FINAL REPORT ◦ APRIL 2013

Lower Tuolumne River Instream Flow Study

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Cover photo: Tuolumne River upstream of Basso Bridge, summer 2011, 600 cfs.

Table of Contents

Tables

Figures

Appendices

Acknowledgements

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1 INTRODUCTION

1.1 Project Description

Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt Don Pedro Project (FERC Project No. 2299) located at river mile (RM) 54.8 of the Tuolumne River in western Tuolumne County, in the Central Valley region of California.

Project facilities include Don Pedro Reservoir (2.03 million acre-feet capacity at normal maximum elevation of 830 feet), 580-foot-high Don Pedro Dam (completed in 1971), a four-unit powerhouse situated at the base of the dam, and related facilities. Downstream of the Don Pedro Project, at approximately RM 51.7, La Grange Dam diverts water into canals to the north and south that supply Modesto Irrigation District and Turlock Irrigation District, respectively.

Downstream of La Grange Dam, the lower Tuolumne River runs approximately 52 miles to its confluence with the San Joaquin River. Dry Creek, at RM 16, is the largest tributary to the lower Tuolumne River. All tributary inflows are highly seasonal, and none of them provide significant flow to the Tuolumne River on a year-round basis.

1.2 Background and Purpose

Pursuant to the Federal Energy Regulatory Commission (FERC or Commission) Order of July 16, 2009 (128 FERC ¶ 61,035), the Districts were required, in consultation with fishery resource agencies, to develop and implement an Instream Flow Incremental Methodology (IFIM) study. The Tuolumne River Instream Flow Studies Study Plan (Study Plan) (Stillwater Sciences 2009), including the development of an IFIM study, was filed with the Commission on October 14, 2009. The Study Plan was approved, pursuant to Ordering paragraphs (A) through (E) of the Commission's May 12, 2010 Order. A revised implementation schedule was approved under the July 21, 2010 FERC Order and a follow-up study extension request to file the Instream Flow Study Report on April 29, 2013 was approved under the December 5, 2011 FERC Order (FERC 2011).

Separate from the IFIM study component of the Study Plan, a Pulse Flow Study Report was submitted on June 18, 2012 (TID/MID 2012).

The purpose of the IFIM study under the July 16, 2009 Order (128 FERC ¶ 61,035) is "to determine instream flows necessary to maximize fall-run Chinook salmon *(Oncorhynchus tshawytscha)* and *O. mykiss* production and survival throughout their various life stages." This IFIM Study Report has been prepared both in fulfillment of Ordering Paragraph (D) of the May 12, 2010 Order modifying and approving Instream Flow and Water Temperature Model Study Plans, and in accordance with the revised implementation schedule approved by the December 5, 2011 Order, and provides detailed methods and results for the study (FERC 2011).

Two prior physical habitat simulation (PHABSIM) studies of the lower Tuolumne River have been conducted for the Don Pedro Project as part of the approved FERC Fisheries Study Plan. A 1981 study by the California Department of Fish and Game (CDFG) (now California Department of Fish and Wildlife [CDFW]) (TID/MID 1992a) was focused within a nine-mile reach (RM 50.5–42.0) extending from near the town of La Grange to near Turlock Lake State Recreation

Area. A reanalysis of the 1981 CDFG data was also completed by EA Engineering, Science, and Technology (EA) in 1991 on behalf of the Districts (TID/MID 1992b). Selected elements of the CDFG study are summarized in Table 1 below.

In 1992, the second PHABSIM study was conducted by the U.S. Fish and Wildlife Service (USFWS) (USFWS 1995), which is also briefly summarized in Table 1. The USFWS study reaches included the entire lower Tuolumne River from La Grange Dam (RM 52.2) downstream to the confluence with the San Joaquin River (RM 0.0), although the most extensive field efforts were focused in riffle and run habitats in the 21-mile reach upstream of Waterford (RM 31) that is most heavily utilized for spawning by salmonid species. Using the results of the USFWS study, the Districts previously responded to an August 2003 information request from FERC staff to develop a flow vs. habitat evaluation that incorporated water temperature effects on Weighted Usable Area (WUA) (Stillwater Sciences 2003).

Table 1. Selected instream flow model details for studies on the lower Tuolumne River in 1981 and 1992.

Study	Upper RM	Lower RM	Total transects	Calibration flows (approx. cfs)			Simulation range (cfs)
				Low	Mid	High	
CDFG reanalysis (TID/MID 1992b)	50.5	42.0	19	120	260	410	20–600
USFWS (1995)	52.2	0.0	25 (23 used)	250	600	1,050	25–1,200

Both prior studies included simulations for various life stages of *O. mykiss* and Chinook salmon. In addition to the previous IFIM studies and evaluations, the Districts have also produced flow-related reports on flow fluctuation and juvenile salmonid stranding analyses at flows up to 8,400 cfs (TID/MID 1992c and 1992d; TID/MID 2001, Report 2000-6; TID/MID 2005, Appendix E), as well as geographic information system (GIS) based mapping of overbank inundation surfaces at several flows within this range (TID/MID 2005, Appendix F). Additionally, as part of the Lower Tuolumne River Instream Flow Studies, a 2D assessment of temporarily inundated portions of Tuolumne River overbank areas was completed in 2012 (TID/MID 2012).

The current study described below is an independent, standalone investigation that is not dependent on data from the previous IFIM studies, although some prior data are presented for comparison purposes. The habitat results presented herein are a single, albeit important, consideration in the overall production of Chinook salmon and *O. mykiss* in the Tuolumne River. In addition to these results, information on geomorphic processes, water temperature, population dynamics, spawning area, and a variety of other factors are being considered in the evaluation of fish and flow management options for the lower Tuolumne River.

1.3 Study Plan Implementation and Agency Consultation

In accordance with Ordering Paragraph (D) of the May 12, 2010 FERC Order and as modified by Ordering Paragraph (A) of the July 21, 2010 FERC Order, the Districts developed the Study Plan and implemented the IFIM study through consultation with the National Marine Fisheries Service (NMFS), USFWS, and CDFW. As specified in the July 21, 2010 Order, the Districts held a series of workshops and meetings covering initial study planning, habitat typing, site selection and transect placement, habitat suitability criteria (HSC) development, and model calibration. Workshop summaries are provided in Appendices A through F.

An initial IFIM study progress report was filed with the Commission on December 10, 2010, detailing initial agency consultation activities and key decisions. A second progress report was filed on July 29, 2011 summarizing work performed by the Districts to implement the final study plan; it also requested a flow variance or study extension to address constraints created by high runoff conditions extending throughout water year 2011. A study extension was granted by FERC on December 5, 2011.

Pursuant to the requirements of the FERC Order, the Lower Tuolumne River Instream Flow Study Draft Report was circulated for a 30-day review period (February 28, 2013 – April 1, 2013) to the resource agencies, non-government organizations, and other interested parties. Following the 30-day review period, the USFWS provided comments on April 8, 2013, which have been addressed in this final report (Appendix K).

1.4 Relationship to Relicensing

Since initiation of the instream flow study, the Districts have started the relicensing process for the Don Pedro Project. A variety of studies are being conducted as part of relicensing, some of which are related to, or expecting to use, results of the ongoing instream flow study. Relicensing is a separate process (with a different schedule) from the FERC Order for the instream flow study, but it is the Districts' intent to integrate the instream flow study results (as they become available) into all relicensing studies and analyses where they are useful. An in-progress draft of this report was filed with FERC on January 17, 2013 as part of the Districts' Initial Study Report for relicensing of the Don Pedro Project (TID/MID 2013a). Subsequent to filing of this final report per the revised implementation schedule in the December 5, 2011 FERC Order, two additional tasks will be completed to address updated information being developed as part of the ongoing relicensing process for the Don Pedro Project (FERC No. 2299-075):

1. An evaluation of effective weighted usable area of affected salmonid life stages, which requires finalization of the current Lower Tuolumne River water temperature model (Study W&AR-16) being developed as part of relicensing. Completion of this analysis is anticipated by September 30, 2013.
2. Additional weighted usable area versus flow analyses for Sacramento splittail and Pacific lamprey, per FERC's December 22, 2011 relicensing Study Plan Determination letter and the habitat suitability criteria provided by the USFWS on April 8, 2013. The results of this analysis are expected to be available by July 30, 2013.

Any comments on the supplemental analyses identified above will be addressed in the Draft License Application.

2 METHODS

The instream flow assessment methodology (Bovee 1982) described below applies a mesohabitat and transect-based approach (commonly referred to as the 1-D method) for implementing the PHABSIM component of the USFWS Instream Flow Incremental Methodology to address flow-habitat relationships in the lower Tuolumne River. For this study, the RHABSIM (riverine habitat simulation) version of the model (Payne 1998) was applied using a one-flow velocity calibration approach, where transect and cell-specific data were derived from field survey data. The model calculates a habitat index that reflects the WUA based on simulation of river depths and velocities from the 1-D hydraulic models. Cross sections (transects) are used to represent the river, and habitat suitability criteria are applied which define the physical and hydraulic characteristics considered suitable for particular species and life stages of interest.

2.1 Habitat Mapping

In order to support appropriate reach segmentation and habitat representation of the lower Tuolumne River, habitat mapping data down to RM 29.0 below the City of Waterford were utilized to determine habitat composition and distribution (Figure 1). Mesohabitat delineation followed a geomorphic-based habitat mapping system (requested by the USFWS in their letter of October 5, 2009 [USFWS 2009]) using eight mesohabitat types: bar complex glides, bar complex pools, bar complex riffles, bar complex runs, flatwater glides, flatwater pools, flatwater riffles, and flatwater runs (Snider et al. 1992). Side channel habitat was originally proposed as a separate channel form (e.g., bar complex, flatwater), resulting in 12 potential habitat types; however, side channel was subsequently included as a separate feature during the study planning workshop and was mapped separately during field surveys to determine the total representation for transect selection purposes. The mesohabitat types selected by consensus[1] of the workgroup are described in Table 2. The study planning process was documented in the study planning workshop notes, included as Appendix A.

Habitat mapping was conducted from boats by teams of two individuals using low-elevation aerial photos of the river to delineate mesohabitat unit breaks. Mesohabitat units were numbered consecutively extending from the La Grange gage (RM 51.7) downstream to the existing rotary screw trap (RST) location near the City of Waterford (RM 29.0). Digital reference points at the upstream and downstream boundaries were recorded during the habitat mapping field survey. Distinct habitat units were defined when the unit length was at least equal to the active channel width or if the unit was otherwise distinctive. Additional habitat attributes described in Table 3 were recorded during the field survey. The relative abundance (i.e., frequency), percent composition, and total length of the mesohabitat units were calculated for use in PHABSIM modeling.

The percent composition of mesohabitat types in the study area are documented in Table 4 (La Grange gage at RM 51.7 to downstream of Waterford at RM 29).

[1] For purposes of this study, "consensus" is defined as the concurrence of all parties in attendance at the time and place that decisions were made.

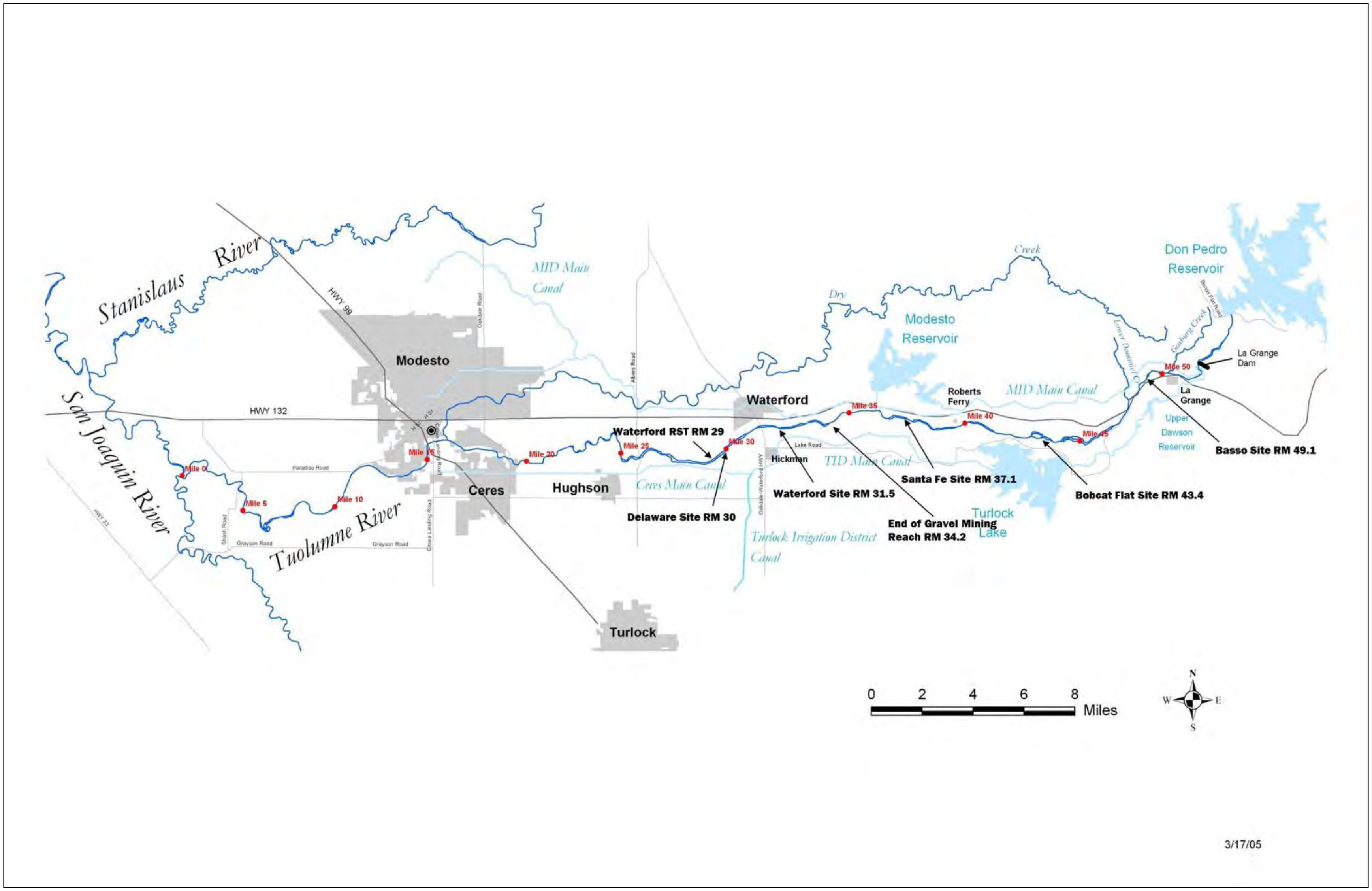

Figure 1. Vicinity map and study site locations for the lower Tuolumne River Instream Flow Study.

