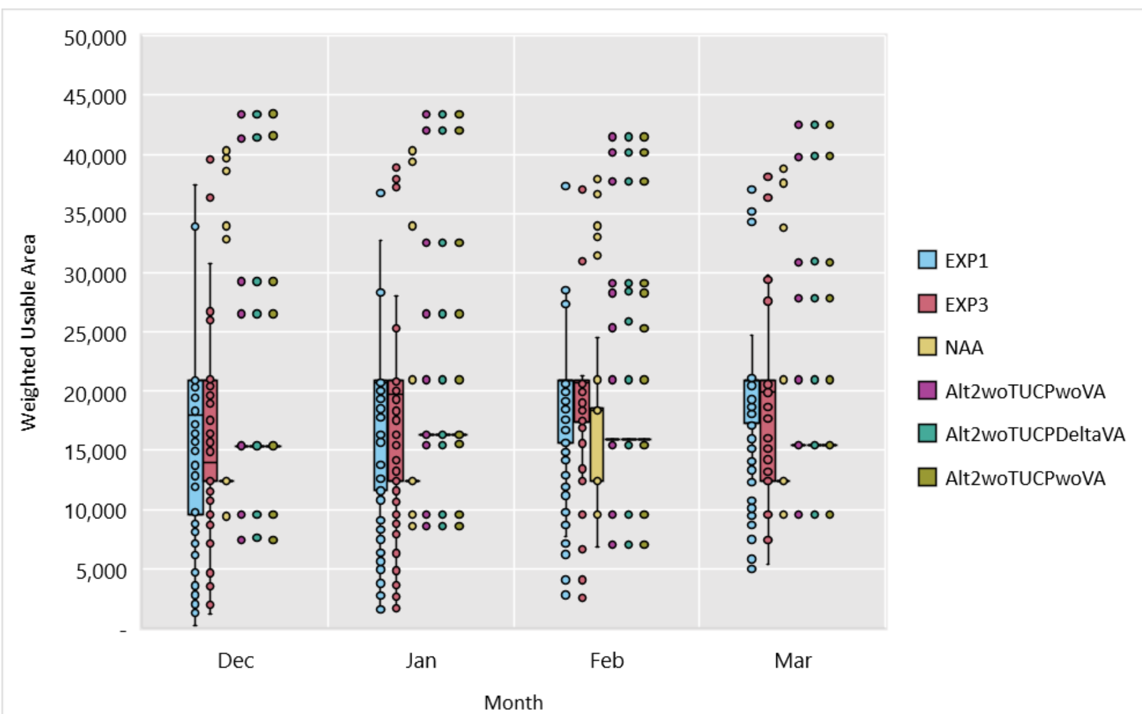

Figure O.1-12. Expected WUA for Steelhead Spawning in Clear Creek for EXP1, EXP3, NAA, and three Alternative 2 components by Month