Table 2. Mesohabitat types used during instream flow surveys.

Channel form/ Habitat type	Description
Bar Complex	Submerged and emergent bars are the primary feature, sloping cross-sectional channel profile.
Flatwater	Primary channel is uniform, simple and without gravel bars or channel controls, fairly uniform depth across channel.
Pool	Primary determinant is downstream control - thalweg gets deeper going upstream from tail of pool. Fine and uniform substrate, below average water velocity, above average depth, tranquil water surface.
Glide	Primary determinants are no turbulence (surface smooth, slow and laminar) and no downstream control. Low gradient, substrate uniform across channel width and composed of small gravel and/or sand/silt, depth below average and similar across channel width (but depth not similar across channel width for Bar Complex Glide), below average water velocities, generally associated with tails of pools or heads of riffles, width of channel tends to spread out, thalweg has relatively uniform slope going downstream.
Run	Primary determinants are moderate turbulence and average depth. Moderate gradient, substrate a mix of particle sizes and composed of small cobble and gravel, with some large cobble and boulders, above average water velocities, usually slight gradient change from top to bottom, generally associated with downstream extent of riffles, thalweg has relatively uniform slope going downstream.
Riffle	Primary determinants are high gradient and turbulence. Below average depth, above average velocity, thalweg has relatively uniform slope going downstream, substrate of uniform size and composed of large gravel and/or cobble, change in gradient noticeable.

Table 3. Mesohabitat attributes assessed during habitat mapping surveys.

Attribute	Description
Stream width	Average wetted width of a unit calculated from GIS by dividing the unit area by unit length.
Stream depth	The maximum estimated depth of each habitat unit categorized into three groups: 1-4 feet deep; 4-10 feet deep, and >10 feet deep.
Channel confinement	Estimated ratio of width of active (wetted) channel to total stream channel (floodplain) width: • Confined – shallow = channel width confined and stream shallow (<4 ft) • Confined – deep = channel width confined and stream deep (>4 ft) • Moderate Confined = total channel width < 2 wetted channel widths • Unconfined = total channel width ≥ 2 wetted channel widths
Pool tail embeddedness	Percent in which gravel or larger substrates are vertically embedded in sand or smaller substrates at the downstream end of pool habitat.
Spawning gravel patch size	Estimates the largest patch of spawnable gravel within one unit (for salmonid species).
Tributary inflow	Estimate of the tributary inflow.

Table 4. Mesohabitat types and percent occurrence in the lower Tuolumne River Study Area from RM 51.7 to RM 29.0

Habitat type	No. of units	Total area (sq ft)	Percent of study reach
Bar Complex Glide	8	304,131	1.89
Bar Complex Pool	18	1,322,592	8.21
Bar Complex Riffle	57	2,259,617	14.04
Bar Complex Run	39	2,829,754	17.58
Flatwater Glide	14	484,716	3.01
Flatwater Pool	19	3,547,725	22.04
Flatwater Riffle	16	781,166	4.85
Flatwater Run	36	4,570,070	28.39
Totals	**207**	**16,099,772**	**100.0%**

2.2 Study Site Selection

Study sites were selected through a collaborative series of workshops with agency and non-governmental organization (NGO) representatives, using a collection of maps, aerial photos, gradient plots, habitat typing data, and other resources. The transect selection team targeted sampling of habitat types with a minimum of 5 percent occurrence, but with a reduced number of replicates/transects for those with less than 10 percent occurrence. The site selection process was documented in workshop notes included as Appendix B. A map of the study site locations is presented in Figure 1.

2.3 Transect Selection and Weighting

Initial habitat units for each site were randomly selected from either (1) key spawning riffles, or (2) other limited habitat unit types (e.g., bar complex spawning riffle), then selecting contiguous habitat units upstream or downstream from that habitat unit until the desired number and type of units for that river section were obtained. Units were typically contiguous unless an intervening unit was (1) not required for sampling and therefore skipped, or (2) exceptionally long and therefore effectively acted as a “boundary” to the local collection of transects.

Transect placement was determined during a field reconnaissance survey of each selected study site with representatives from CDFW and USFWS. Within each study site, transects were placed in each randomly selected habitat unit by professional judgment and on-site concurrence of the transect selection team. Transects were placed to capture the hydraulic variability within the randomly selected unit, while avoiding hydraulic anomalies or other features (e.g., re-circulating, vertical, or multi-directional flow, etc.) that cannot be accurately modeled.

A sufficient number of transects were established to model approximately three replicates of each major habitat unit type in the reach (e.g., runs, riffles, and pools), with the number of replicates dependent on the relative proportions of the major habitat unit types. Agency staff participating in the transect selection concurred on the number and placement of all transects. The transect selection process notes and list of transects are presented in Appendix B, along with documentation of agency concurrence and aerial photos of the transect locations.

For modeling purposes, individual transects were weighted to represent the proportion of their channel length and mesohabitat type (e.g., bar complex or flatwater glide, pool, riffle, and run) in the reach. These proportions were calculated based on habitat unit results from the habitat mapping data. Each habitat type was apportioned its respective length of the entire reach (e.g., bar complex riffles are 17.8% of the reach). Each transect in a habitat type was weighted equally based on the reach representation of the habitat type (e.g., each of 7 bar complex riffle transects would be weighted at 2.54% per transect if bar complex riffles represent 17.8% of the reach). A summary of transect weighting is provided in Table 5.

Table 5. Transect weighting used for lower Tuolumne River PHABSIM model.

Channel form	Mesohabitat type	Total Length (ft)	Total Length (%)	Number of transects	Weight per transect (%)	Weight per mesohabitat (%)
Bar Complex	Glide	2,085	1.73	2	0.86	1.73
Bar Complex	Pool	9,607	7.96	5	1.59	7.96
Bar Complex	Riffle	21,480	17.80	7	2.54	17.80
Bar Complex	Run	24,045	19.93	6	3.32	19.93
Flatwater	Glide	3,895	3.23	3	1.08	3.23
Flatwater	Pool	20,190	16.73	6	2.79	16.73
Flatwater	Riffle	6,660	5.52	2	2.76	5.52
Flatwater	Run	32,700	27.10	9	3.01	27.10
Totals		**120,662**	**100.00**	**40**		**100.00**

2.4 Calibration Flows

Model calibration flows were targeted based on extrapolation limits, log-scale considerations, and flows available during the field measurement surveys. Target calibration flows were selected to be relatively evenly spaced (on a log scale) and allow for simulated in-channel flows over a range of approximately 50–1,200 cfs, such that the lowest simulated flow would be no less than 0.4 of the lowest calibration flow and the highest simulated flow no more than 2.5 times the highest calibration flow. The proposed target calibration flows were as follows:

- low flow calibration: approximately 100 cfs;
- middle flow calibration: 250 cfs; and
- high flow calibration: 600 cfs.

The final calibration flows were reviewed in detail using all available data at each site, and agreed upon by consensus with agency representatives during the PHABSIM model workshop (Appendix C). Table 6 shows the final calibration flows used for this study.

Table 6. Calibration flows for lower Tuolumne River PHABSIM model.

Reach (site)	River Mile (approx.)	Calibration Flow (cfs)		
		Low	Medium	High
Basso	49.1	103	276	677
Bobcat Flat	43.4	99	282	682
Santa Fe	37.1	123	319	699
Waterford	31.5	120	308	710
Delaware	30.0	138	306	705

2.5 Hydraulic Data Collection

Hydraulic data collection and recording used standard procedures and guidelines for PHABSIM field studies (Trihey and Wegner 1981; Milhous et al. 1984; Bovee 1997). Independent elevation reference benchmarks were established for level control, as well as semi-permanent headpins and tailpins at each transect.

The local benchmarks established for each transect served as the reference elevations to which all elevations (streambed and water surface) were tied. The benchmarks were established at locations that will not change elevation over time, such as lag bolts driven into trees, painted bedrock points, or local infrastructure. Benchmark elevations were tied together for all sites, for efficient analysis, graphing, and QA/QC procedures.

Channel cross section profiles above the highest measured calibration flow were surveyed (to the nearest 0.1 foot) with a stadia rod and Topcon AT-G3 auto-level or total station to establish the overbank channel profile up to or beyond the water's edge at the highest flow to be modeled, with sufficiently close spacing of verticals to document changes in slope. In-channel profiles were calculated by subtracting the depth of water measured during the velocity measurements from the average water surface elevations (WSE). Additional topographic data collection for each transect included stage-of-zero-flow (SZF) elevation, which is the controlling elevation within or downstream of the transect line below which flow ceases.

Water surface elevations (i.e., stage) were measured using an auto-level and stadia rod along each transect at each calibration flow; WSE was typically measured near each bank (to the nearest 0.01 foot), and in mid-channel areas where a significant difference between the near-bank WSE existed. A level loop survey tied to the local benchmark was conducted at each calibration flow to ensure the accuracy of each survey. Benchmark and transect locations were recorded with a GPS, where feasible.

Temporary and permanent staff gage readings and time-of-day were recorded at the beginning and end of each transect measurement to check that the stage had not changed appreciably during the transect measurement, nor the calibration flow measurement for the entire study site.

Depths and mean column water velocities were measured across each transect at the middle calibration flow. The number of cells sampled for depth and velocity was based on a goal of retaining a minimum of 20–25 stations that would remain in-water at the low calibration flow. Discharge measurements were collected at each calibration flow following techniques outlined in Rantz (1982). These techniques include:

- cross section lies within a straight reach and streamlines are parallel to each other;
- velocities are greater than 0.5 ft/s and depths are greater than 0.5 ft;
- streambed is relatively uniform and free of numerous boulders and heavy aquatic growth; and
- flow is relatively uniform and free of eddies, slack water, and excessive turbulence.

Discharge measurements were made at each grouping of transects in hydrologically distinct areas, using either an existing habitat transect (if deemed suitable) or at some other suitable transect established solely for measuring discharge. These discharge measurements were used in conjunction with data from the La Grange gaging station (USGS No. 11289650) to determine more precisely the calibration flow and account for accretion, if any, within the study reach.

At transects that could be crossed by wading, velocities were measured using a Marsh-McBirney Flowmate 2000 flow meter and standard U.S. Geological Service (USGS) topset wading rod. Velocities were measured at six-tenths of the depth (0.6 depth) when depths were less than 2.5 feet, and at two-tenths (0.2 depth) and eight-tenths (0.8 depth) of the depth when depths were equal to or exceeded 2.5 feet, or when the expected velocity profile was altered by an obstruction immediately upstream. In instances of increased turbulence or obstructions, measurements were taken at all three depths (0.2, 0.6, and 0.8) and a weighted average calculated (Bovee and Milhous 1978). For transects where wading was not possible, a Teledyne RD Instruments Workhorse Rio Grande 1,200 kHz Acoustic Doppler Current Profiler (ADCP) with Ohmex Sonarmite depth sounder and Trimble R8 GNSS antenna mounted to a tethered OceanScience Riverboat was used to collect both velocity and channel bed elevation data. The ADCP was operated from a shore-based laptop through a wireless modem connection.

The ADCP transmits a series of short acoustic pulses and measures the change in frequency of acoustic energy reflected back (backscatter) from particles suspended in the water column. The ADCP software determines water velocity based on the principles of the Doppler effect, and water depth from pulse time delay of the reflected backscatter data. The ADCP depth and velocity data is resolved at a high frequency, approximately 1 ensemble or data point per second. An ensemble is analogous to a width cell or station in a traditional point-velocity discharge measurement, and represents a column of water along a measurement transect. The width of an ensemble is a function of the ADCP sampling rate and cross-stream ADCP velocity. One ensemble is divided into a number of discrete depth cells or bins whose depth range is set by the ADCP operator. Following the same assumptions as a traditional point-velocity discharge measurement, the ADCP discharge is computed as the product of cross-sectional area and mean water velocity perpendicular to cross-sectional area for each depth bin (Mueller and Wagner 2009). Total discharge is the sum of measured discharge, plus estimates of four unmeasured portions of each transect. The unmeasured portions of each transect are: top zone - instrument draft depth plus blanking distance at face of ADCP transducers, bottom zone of potential side lobe interference, and shallow areas at the start and end of transect. Velocity profile data was measured in the shallow unmeasured zones for each ADCP transect with the topset wading rod and flow meter.

Mean water column velocity and direction for each ensemble in an ADCP velocity calibration transect was exported from the ADCP software into GIS for processing. Due to the relatively high ADCP sampling frequency, the number of ensembles or stations across an ADCP velocity transect is much greater than a traditional point-velocity measurement. For purposes of providing input to the RHABSIM model, arbitrary stations were established at 2–3 foot intervals across transects and the mean water column velocity at each station was used.

Hydraulic field data were collected on the following dates:

- High Flows: July 26-29, 2011;
- Mid Flows: September 24-27, 2011; and
- Low Flows: June 25-29, 2012.

2.6 Substrate and Cover Data

Substrate data collection used a modified Wentworth Scale, with small cobble divided into two groups (3-4.5 in. and 4.5-6 in.), as agreed by the collaborative work group. The substrate scale is presented in Table 7.

Table 7. Modified Wentworth substrate scale used in the lower Tuolumne River PHABSIM model.

Description	Size (inches)
Organic	N/A
Silt	<0.1
Sand	0.1–0.2
Small Gravel	0.2–1.0
Medium Gravel	1–2
Large Gravel	2–3
Very Small Cobble	3–4.5
Small Cobble	4.5–6
Medium Cobble	6–9
Large Cobble	9–12
Boulder	>12
Bedrock	N/A

Fish cover recorded in the field included nine types, which were then collapsed into four categories for modeling purposes (in order to increase sample size and provide more meaningful results), as presented in Table 8. Cover was recorded in the field as a percent of area for each cover type, where the sum of all cover types present could sum to over 100 percent, as some areas may have overlapping types. For example, an evaluation area may have 100 percent turbulence cover with 50 percent overhead vegetation, and submerged large woody debris. The only restriction in assigning percentages is that no single cover type percentage can exceed 100 minus the area containing no cover. For example, if 60 percent of the evaluation area contained no cover, no individual type could exceed 40 percent.

Table 8. Fish cover types collected and used in the lower Tuolumne River PHABSIM model.

Cover Type	Category
No available cover	None
Cobble	Object Cover
Boulder	
Fine woody debris	
Large woody debris	
Overhanging vegetation	Overhead cover
Aquatic vegetation	
Undercut bank	
Rootwad	
Water surface turbulence (having entrained air)	
A combination of both overhead cover and object cover	Both

The four cover categories used in the model (object cover, overhead cover, both, or none) were based on presence/absence of the cover type. Cover presence/absence was evaluated in an area within 2 feet radius of a fish focal point, or within the PHABSIM transect cell (discussed in Section 2.5, *Hydraulic Data Collection*). The cover and substrate coding specifications were collaboratively developed with technical workgroup participants, and the process documented in workshop notes included as Appendix A.

2.7 Hydraulic Model Calibration

2.7.1 Stage and velocity calibration

Hydraulic data were calibrated using the HYDSIM module of RHABSIM v3.0 (Payne 1998). Stage-discharge relationships were developed from measured discharge and stage using both an empirical log/log formula (IFG4) and the Manning's channel conveyance procedure (MANSQ). Using either method, each transect is modeled independently of other transects. Based on review and consensus by agency participants, the most appropriate and accurate method was selected on a transect-by-transect basis (Appendix C).

The IFG4 method requires a minimum of three sets of stage-discharge measurements and an estimate of SZF for each transect. The SZF estimates were based on either the measured thalweg depth across a transect, or the measured thalweg depth of a downstream hydraulic control. The MANSQ procedure requires only a single stage-discharge measurement along with a SZF and uses a power function of the ratio of simulated discharge to observed discharge. The quality of the stage-discharge relationships was evaluated by examination of mean error and slope equation from the IFG4 results and the beta coefficient values from MANSQ. Using either method, mean errors should be less than 10%, with predicted water surface elevations within 0.1 feet of measured elevations. The MANSQ beta values should range between 0.0 and 0.5.

The one-flow velocity method, using a single set of velocities collected at the medium calibration flow, was used for all transects for velocity calibration. This technique uses a single set of measured velocities to predict individual cell velocities over a range of flows. Simulated velocities are based on measured data and a relationship between a fixed roughness coefficient (Manning's 'n') and depth. In some cases, roughness is modified for individual cells if substantial velocity errors are noted at the velocity calibration flows. Velocity adjustment factors (VAFs) were examined to detect any significant deviations and determine if cell velocities changed consistently with stage and total discharge.

2.7.2 Calibration metrics

Hydraulic calibration results of water surface elevation and velocity for the lower Tuolumne River model are shown in Table 9. Results show mean errors for all transects at less than 5.25%. The range of beta values for transects using MANSQ calibration was 0.045 to 0.479. Both the mean error and beta value metrics were in acceptable ranges.

Differences between observed and predicted water surface elevations ranged from 0.00 to 0.13 feet and averaged 0.02 feet. The VAF range at the calibration flow after adjustments to specific cell n-values was 0.8052 to 1.1905, with 77.5 percent (31 of 40) transects rated as "Good" and 22.5 percent (9 of 40) rated "Fair."

Table 9. Hydraulic calibration results for the lower Tuolumne River PHABSIM model.

Reach (site)	Transect	Method	Mean error (%)	Beta	Observed-predicted WSE			VAF	Rating
					Low	Mid	High		
Basso	40-24A-FG	Log-Log	5.243		0.02	-0.04	0.03	1.0008	Good
Basso	39-24B-FG	Log-Log	4.156		0.01	-0.03	0.02	0.9870	Good
Basso	38-25A-BR	MANSQ	0.393	0.045	0.00	-0.01	0.00	0.8166	Fair
Basso	37-25B-BR	Log-Log	2.254		0.01	-0.03	0.02	0.9849	Good
Basso	36-26A-BN	Log-Log	1.086		0.00	-0.01	0.01	0.8052	Fair
Basso	35-26B-BN	Log-Log	1.955		0.01	-0.02	0.01	1.0012	Good
Basso	34-28A-FN	Log-Log	1.870		0.01	-0.02	0.01	0.9059	Good
Basso	33-28B-FN	Log-Log	1.554		0.01	-0.02	0.01	0.8373	Fair
Basso	32-29A-FG	Log-Log	1.916		0.01	-0.02	0.01	0.9548	Good
Basso	31-30A-FR	Log-Log	0.766		0.01	-0.02	0.01	0.9309	Good
Basso	30-30B-FR	Log-Log	0.128		0.00	0.00	0.00	0.9474	Good
Bobcat	29-82C-FN	Log-Log	2.760		0.02	-0.05	0.04	0.9141	Good
Bobcat	28-83A-BN	Log-Log	1.410		0.01	-0.02	0.02	0.9521	Good
Bobcat	27-84A-FN	MANSQ	0.222	0.283	0.00	0.00	0.01	1.0146	Good
Bobcat	26-84B-FN	MANSQ	0.190	0.466	0.00	0.00	0.00	1.0080	Good
Bobcat	25-84C-FN	MANSQ	0.307	0.479	0.00	0.00	0.01	0.9530	Good
Bobcat	24-85A-BN	Log-Log	2.276		0.01	-0.03	0.02	0.9908	Good
Bobcat	23-86A-FP	Log-Log	1.841		0.01	-0.02	0.02	0.8091	Fair
Bobcat	22-86B-FP	Log-Log	1.756		0.01	-0.02	0.02	0.8286	Fair
Bobcat	21-86C-FP	Log-Log	2.885		0.01	-0.04	0.03	0.8573	Fair
Santa Fe	20-155A-BP	Log-Log	4.492		0.02	-0.05	0.03	1.0771	Good
Santa Fe	19-155B-BP	Log-Log	3.297		0.01	-0.03	0.02	0.9006	Good
Santa Fe	18-156A-BR	Log-Log	1.171		0.00	-0.01	0.01	0.8140	Fair
Santa Fe	17-156B-BR	MANSQ	1.465	0.283	0.02	-0.04	0.03	1.0021	Good
Santa Fe	16-159A-FN	Log-Log	0.886		0.00	-0.01	0.01	1.0162	Good
Santa Fe	15-159B-FN	Log-Log	2.052		0.01	-0.03	0.02	0.9157	Good
Santa Fe	14-159C-FN	Log-Log	1.994		0.01	-0.03	0.02	0.9753	Good
Santa Fe	13-160A-BR	Log-Log	3.359		0.01	-0.04	0.03	1.0022	Good
Santa Fe	12-160B-BR	Log-Log	3.223		0.01	-0.04	0.03	1.0244	Good
Santa Fe	11-161A-BN	Log-Log	3.833		0.02	-0.05	0.04	0.9371	Good
Santa Fe	10-161B-BN	Log-Log	3.239		0.01	-0.04	0.03	1.0773	Good
Santa Fe	9-162A-BR	MANSQ	4.971	0.085	0.00	-0.13	0.00	0.9864	Good
Santa Fe	8-163A-BP	Log-Log	4.340		0.02	-0.06	0.04	1.1905	Fair
Santa Fe	7-163B-BP	Log-Log	4.737		0.02	-0.06	0.05	0.8362	Fair
Santa Fe	6-163C-BP	Log-Log	4.525		0.02	-0.06	0.05	0.9346	Good
Waterford	5-205A-BG	Log-Log	0.849		0.00	-0.01	0.01	1.0591	Good
Waterford	4-205B-BG	Log-Log	0.980		0.00	-0.01	0.01	0.9443	Good
Delaware	3-225A-FP	Log-Log	1.301		-0.01	0.02	-0.02	1.0165	Good
Delaware	2-225B-FP	Log-Log	0.959		-0.01	0.02	-0.01	0.9041	Good
Delaware	1-225C-FP	Log-Log	2.355		-0.01	0.04	-0.03	1.0440	Good

2.7.3 Agency consultation

Calibration data and model details were reviewed and refined during a technical workshop that was attended by representatives from CDFW. Refinements to the model were made at that time, and are reflected in the calibration results reported above. The agency participants concurred that the model was suitably calibrated for subsequent use in the various analyses; notes from the model calibration workshop are presented in Appendix C.

2.8 Habitat Time Series

A Habitat Time Series (HTS) analysis was conducted to assess how habitat values for each species and life stage vary over time, under different water year type scenarios. Water year types selected for analysis were the five San Joaquin Basin 60-20-20 Index types: Critical, Dry, Below Normal, Above Normal, and Wet, as represented by Water Years 2008-2012 (the most recent years of these index types) and presented in Table 10.

Table 10. San Joaquin Basin 60-20-20 Index, corresponding water year types, and representative water years used for habitat time series analysis in the lower Tuolumne River instream flow study.

San Joaquin Basin 60-20-20 Index[1]	Water Year Type	Representative Water Year
2.06	Critical	2008
2.18	Dry	2012
2.73	Below Normal	2009
3.55	Above Normal	2010
5.59	Wet	2011

[1]In million acre-feet

Daily flow values for the lower Tuolumne River were obtained from the USGS gaging station at La Grange (No. 11289560) and were compiled for all Water Year types. No downstream adjustments for accretion or depletion were applied.[2] The associated WUA values were assigned based on the daily flows using a lookup table of WUA values from the PHABSIM results, interpolated to 5 cfs intervals.

For flows over the WUA extrapolation limit of 1,200 cfs, a variety of methods were considered for estimating WUA:

1) Extrapolating the downward trend of the WUA vs. flow relationship at the same slope that occurs between ~900-1,200 cfs. A drawback of this approach is that downward trends in WUA typically level off at some unknown, minimum level that would not be captured by this approach. In addition, overbank flooding effects would be expected to cause some less predictable inflection in the WUA vs. flow relationship when flows go out-of-channel.
2) Extrapolating upward trends at the same slope that occurs between ~900-1,200 cfs. This technique has a similar drawback to the one above, since upward trends will typically level off at some point and/or eventually descend at higher flows.
3) Do not extrapolate above 1,200 cfs. This method would preclude any estimate of WUA conditions that may exist during much of the spring season, when flows are highest and variability is greatest, and therefore compromise the utility of any HTS analysis.
4) Maintain WUA estimates for flows above 1,200 cfs at the 1,200 cfs level (e.g., "flatline" the WUA value). This approach assumes that in-channel WUA will not get significantly higher (or will get higher, then descend again) or lower (or go lower and rise again or level

[2] Accretion/depletion studies performed by the Districts suggest that flow changes along the study reach (which does not contain major tributaries) are relatively small compared to the scale of most HTS flows and the associated WUA reporting increments, and therefore the HTS results were not adjusted for these changes.

off) than where it was at 1,200 cfs. This is a more conservative approach, but it does have the drawback that all flows above 1,200 cfs will return the same WUA value and a depiction of potential variability at higher flows is lost.

For purposes of this analysis, method 4 was applied, and WUA values were maintained at the 1,200 cfs level (e.g., flatlined).

2.9 Effective Habitat

An "effective" WUA (eWUA) analysis will be conducted after current water temperature model data being developed as part of the relicensing studies become available. The eWUA analysis relates to summertime water temperature suitability for *O. mykiss*, and integrates both micro- and macro-habitat considerations. The results from the current water temperature model (in development) over a range of flows will be combined with the summer WUA results so that areas ("macrohabitats") with unsuitable water temperatures are excluded from the total WUA sum. In other words, if a given reach has 100,000 square feet of suitable habitat (i.e., WUA) based on hydraulic microhabitat conditions at flow 'X', but 30 percent of the reach at flow 'X' is above a critical temperature threshold for the species life stage of interest, the eWUA would be 70,000 square feet. This type of analysis was previously conducted, at a coarser level by Stillwater Sciences (2003), using a combination of the 1992 IFIM evaluation for the lower Tuolumne River (USFWS 1995) and the earlier SNTEMP model results (TID/MID 1992e).

2.10 Habitat Suitability Criteria

Use of the PHABSIM model requires application of HSC to the results of the hydraulic model in order to generate an index of habitat suitability (weighted usable area, or WUA) versus flow. Suitability criteria were developed from both existing published criteria and new site-specific data. The target species and life stages were:

- *O. mykiss:* adult, spawning, fry, and juvenile.
- Fall-run Chinook salmon: spawning, fry, and juvenile.

2.10.1 Existing habitat suitability criteria data

Existing HSC data were compiled for the target species and life stages, in collaboration with resource agencies and other interested parties, to create a database of curves that could be reviewed for applicability to the current study. Habitat suitability criteria from prior lower Tuolumne River studies (Tables 11 and 12) were included in the HSC database for consideration. The database of curves was reviewed in consultation with workgroup participants, and screening criteria applied as necessary to minimize the number of curves for further consideration. Screening criteria included the following, although no single criterion was used to qualify or disqualify a curve from further consideration.

- Minimum of 150 observations
- Clear identification of fish size classes
- Depth and velocity HSC
- Category II or III data (Bovee 1986)
- Comparable stream size and morphology (e.g., hydrology, stream width and depth, gradient, geomorphology, etc.)
- Source data from the lower Tuolumne River (or other Central Valley streams)

- Habitat availability data collected
- Data collected at high enough flow that depths and velocities are not biased by flow availability
- Availability of presence/absence data

Table 11. Habitat suitability criteria summary 1981 CDFG IFIM study (TID/MID 1992b).

Species	Life stage	Depth	Velocity	Substrate	Source [1]
Chinook	Spawning	Yes	Yes	Yes	CDFG site-specific[2]
Chinook	Fry	Yes	Yes	All suitable	USFWS (1985)
Chinook	Juvenile	Yes	Yes	All suitable	USFWS (1985)
Rainbow	Adult	Yes	Yes	Yes	Raleigh et al. (1984)
Rainbow	Juvenile	Yes	Yes	Yes	Raleigh et al. (1984)

[1] 1981 CDFG suitability criteria used are from the reanalysis performed in 1991 (TID/MID 1992b).
[2] Spawning depth criteria were modified for reanalysis in 1991 (TID/MID 1992b).

Table 12. Habitat suitability criteria summary from USFWS (1995) IFIM study.

Species	Life stage	Depth	Velocity	Substrate	Source
Chinook	Spawning	Yes	Yes	Combined Substrate / Embeddedness Code	CDFG site-specific[1]
Chinook	Fry	Yes	Yes	All suitable	USFWS (1988) site-specific (Tuolumne River)
Chinook	Juvenile	Yes	Yes	All suitable	USFWS (1990) site-specific (Stanislaus River 1989)
Rainbow	Adult	Yes	Yes	Combined Substrate / Embeddedness Code	Bovee (1978)
Rainbow	Juvenile	Yes	Yes	Combined Substrate / Embeddedness Code	Bovee (1978)

[1] Same criteria as used in the 1991 reanalysis of the 1981 CDFG IFIM study (TID/MID 1992b).

During a series of workshops with interested parties, applicable HSC curves were reviewed and discussed, and existing curves were selected and/or modified for use in the current study. Decisions were made for all of the target species and life stages identified, with the exception of Chinook fry depth criteria, and cover criteria. The workgroup decided to apply substrate criteria to spawning life stages only, and recommended cover data be collected during site-specific validation surveys (discussed below). The participants, notes, and results from the workshops are presented in Appendices D through F.