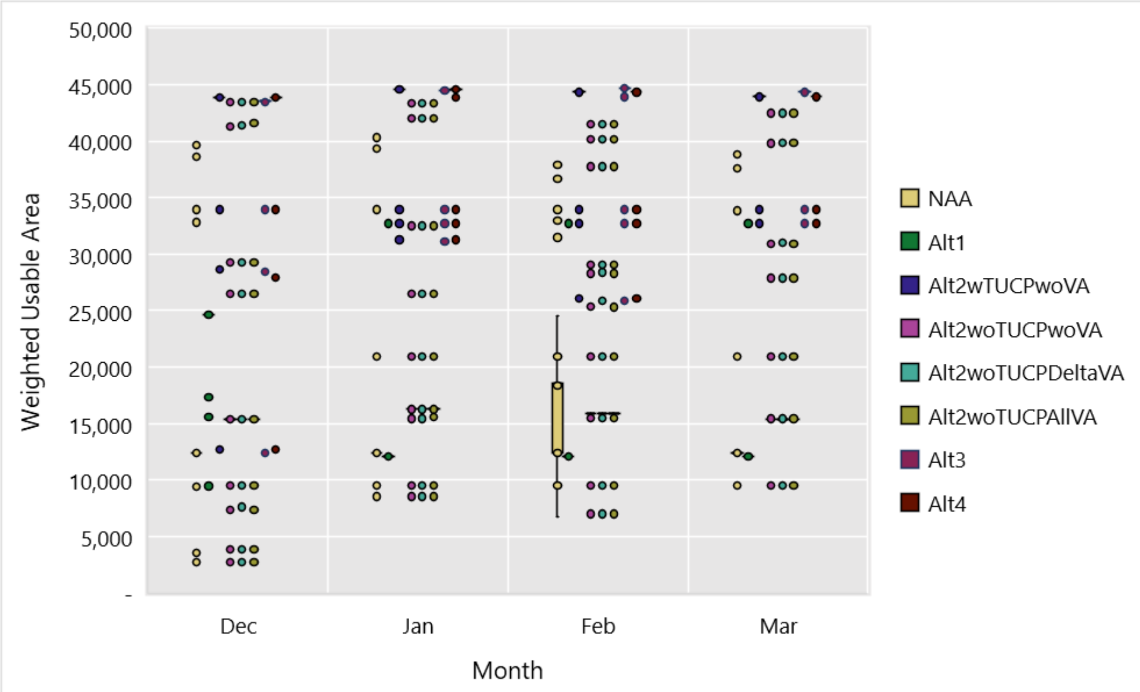

Figure O.1-13. Expected WUA for Steelhead Spawning in Clear Creek for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

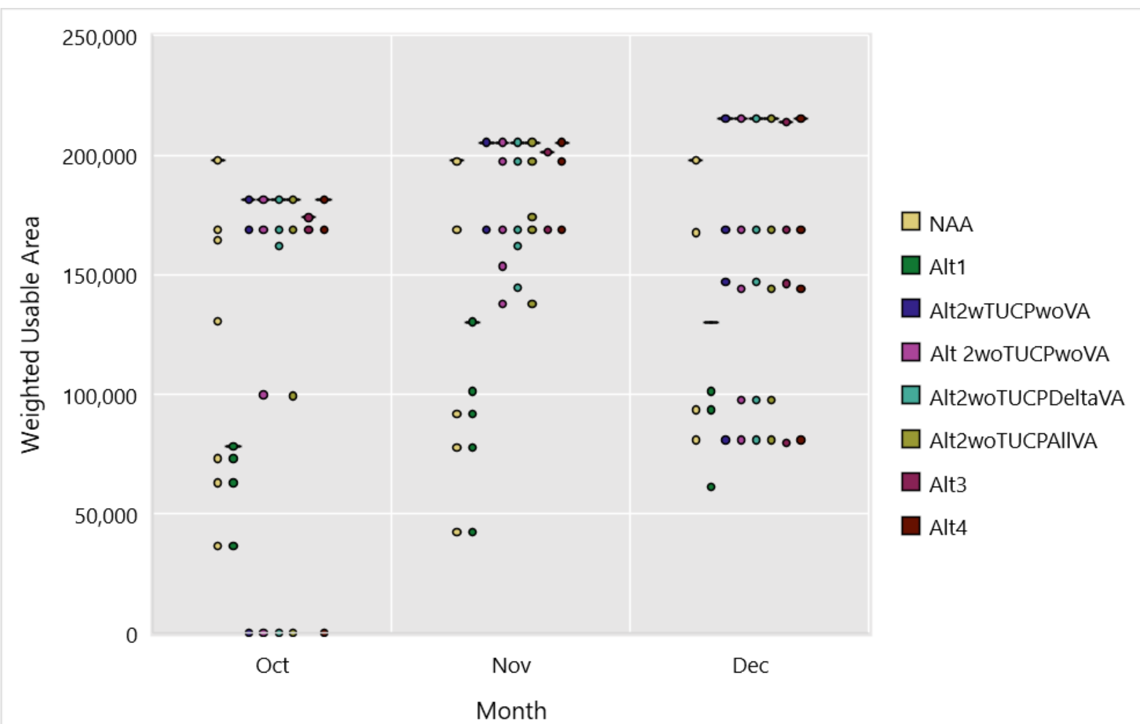

Figure O.1-14. Expected WUA for Fall-run Chinook Salmon Spawning in Clear Creek for the Baseline Scenario, NAA, and Seven Management Alternatives by Month