2.10.2 Site-specific habitat suitability criteria

Where existing curves for key species and life stages were considered potentially inadequate by the workshop participants, the Districts initiated efforts to validate existing HSC or develop site-specific HSC. These efforts involved making observations of Chinook salmon fry and juvenile life stages, and *O. mykiss* fry, juvenile, and adult life stages. In order to target the different life stages and to account for variation in habitat use under a variety of conditions, data were collected during multiple survey efforts (February 7-10, March 26-30, May 9-12, and July 11-13, 2012); covering a range of seasons (winter, spring, and summer); and a range of flow conditions (100 cfs, 350 cfs, and 2,000 cfs).

The existing site-specific criteria for Chinook salmon spawning, developed by CDFG (TID/MID 1992a), were found to be sufficient, and the workgroup expected the number of any site-specific observations of spawning *O. mykiss* to be insufficient to produce meaningful results. Therefore, additional site-specific spawning surveys were not conducted for either species.

2.10.2.1 Habitat suitability criteria study site selection

Site-specific HSC surveys were conducted in the lower Tuolumne River from just below La Grange Dam (RM 52) downstream to Waterford (RM 31). Survey locations were selected prior to each effort using a stratified random selection approach, where individual habitat units (based on the habitat mapping delineation described in Section 2.1, *Habitat Mapping*) between La Grange Dam and the city of Waterford were selected using a random number generator in Microsoft Excel, then sorted by habitat type. Randomly selected habitat units were included in the sampling based on equal distribution between the eight mesohabitat types. Additionally, under higher flow conditions, both floodplain and side-channel habitats were included. Individual survey locations, by season, are shown on Figure 2A–2D.

Within each sampled habitat unit, 3–5 10x10 m "cells" were selected using stratified random selection methods and a 10x10 m alpha-numeric grid overlay on the aerial photos (Figure 3). Randomly selected cells were included based on: (1) the likelihood of being within the wetted channel at the current flow; (2) stratified distribution within the head, body, and tail of each habitat unit, where applicable;[3] and (3) distribution across a range of shallow/deep water depths (i.e., </> 4 ft) and slow/fast velocities (i.e., </> 2 fps). Cells that were selected and only partially within the wetted channel were shifted to include a full 10x10 m area within the wetted channel. Because the wetted channel coverage area and depth/velocity criteria could not reliably be pre-determined in the office, pre-selected cells that were out of water were subsequently rejected in the field. Additionally, in an attempt to capture habitats with under-represented availability (e.g., > 4 ft deep with > 2 fps mean column velocity, or inundated floodplain habitat), cells containing those habitat attributes were directly targeted in place of pre-selected cells. Once cells were selected using the above criteria, each cell was subdivided into four 5x5 m quadrants during the field survey, each quadrant representing one potential habitat availability data point.

The selection process generally resulted in three cells, or 12 quadrants, per habitat unit surveyed, with multiple replicates of each habitat type surveyed during each effort. This approach was repeated for each field effort; however, the river reach length surveyed was reduced during the May and July efforts due to declining numbers of fish observations in downstream sections.

[3] Prior habitat mapping efforts delineated mesohabitat units into unit components, including head, body, and tail, where the component delineations were clear, such as a pool. These delineations were used during the placement of cells in order to better distribute sampling points within the selected habitat units.

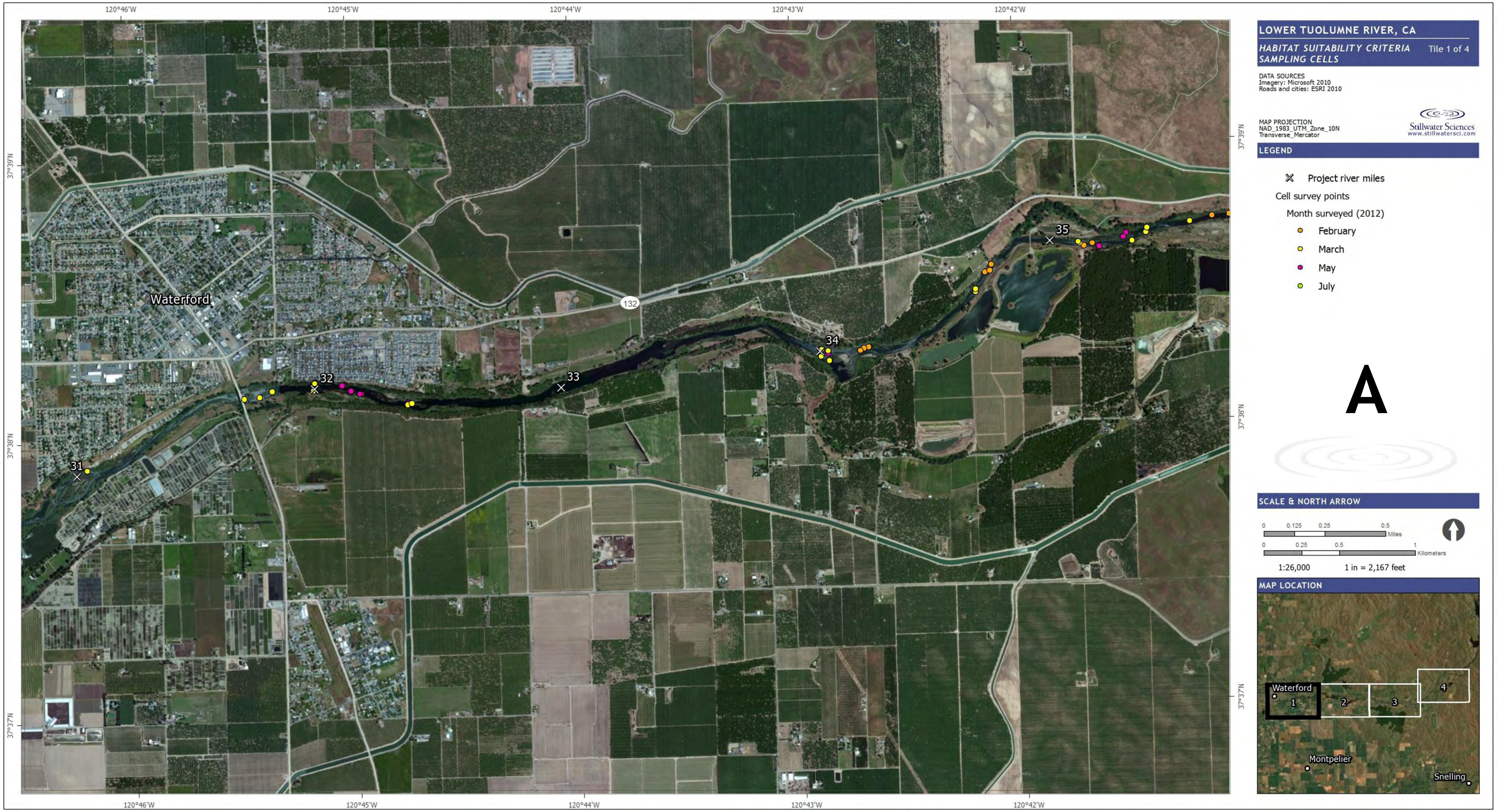

Figure 2A. Site-specific habitat suitability criteria survey locations in the lower Tuolumne River, 2012. (A) Tile 1: RM 31-35, (B) Tile 2: RM 35-40, (C) Tile 3: RM 41-46, and (D) Tile 4: RM 46-52.

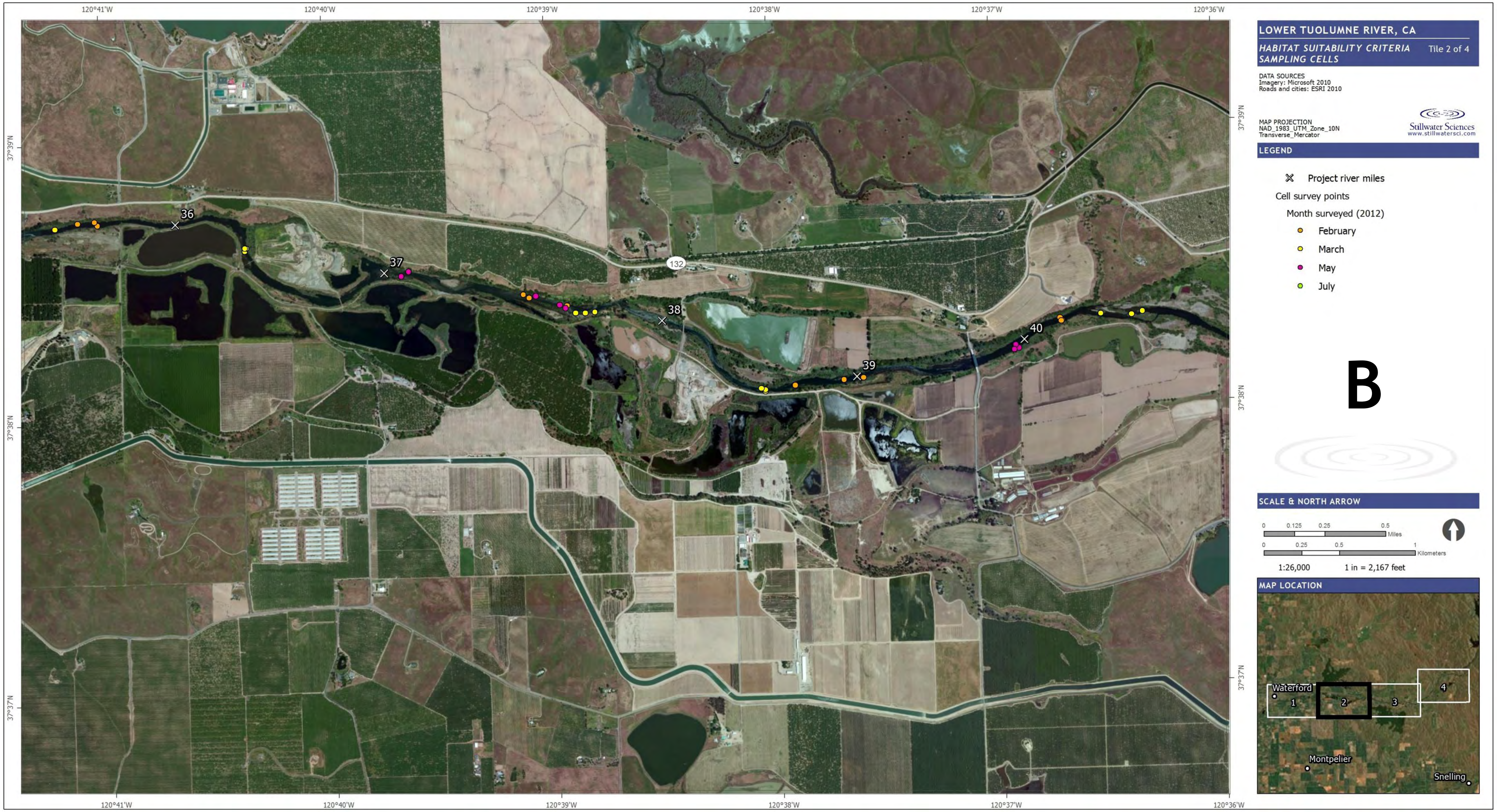

Figure 2B. Site-specific habitat suitability criteria survey locations in the lower Tuolumne River, 2012. (A) Tile 1: RM 31-35, (B) Tile 2: RM 35-40, (C) Tile 3: RM 41-46, and (D) Tile 4: RM 46-52.

Figure 2C. Site-specific habitat suitability criteria survey locations in the lower Tuolumne River, 2012. (A) Tile 1: RM 31-35, (B) Tile 2: RM 35-40, (C) Tile 3: RM 41-46, and (D) Tile 4: RM 46-52.

Figure 2D. Site-specific habitat suitability criteria survey locations in the lower Tuolumne River, 2012. (A) Tile 1: RM 31-35, (B) Tile 2: RM 35-40, (C) Tile 3: RM 41-46, and (D) Tile 4: RM 46-52.

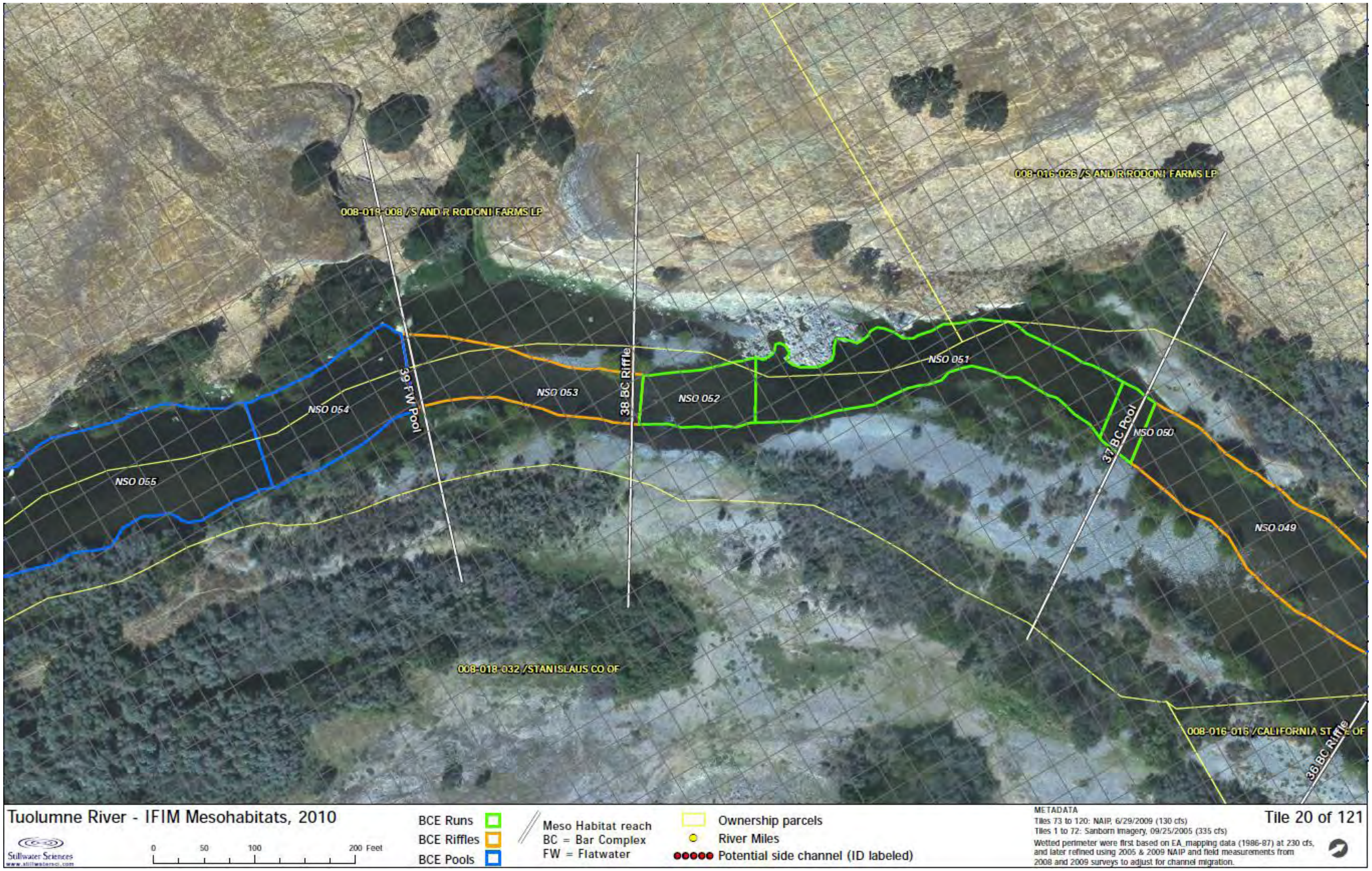

Figure 3. Example aerial photo showing grid used during random sampling site selection, and subdivision of pool into head, body, and tail.

2.10.2.2 Direct observation and field measurements

Once the sample cell was located in the field, two snorkelers entered the water from at least 20 ft downstream of the cell. Snorkelers were spaced at approximately one-third and two-thirds of the cell width (or in the middle of each lower quadrant) and moved uniformly in an upstream direction through the length of the cell to reduce the potential for fish disturbance. Each observation location was marked with a weighted flag so that site-specific measurements could be collected after snorkeling was complete, so to minimize disruptions to fish behavior.

Fish observation data included species name, number observed, total length (for individuals) or size range (for groups), focal depth, and activity (i.e., holding, feeding, roving, and spawning). Habitat observations included percent of fish cover and dominant and subdominant substrates (see Section 2.6, *Substrate and Cover Data*). After the snorkeling was completed, measurements were taken within each cell quadrant. Each observation point within occupied quadrants (quadrants with fish observations) included cell quadrant identification, water depth, mean column velocity, focal point water velocity, and adjacent water velocity (i.e., a potentially higher velocity within 2 ft of the focal point, in any direction). The same measurements and habitat observations, excluding focal depth, focal velocity, and adjacent velocity, were recorded at one representative location within each unoccupied and occupied quadrant of the cell in order to document habitat availability.

General site information was recorded, and included water temperature, water visibility (via secchi disk reading), discharge (based on USGS gage data for La Grange), GPS coordinates, and site photos.

2.10.2.3 Data analysis

All data were entered into a standardized database and checked against the field datasheets for quality assurance. Species life stages were determined based on total fish length, where fry included individuals measuring 50 mm or less; juveniles ranged from 51–150 mm, and adults included individuals greater than 150 mm. Fish cover identified during the field surveys was assessed for suitability using four categories: 1) no cover; 2) object cover, which includes cobble, boulder, fine woody debris, and large woody debris; 3) overhead cover, which includes overhanging vegetation, aquatic vegetation, undercut bank/rootwad, and water-surface turbulence; and 4) combined cover, which includes any combination of object and overhead cover types (Table 8).

Individual observations were assigned a frequency of one, regardless of the number of fish at that location (i.e., a fish observation could include a single fish, or a group of fish). The frequencies of occupied and unoccupied observations were plotted together as a histogram for each parameter (i.e., depth, velocity, and cover) for each of the target species and life stages. The combined frequency of occupied and unoccupied observations makes up habitat availability.

Habitat availability and occupied frequency were used to develop utilization and preference curves using methods described in Bovee (1986). Fish cover utilization values were developed based on the frequency of fish observations per habitat parameter increment divided by the total number of fish observations.

Utilization and preference indices for depth and velocity were plotted over occupied frequency histograms for ease of comparison and analysis. Because the sample sizes were limited for most life stages (e.g., n<150), these histogram estimates were quite "rough," with multiple peaks and valleys, which resulted in a non-normalized binning distribution of the raw data for most life stages. The suitability indexes subsequently required additional statistical treatment in order to generate continuous density functions of availability and utilization that would more fully represent actual fish habitat and behavior.

The first step in the statistical treatment is to express availability (A), utilization (U), and preference (P) in the form of probability density functions (PDFs). Doing so reflects the distribution of values of the habitat parameter, and the distribution of fish with respect to the habitat.

The PDFs are defined as follows:

$$A(x)dx \propto \Pr\left(\begin{array}{c}\text{a randomly chosen site will have a}\\ \text{parameter value between } x \text{ and } x+dx\end{array}\right)$$

$$U(x)dx \propto \Pr\left(\begin{array}{c}\text{a randomly chosen site will have a}\\ \text{parameter value between } x \text{ and } x+dx\\ \text{if a fish is observed there}\end{array}\right)$$

$$P(x)dx \propto \Pr\left(\begin{array}{c}\text{a fish will be observed at a site if the}\\ \text{parameter value is between } x \text{ and } x+dx\end{array}\right)$$

Each PDF describes the relative likelihood of occurrence for a given parameter value. The probability of any given parameter value cannot exceed 1.

The next step is to relate A and U to P. According to basic probability theory, P is proportional to U/A, therefore we can express P as follows:

$$P_i = \frac{U_i}{A_i}$$

The last step in our statistical treatment is based on work by Bovee (1986) in which the PDFs for A and U are approximated by histograms. The histogram serves to divide the likelihood of a given habitat parameter value into intervals

$$x_0 < x_1 < \cdots < x_n$$

Where for each interval

$$I_i = [x_{i-1}, x_i],\ i = 1, \ldots, n:$$

$$A_i = \frac{\text{number of sites with } x \text{ in } I_i}{\text{total number of sites}}$$

$$U_i = \frac{\text{number of fish observed with } x \text{ in } I_i}{\text{total number of fish observed}}$$

This allows the preference function to also be approximated as a histogram

$$P(x) \doteq P_i \text{, where } x_{i-1} \le x < x_i.$$

The kernel density estimation method was used to obtain smoother preference curves for depth and velocity indices. This method is widely used, and has a well-developed theory; standard references include Silverman (1986), Simonoff (1996), and Bowman and Azzalini (1997). A gaussian kernel was used, with Gasser and Müller boundary kernels, as described in Simonoff (1996), to account for the fact that depths and velocities should be non-negative. Smoothing parameters were chosen informally, with the goal of smoothing only enough to make the local behavior of the curves "reasonable" (e.g., the utilization and availability curves should be unimodal, and the preference curve at least close to unimodal). The calculations were carried out using the statistical programming language "R."

2.10.2.4 Adjacent velocity

Adjacent velocity analyses are sometimes used to assess whether fish are occupying lower velocity locations (presumably for energy conservation) while still positioning themselves near higher velocity "feeding lanes" for foraging. Such analyses can be useful for assessing water velocity "preferences" separate from water velocities typically occupied by the fish, particularly in higher gradient streams with a lot of boulder cover and the associated complex lateral variation in water velocity distributions. An assumption of such analyses is that habitat of a particular velocity and habitat suitability index value in close proximity to feeding lanes is of higher value than habitat with the same velocity that is not in close proximity to a feeding lane.

Adjacent velocities were first evaluated by comparing the mean column velocity at the focal location of the fish to the adjacent mean column velocity, using a paired t-test for each target species and life stage, in order to determine if there were any statistically significant differences that warranted further evaluation. In order to be evaluated further, adjacent velocities had to: 1) demonstrate a statistically significant difference from mean column velocities at the fish focal points, 2) be faster than the focal point mean column velocities, and 3) be in a velocity range with a lower suitability index (i.e., <0.5) than the velocity range where the fish were most frequently found (suggesting they were areas of brief feeding lane forays, rather than more continuously occupied areas).

3 RESULTS

3.1 Habitat Suitability Criteria

3.1.1 Habitat suitability criteria selection

The technical workgroup participants reviewed and selected Chinook salmon and *O. mykiss* criteria for the lower Tuolumne River as documented in the workshop notes (Appendices D–F), subject to validation of those HSC by site-specific studies.[4] Final HSC are included below, along with the validation results.

3.1.2 Site-specific habitat suitability criteria development and validation

Site-specific surveys were conducted during February, March, May, and July 2012, at 100 cfs, 350 cfs, and 2,000 cfs. Surveys were conducted within each habitat type, including side channel and overbank habitats. The stratified random sampling method was targeted at producing a similar level of sampling effort among each habitat and channel form combination, with each combination surveyed for a variety of deep/shallow and fast/slow hydraulic conditions. Not all deep/shallow and fast/slow conditions occur with sufficient frequency to allow for completely balanced sampling while still surveying sufficient area to collect enough fish observations (Table 13). Despite this limitation, a wide range of channel, habitat, and hydraulic conditions was sampled over a range of flows, thus minimizing the potential for any bias in the fish observation results.

In total, 4,616 Chinook salmon and *O. mykiss* were counted at 570 separate observation points among 763 sample quadrants (Table 14). The number of observations allowed for evaluation of each of the targeted species and life stages selected for validation (Chinook salmon fry and juvenile; *O. mykiss* fry, juvenile, and adult), and development of site-specific Chinook salmon fry suitability criteria.

[4] Subsequent to conclusion of the technical workshops on HSC selection, the Tuolumne River Conservancy withdrew their support for any decisions made by the technical workgroup regarding *O. mykiss*, as documented in the workshop notes.

Table 13. Summary of habitat suitability sample quadrants in the lower Tuolumne River during surveys conducted between February and July 2012.

Habitat		Velocity[1]	Deep (≥ 4 ft)	Shallow (< 4 ft)	Total Number of Sample Quadrants	
Glide	Bar Complex	Fast	0	3	20	68
		Slow	0	17		
	Flatwater	Fast	8	0	48	
		Slow	8	32		
Riffle	Bar Complex	Fast	13	41	120	197
		Slow	11	55		
	Flatwater	Fast	4	14	77	
		Slow	18	41		
Run	Bar Complex	Fast	16	17	112	222
		Slow	19	60		
	Flatwater	Fast	10	5	110	
		Slow	30	65		
Pool	Bar Complex	Fast	11	2	76	164
		Slow	18	45		
	Flatwater	Fast	2	5	88	
		Slow	42	39		
Side Channel	--	Fast	3	8	76	76
		Slow	4	61		
Overbank	--	Fast	0	8	36	36
		Slow	2	26		
Total			**219**	**544**	**763**	

[1] Fast water includes velocities ≥ 2 fps and slow water includes velocities < 2 fps.

Table 14. Summary of site-specific fish observation samples collected in the lower Tuolumne River during surveys conducted between February and July 2012.

Species	Life stage	Observations	Number of Fish Observed
Chinook salmon	fry	218	2,641
	juvenile	87	740
Chinook salmon Total		305	3,381
O. mykiss	fry	97	731
	juvenile	93	378
	adult	75	126
O. mykiss Total		265	1,235
Total		**570**	**4,616**

For purposes of this study, workgroup-selected HSC were considered “validated” if the HSC utilization curve developed from site-specific observations fell within the “envelope” of the workgroup-selected curve. Additional statistical comparisons of the resulting curves was not pursued, given the unavailability (or non-existence) of underlying empirical data for many of the workgroup-selected curves. No attempt was made to further restrict the range of the workgroup-selected curve based on the site-specific results, since in most cases the site-specific sample size does not clearly support such an adjustment. The following protocol was used to select the final curves used in the PHABSIM analysis:

- If the site-specific utilization and preference (in the case of Chinook fry) curves were within the workgroup consensus curve, then the consensus curve was considered validated and subsequently used in the PHABSIM analysis (seven curves).
- Where the workgroup consensus curve was closely spaced between the site-specific utilization and preference curves, the workgroup consensus curve was used based on the expectation that a larger sample size would likely push the site-specific results to look more like the workgroup consensus curve (one curve: *O. mykiss* adult velocity).
- If the site-specific utilization and preference curves both extended beyond the workgroup consensus curve, then the consensus curve was expanded to include the site-specific utilization curve data (two curves).

The workgroup consensus curves that were validated included:

- Chinook salmon juvenile velocity
- Chinook salmon fry depth and velocity[5]
- *O. mykiss* fry velocity
- *O. mykiss* juvenile depth and velocity
- *O. mykiss* adult depth and velocity

The curves that were expanded as a result of the site-specific surveys included:

- Chinook salmon juvenile depth
- *O. mykiss* fry depth

Previously developed Tuolumne River (Chinook spawning, depth and velocity curves) or published criteria (*O. mykiss* spawning, depth and velocity curves) were used in the model, as specified by the technical workgroup participants. No consistent and complementary cover criteria data from other sources were identified by the workgroup participants, and therefore site-specific cover data were developed from the Tuolumne River and were applied for life stages with a sufficient sample size.

The suitability criteria used in the model for all species and life stages are shown in Figures 4–20 at the end of this section, along with the most pertinent reference curves. Additional HSC reference data, curves, and curve coordinates are included in Appendix G.

The site-specific Chinook fry depth results (Figure 4) suggest that the workgroup-selected Tuol-Mod curve is appropriate (and matches the utilization data quite well), although the site-specific preference curve is much narrower. The differences between the site-specific utilization and preference curves appear to result primarily from a small sample size anomaly in the shallowest

[5] There was not final consensus on a single Chinook salmon fry depth curve within the technical workgroup participants, and three candidate curves remained under consideration. The curve selected for the PHABSIM model was the one that best matched the subsequently collected site-specific data.

locations, which tends to skew the calculation for the resulting preference curve. This sort of statistical anomaly is not uncommon, and overriding this anomaly through further statistical treatment or professional judgment would likely render a very similar result to the workgroup-selected curve.

The site-specific Chinook juvenile depth curve (Figure 7) indicates that fish are utilizing greater depths than covered by the workgroup-selected curve and, per the protocol described above, the final curve was expanded accordingly.

The site-specific Chinook juvenile velocity curve (Figure 8) suggests that the workgroup-selected curve is too broad. However, the sample size for the site-specific data is too small to justify a modification to the workgroup-selected curve at this point, since additional observations would likely result in greater convergence between the two data sets.

The site-specific *O. mykiss* fry depth curve (Figure 12) shows that fry are utilizing greater depths than covered by the workgroup-selected curve and, per the protocol described above, the final curve was expanded accordingly.

The site-specific *O. mykiss* juvenile velocity curve (Figure 15), like the Chinook juvenile velocity curve, suggests that the workgroup-selected curve is too broad. However, the sample size for the site-specific data is too small to justify a modification to the workgroup-selected curve without additional observations.

The site-specific *O. mykiss* adult depth curve (Figure 19) strongly indicates that the workgroup-selected curve extends to greater depths than Tuolumne River *O. mykiss* are utilizing. However, the sample size for the site-specific data is too small to justify a modification to the workgroup-selected curve without additional observations. Implications of this depth curve disparity are discussed further in Section 4, *Discussion*.