Table O.1-8. Expected WUA for Spring-run Chinook Fry Rearing in Clear Creek for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	37,137	36,563	28,124	29,753	29,752	29,752
AN	36,206	35,427	27,538	29,108	29,108	29,108
BN	29,095	29,311	26,952	28,818	28,803	28,806
Dry	29,007	28,571	26,737	28,809	28,809	28,809
Critical	22,551	24,348	25,418	26,920	26,918	26,915
All	31,274	31,226	27,065	28,814	28,811	28,811

Table O.1-9. Expected WUA for Spring-run Chinook Fry Rearing in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	28,124	25,959	29,758	29,753	29,752	29,752	29,716	29,838
AN	27,538	25,346	29,108	29,108	29,108	29,108	29,090	29,208
BN	26,952	24,942	28,880	28,818	28,803	28,806	28,842	28,971
D	26,737	25,347	28,809	28,809	28,809	28,809	28,764	28,874
C	25,418	24,500	26,928	26,920	26,918	26,915	27,116	27,007
All	27,065	25,310	28,828	28,814	28,811	28,811	28,827	28,910

Table O.1-10 Expected WUA for Spring-run Chinook Juvenile Rearing in Clear Creek for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	38,630	42,247	34,937	34,430	34,430	34,430
AN	38,497	40,849	34,797	34,325	34,325	34,325
BN	32,507	34,810	34,797	34,325	34,325	34,325
Dry	30,253	32,266	34,561	33,884	33,884	33,884
Critical	26,294	25,935	30,780	29,416	29,583	29,668
All	33,525	35,707	34,137	33,463	33,490	33,503

Table O.1-11. Expected WUA for Spring-run Chinook Juvenile Rearing in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	34,937	15,380	34,430	34,430	34,430	34,430	34,806	34,516
AN	34,797	15,121	34,325	34,325	34,325	34,325	34,706	34,412
BN	34,797	15,121	34,325	34,325	34,325	34,325	34,706	34,412
D	34,561	15,121	33,884	33,884	33,884	33,884	34,230	33,962
C	30,780	14,885	29,554	29,416	29,583	29,668	29,165	29,633
All	34,137	15,156	33,485	33,463	33,490	33,503	33,733	33,568

Table O.1-12. Expected WUA for Steelhead Fry Rearing in Clear Creek for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three Alt 2 Management Scenarios.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
Wet	20,616	20,299	17,799	17,708	17,708	17,708
AN	20,591	20,006	17,685	17,599	17,599	17,599
BN	18,827	17,996	17,619	17,599	17,599	17,599
Dry	18,681	18,193	17,437	17,564	17,564	17,564
Critical	17,239	16,917	17,353	17,267	17,275	17,275
All	19,286	18,797	17,592	17,568	17,569	17,569

Table O.1-13. Expected WUA for Steelhead Fry Rearing in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	17,799	18,788	17,708	17,708	17,708	17,708	17,794	17,822
AN	17,685	18,696	17,599	17,599	17,599	17,599	17,689	17,717
BN	17,619	18,696	17,599	17,599	17,599	17,599	17,689	17,717
D	17,437	18,696	17,564	17,564	17,564	17,564	17,639	17,665
C	17,353	18,696	17,240	17,267	17,275	17,275	17,382	17,325
All	17,592	18,722	17,563	17,568	17,569	17,569	17,657	17,671

Table O.1-14. Expected WUA for Steelhead Juvenile Rearing in Clear Creek for the Three Baseline Scenarios EXP1, EXP3, the NAA, and Three Alt 2 Management Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	27,589	36,405	33,925	31,784	31,781	31,781	Wet	27,589
AN	25,911	35,065	33,310	31,466	31,466	31,466	AN	25,911
BN	18,178	29,015	32,859	30,476	30,340	30,314	BN	18,178
Dry	17,090	25,273	33,710	31,520	31,520	31,520	Dry	17,090
Critical	14,319	20,703	29,924	27,203	27,257	27,277	Critical	14,319
All	21,017	29,703	32,955	30,708	30,691	30,690	All	21,017

Table O.1-15. Expected WUA for Steelhead Juvenile Rearing in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	33,925	17,329	31,792	31,784	31,781	31,781	31,247	31,609
AN	33,310	17,092	31,466	31,466	31,466	31,466	30,961	31,302
BN	32,859	16,682	31,064	30,476	30,340	30,314	30,346	30,736
D	33,710	17,267	31,520	31,520	31,520	31,520	31,009	31,355
C	29,924	15,632	27,695	27,203	27,257	27,277	27,347	27,717
All	32,955	16,893	30,894	30,708	30,691	30,690	30,363	30,725