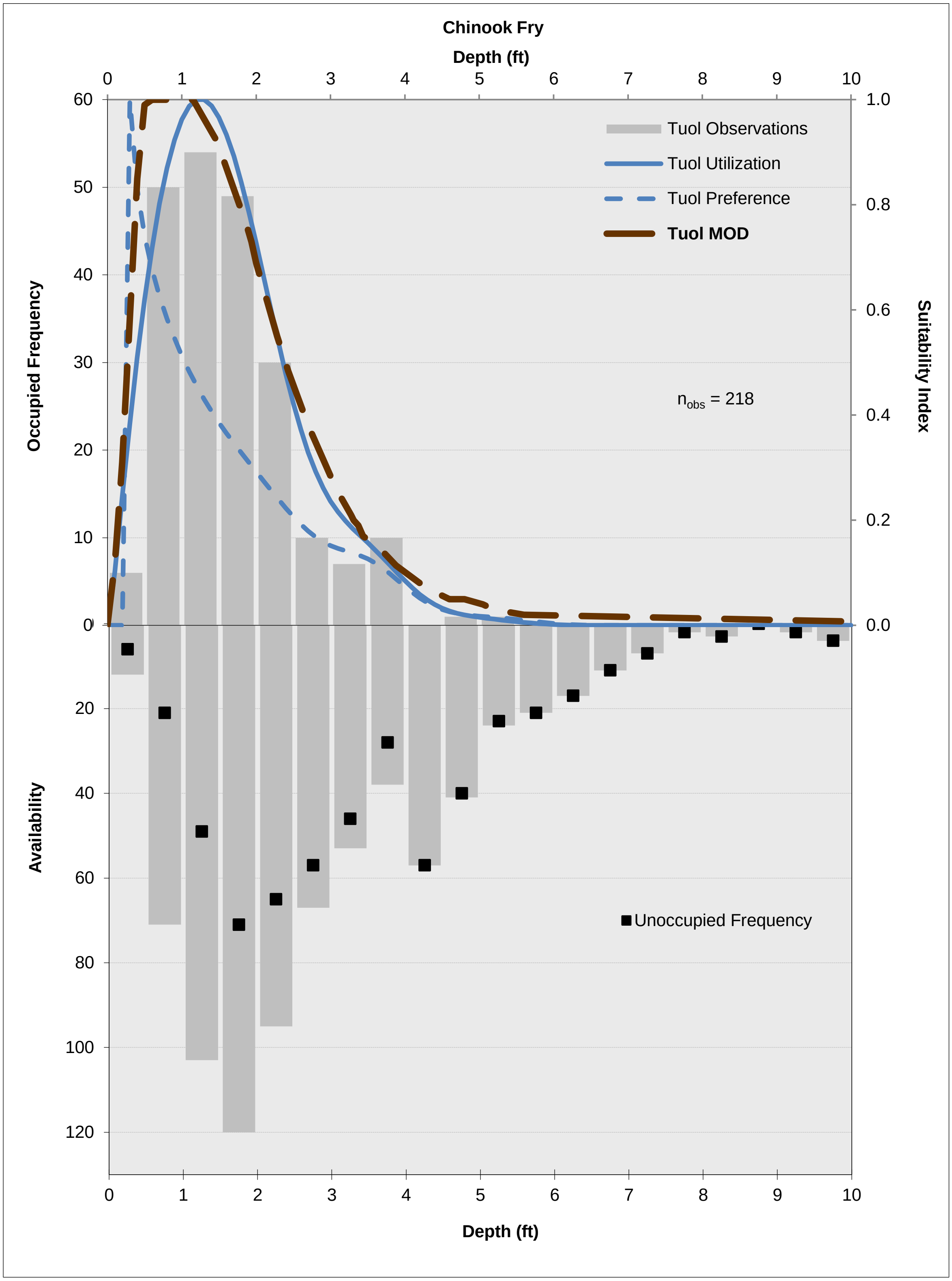

Figure 4. Chinook salmon fry depth suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol MOD.

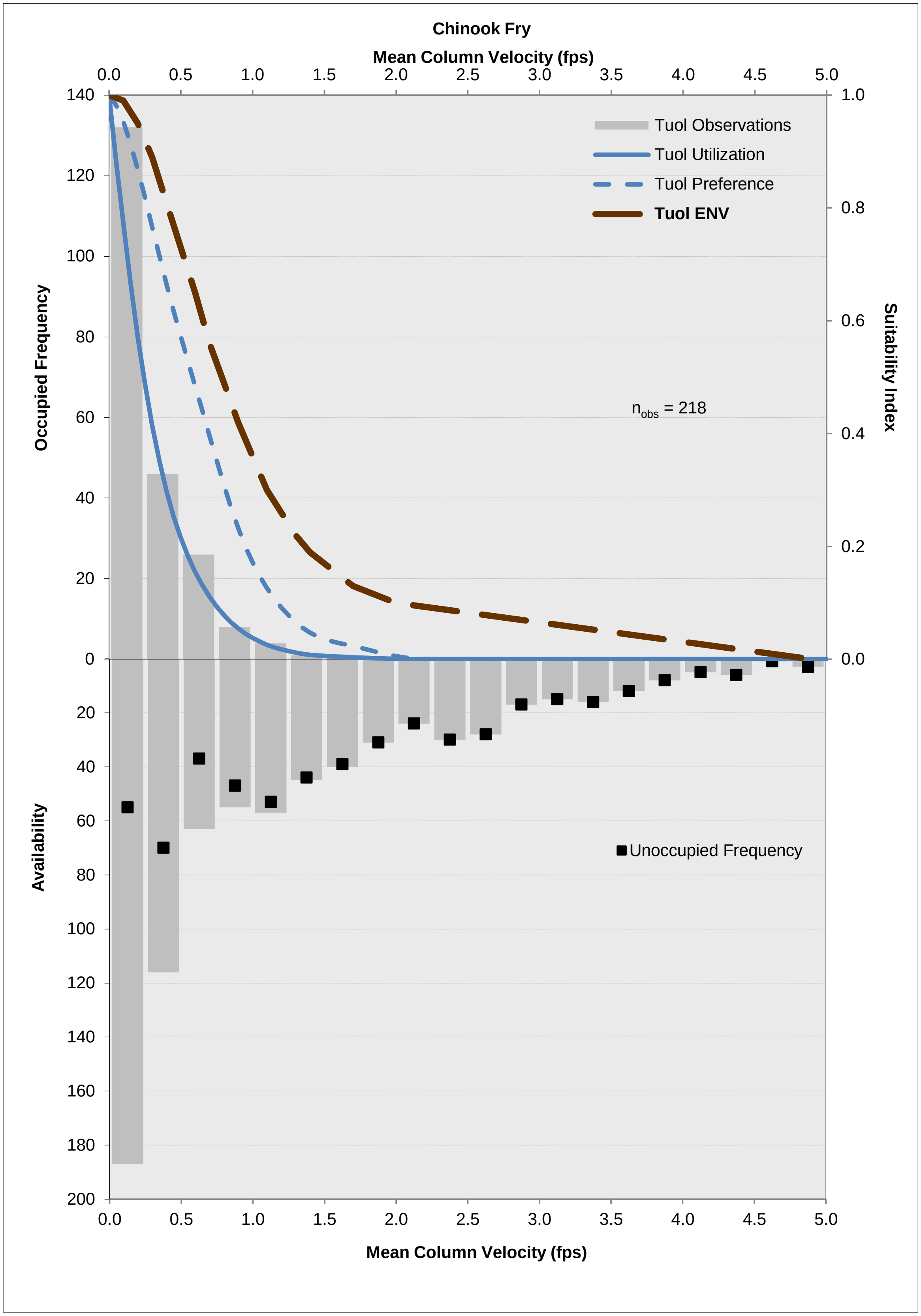

Figure 5. Chinook salmon fry velocity suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol ENV.

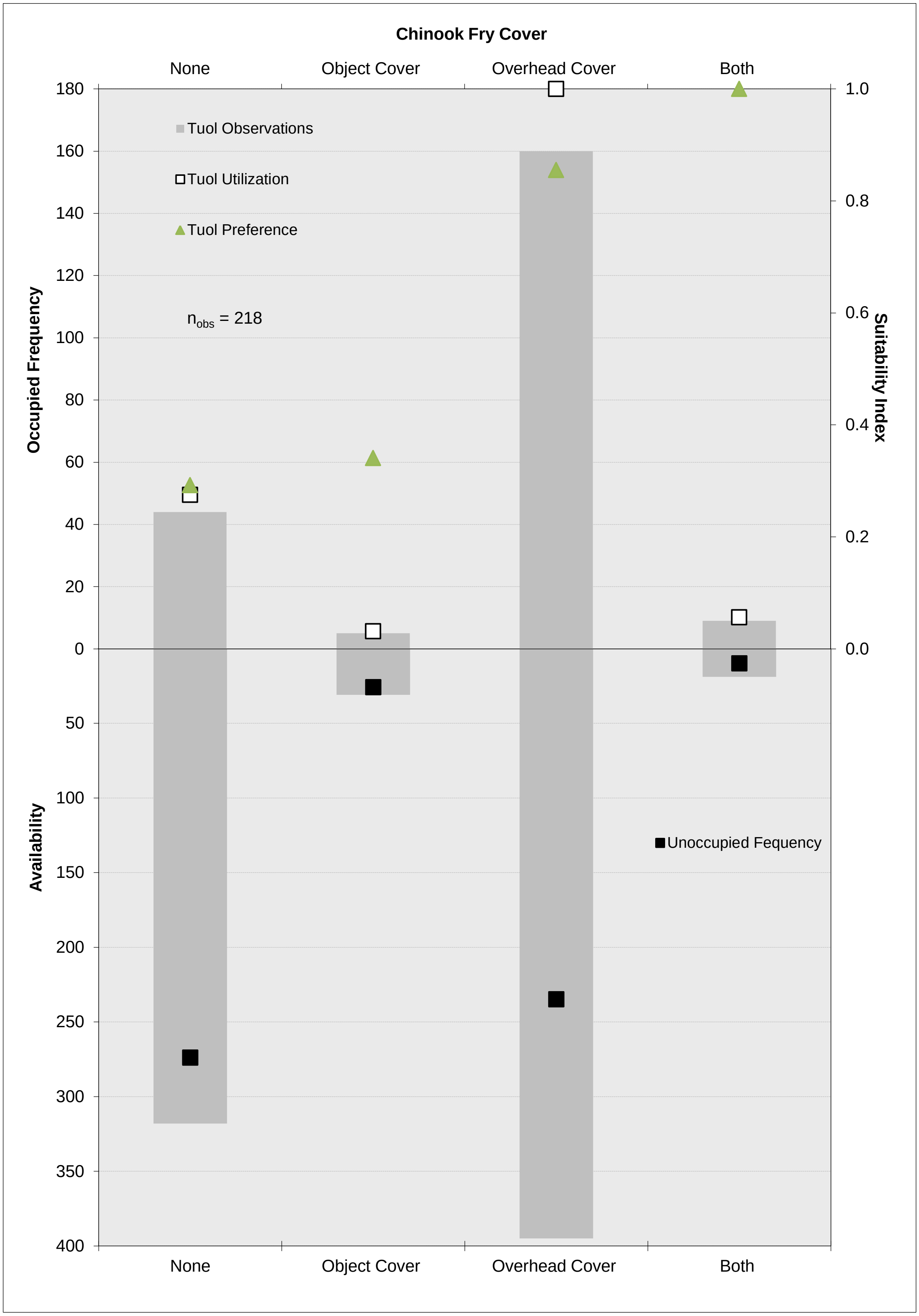

Figure 6. Chinook salmon fry cover suitability criteria for the lower Tuolumne River.

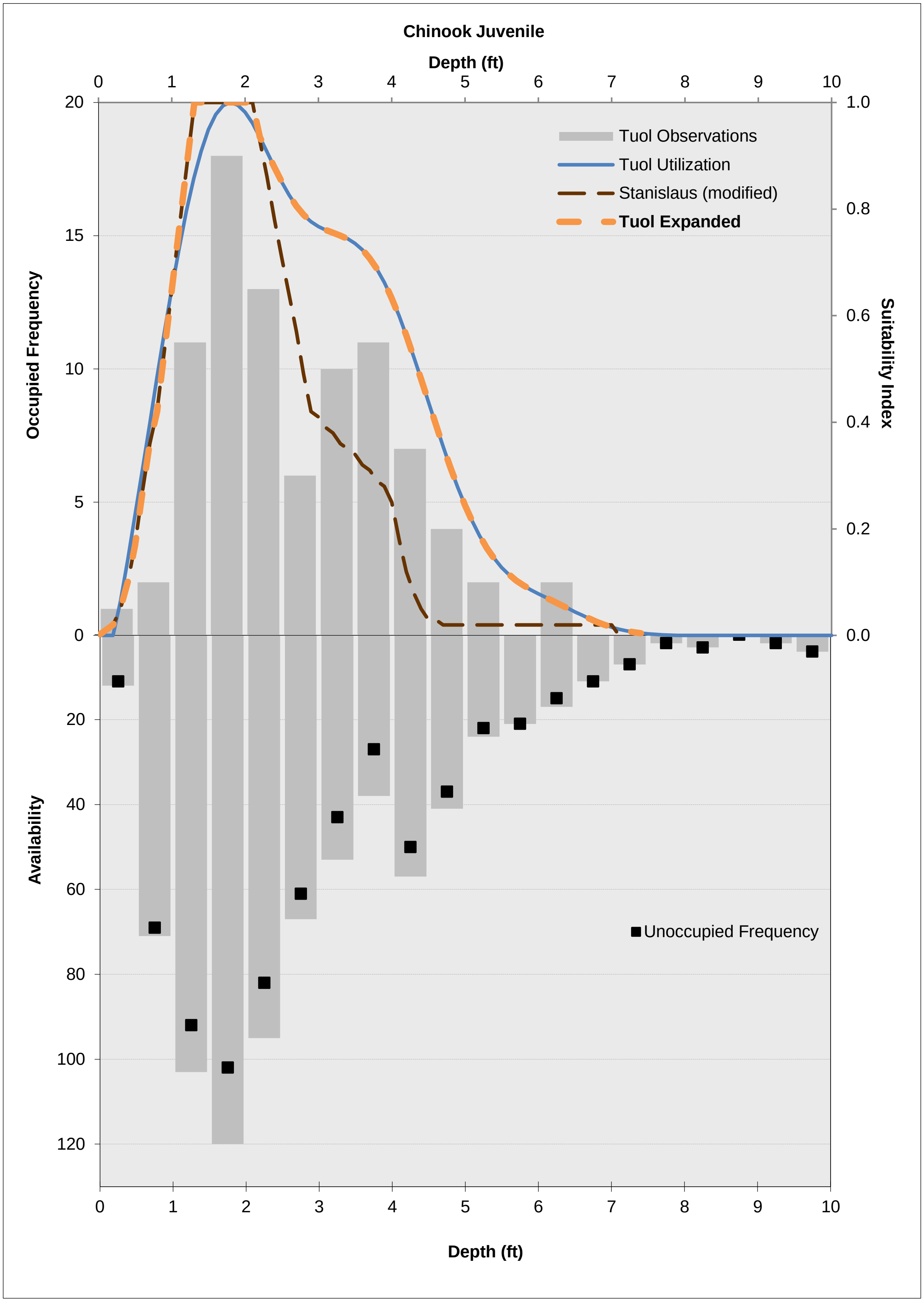

Figure 7. Chinook salmon juvenile depth suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol Expanded.