Table O.1-16. Expected WUA for Fall-run Chinook Fry Rearing in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	38,399	44,136	37,731	37,731	37,731	37,731	37,604	37,731
AN	38,724	44,681	38,052	38,052	38,052	38,052	37,920	38,052
BN	38,798	44,681	38,026	38,030	38,030	38,029	37,894	38,030
D	39,323	44,681	38,409	38,409	38,409	38,409	38,299	38,409
C	40,349	44,680	39,855	39,855	39,855	39,855	39,832	39,855
All	39,050	44,528	38,332	38,332	38,332	38,332	38,224	38,332

Table O.1-17. Expected WUA for Fall-run Chinook Juvenile Rearing in Clear Creek Confluence for the EIS Modeled Baseline Scenario, NAA, and Alternatives Alt 1, Alt 3, Alt 4 and Four Alt 2 Scenarios.

WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	25,782	18,743	24,900	24,900	24,900	24,900	24,755	24,900
AN	25,782	18,743	24,900	24,900	24,900	24,900	24,755	24,900
BN	25,507	18,535	24,900	24,366	24,366	24,366	24,755	24,633
D	25,782	18,743	24,900	24,900	24,900	24,900	24,755	24,900
C	24,511	17,753	22,302	21,731	22,070	22,038	22,991	22,452
All	25,529	18,547	24,484	24,297	24,351	24,346	24,473	24,460

O.1.4 References

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

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

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

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

Jennings, E. D. and A. N. Hendrix. 2020. Spawn Timing of Winter-Run Chinook Salmon in the Upper Sacramento River. *San Francisco Estuary and Watershed Science*, 18(2). https://escholarship.org/uc/item/00c1r2mz

Li, J., H. Qin, S. Pei, L. Yao, W. Wen, L. Yi, J. Zhou, and L. Tang. 2019. Analysis of an Ecological Flow Regime during the *Ctenopharyngodon idella* Spawning Period Based on Reservoir Operations. *Water* 2019, 11(10), 2034; https://doi.org/10.3390/w11102034.

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

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

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

Petts, G. E. 2009. Instream Flow Science for Sustainable River Management. *Journal of the American Water Resources Association* 45:1071-1086.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. *Bioscience* 47:769-784.

Quinn, T. 2005. *The Behavioral Ecology of Pacific Salmon & Trout. American Fisheries Society*, Bethesda, MD. 378 pp.

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

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

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

Sullivan. R. M. and J. P. Hileman. 2019. Effects of Managed Flows on Chinook Salmon (Oncorhynchus tshawytscha) in Relation to Run-Timing, Fertility, and Fluctuations in Water Temperature and Flow Volume. *California Fish and Game* 105(3):132-176.

U.S. Fish and Wildlife Service. 2007. *Flow-Habitat Relationships for Spring-run Chinook Salmon and Steelhead/Rainbow Trout Spawning in Clear Creek between Whiskeytown Dam and Clear Creek Road.* August 15, 2007. Sacramento, CA.

U.S. Fish and Wildlife Service. 2011a. *Flow-Habitat Relationships for Fall-run Chinook Salmon and Steelhead/Rainbow Trout Spawning in Clear Creek between Clear Creek Road and the Sacramento River.* January 21, 2011. Sacramento, CA.

U.S. Fish and Wildlife Service. 2011b. *Flow-Habitat Relationships for Juvenile Spring-run Chinook Salmon and Steelhead/Rainbow Trout Rearing in Clear Creek between Whiskeytown Dam and Clear Creek Road.* September 26, 2011. Sacramento, CA.

U.S. Fish and Wildlife Service. 2013. *Flow-Habitat Relationships for Juvenile Spring-run and Fall-run Chinook Salmon and Steelhead/Rainbow Trout Rearing in Clear Creek between Clear Creek Road and the Sacramento River.* January 11, 2013. Sacramento, CA.

U.S. Fish and Wildlife Service. 2015. *Clear Creek Habitat Synthesis Report.* January 9, 2015. Sacramento, CA.