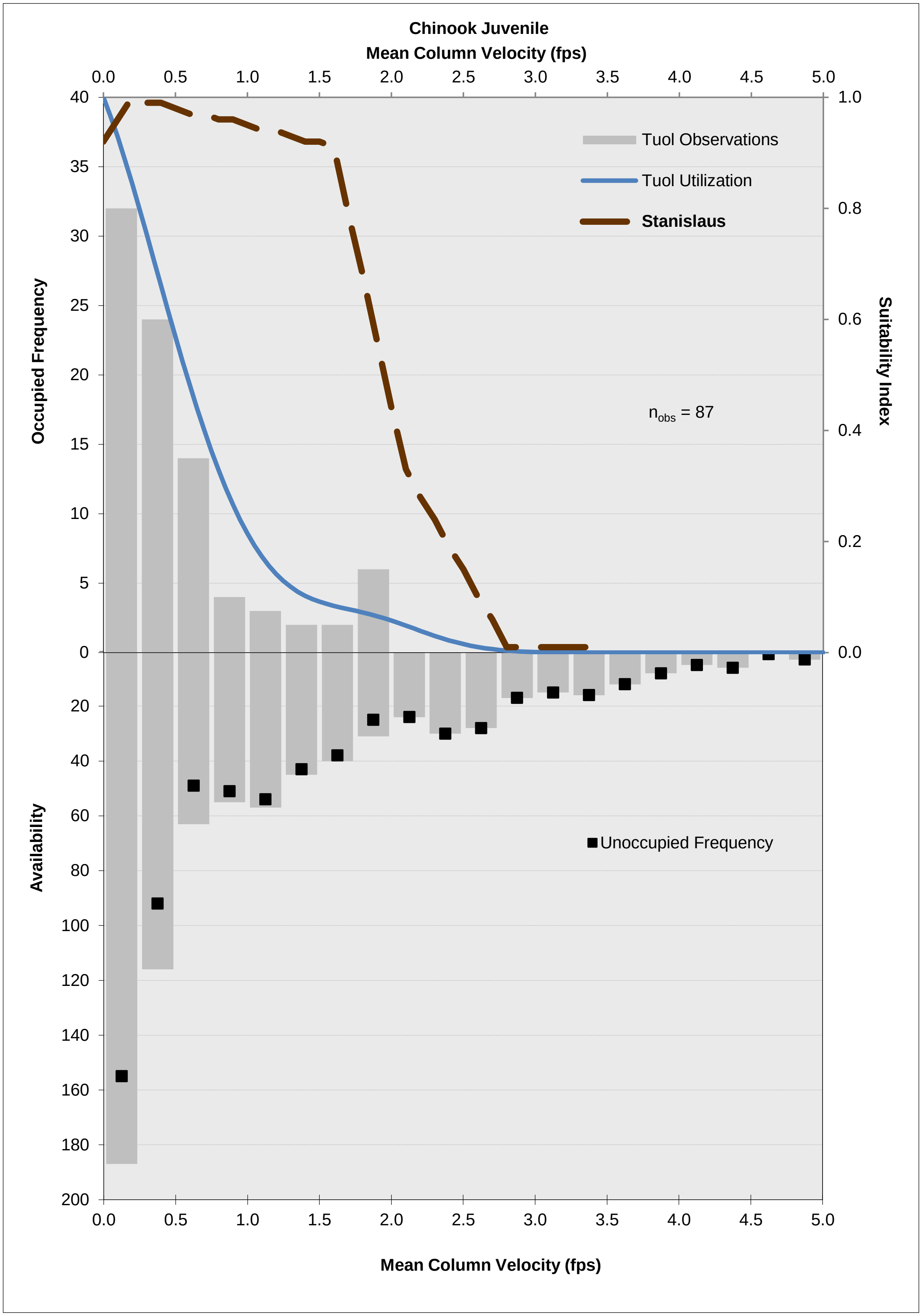

Figure 8. Chinook salmon juvenile velocity suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Stanislaus.

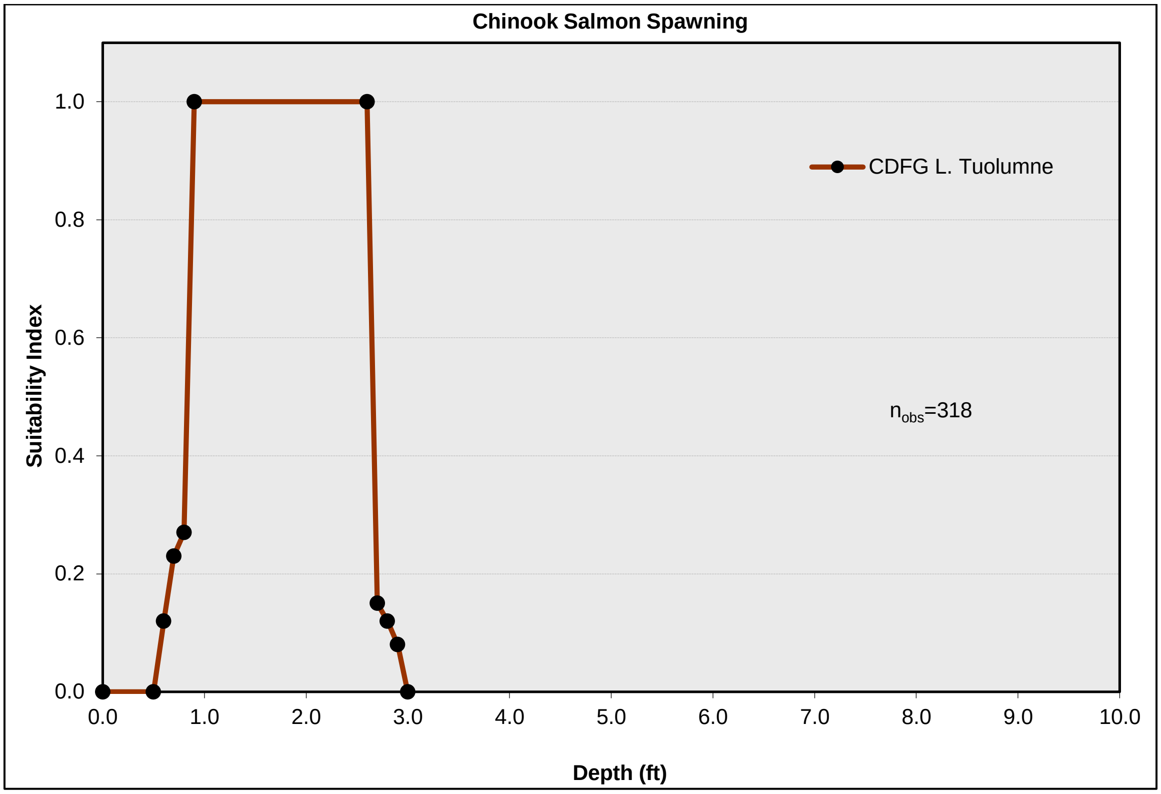

Figure 9. Chinook salmon spawning depth suitability criteria for the lower Tuolumne River.

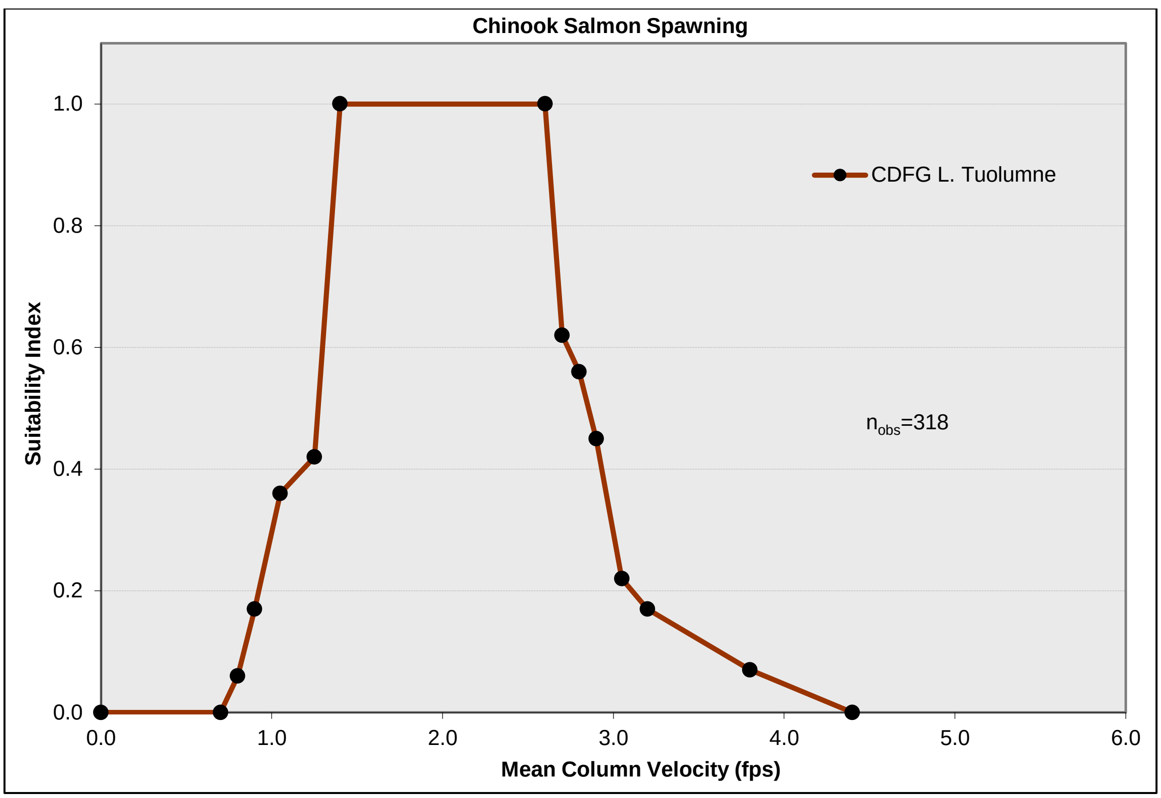

Figure 10. Chinook salmon spawning velocity suitability criteria for the lower Tuolumne River.

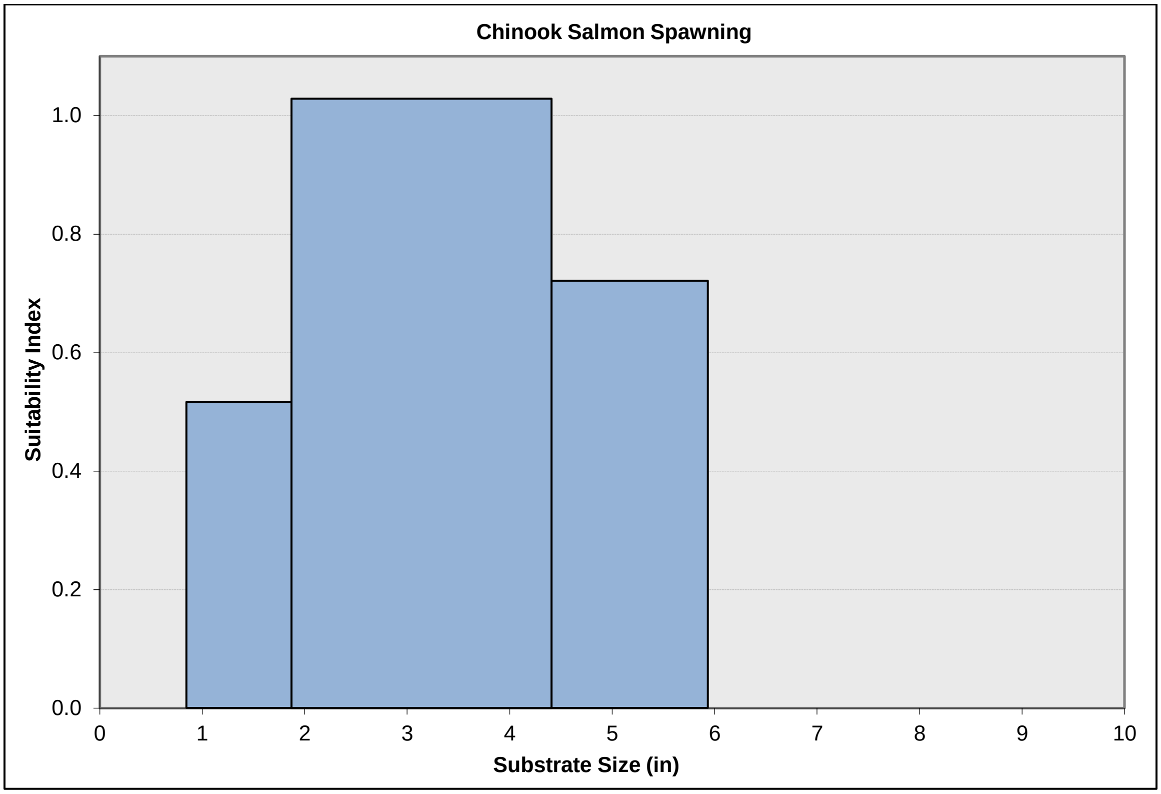

Figure 11. Chinook salmon spawning substrate suitability criteria for the lower Tuolumne River.

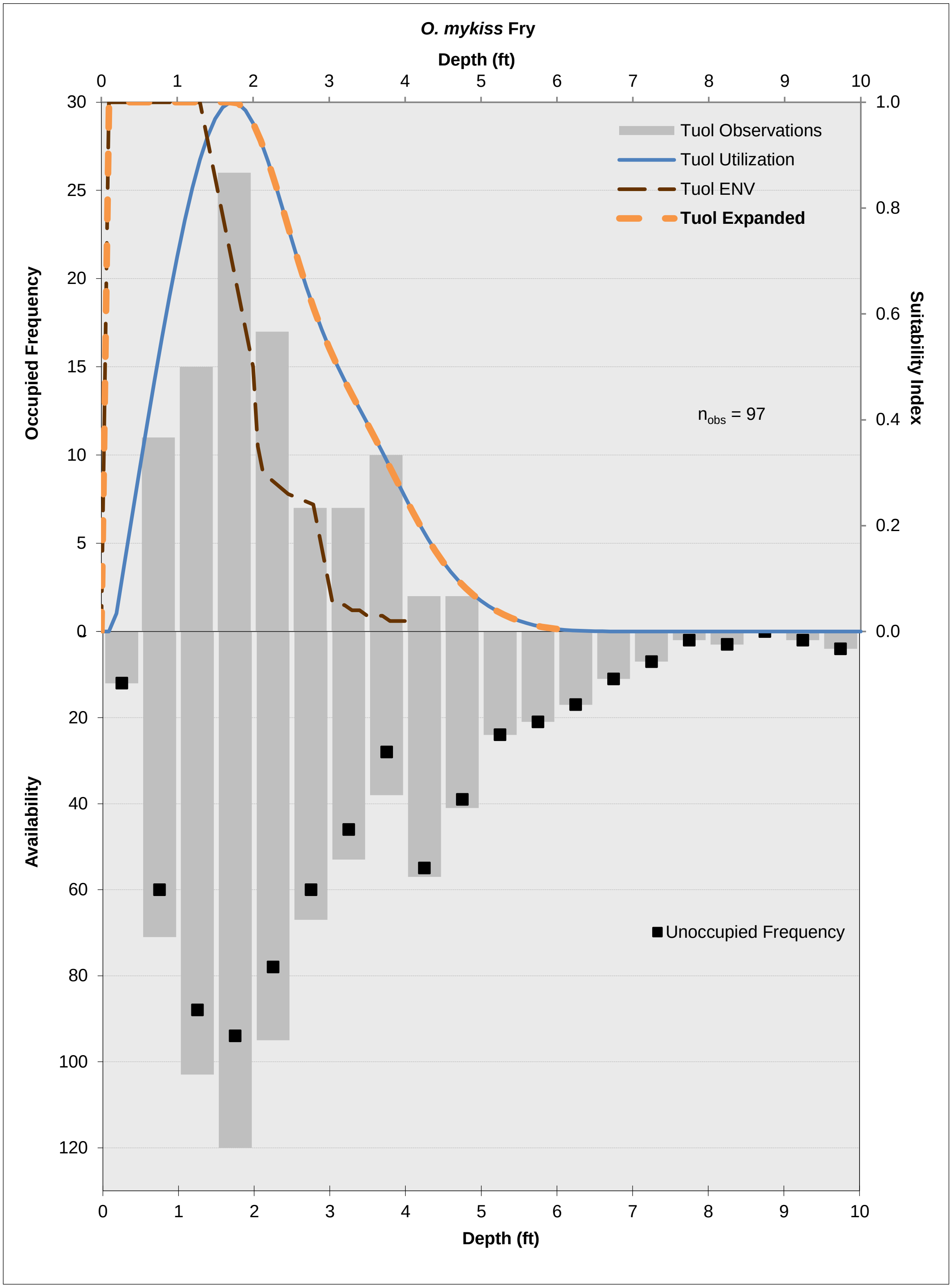

Figure 12. *O. mykiss* fry depth suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol Expanded.

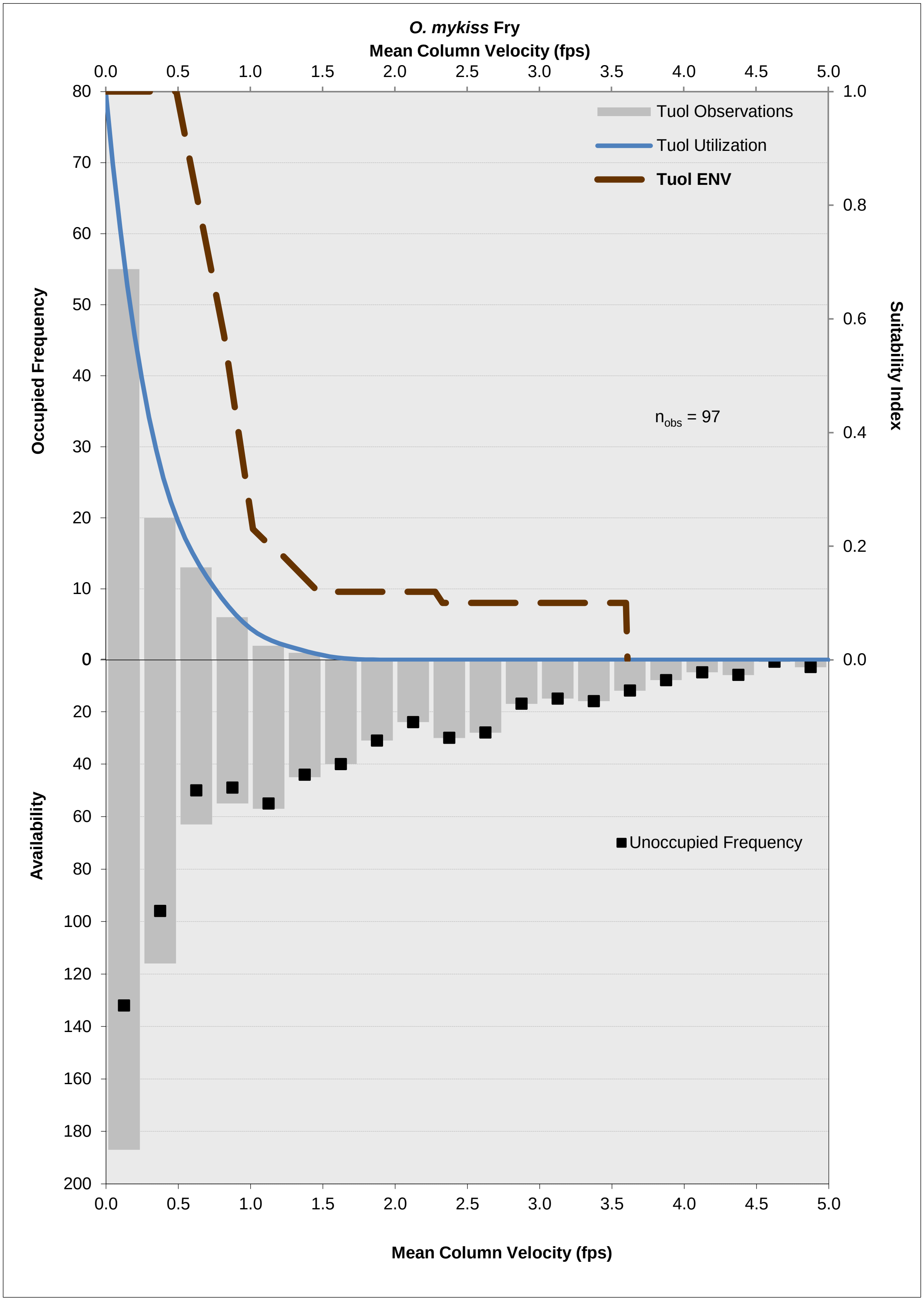

Figure 13. *O. mykiss* fry velocity suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol ENV.

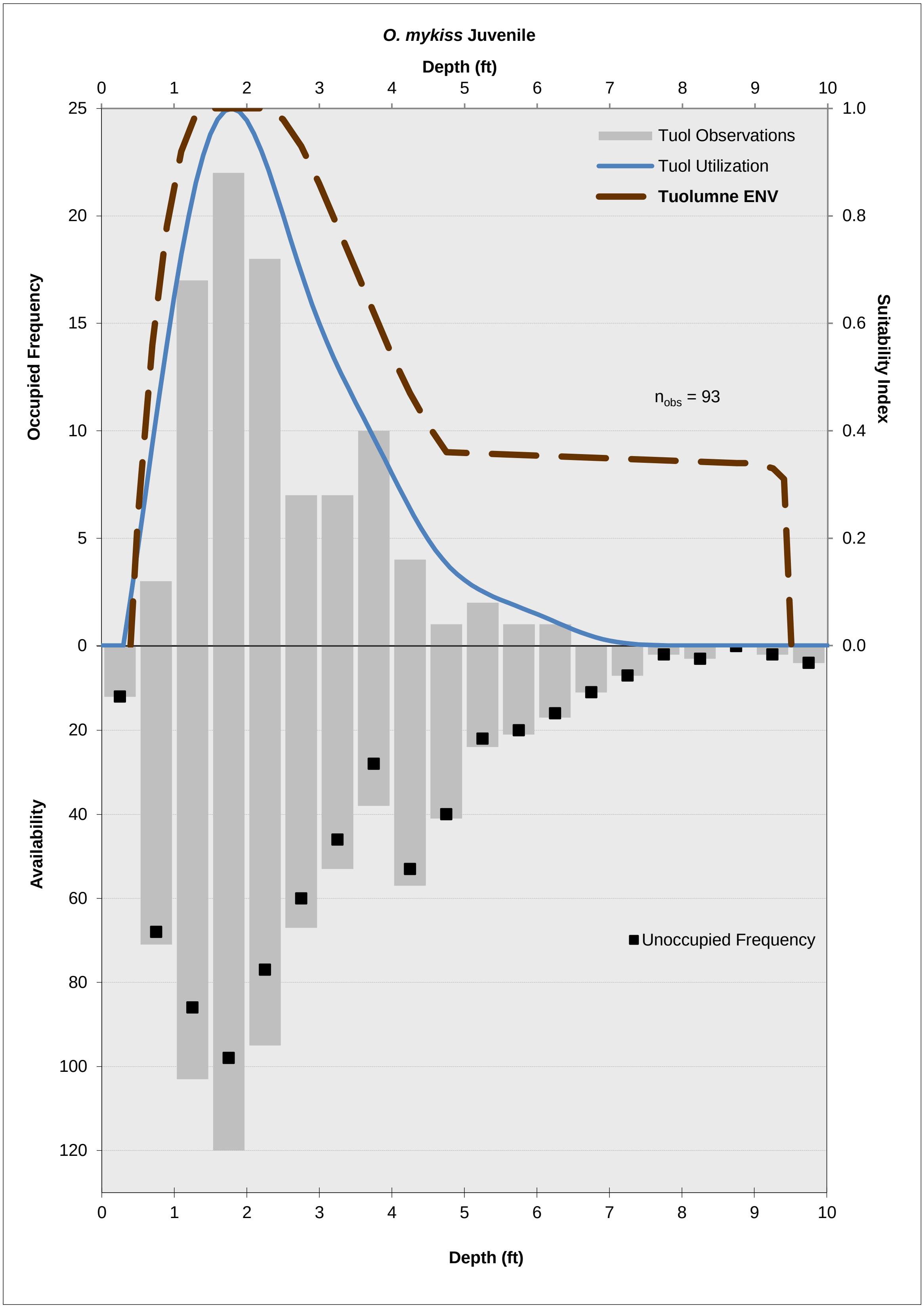

Figure 14. *O. mykiss* juvenile depth suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol ENV.

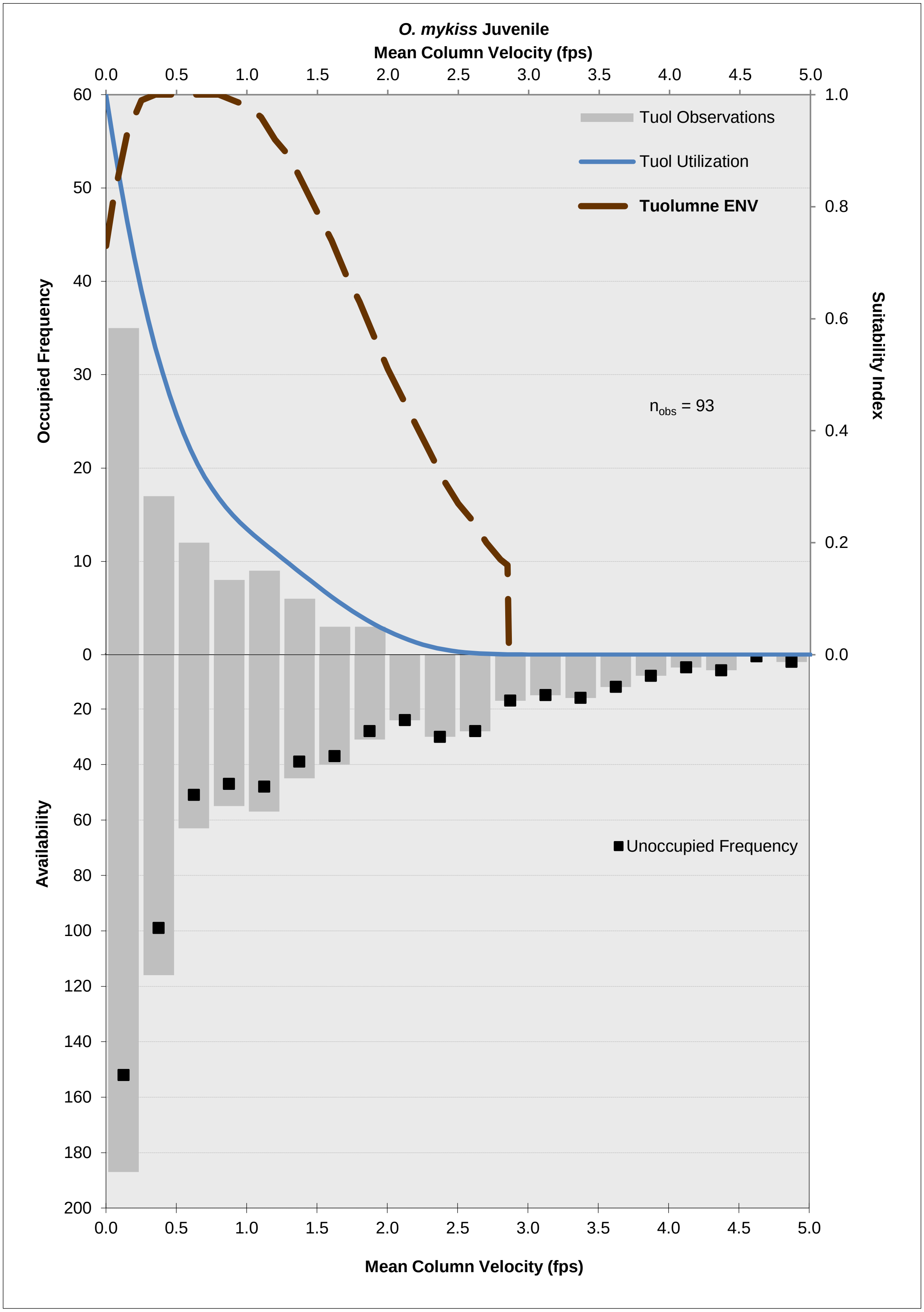

Figure 15. *O. mykiss* juvenile velocity suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was Tuol ENV.

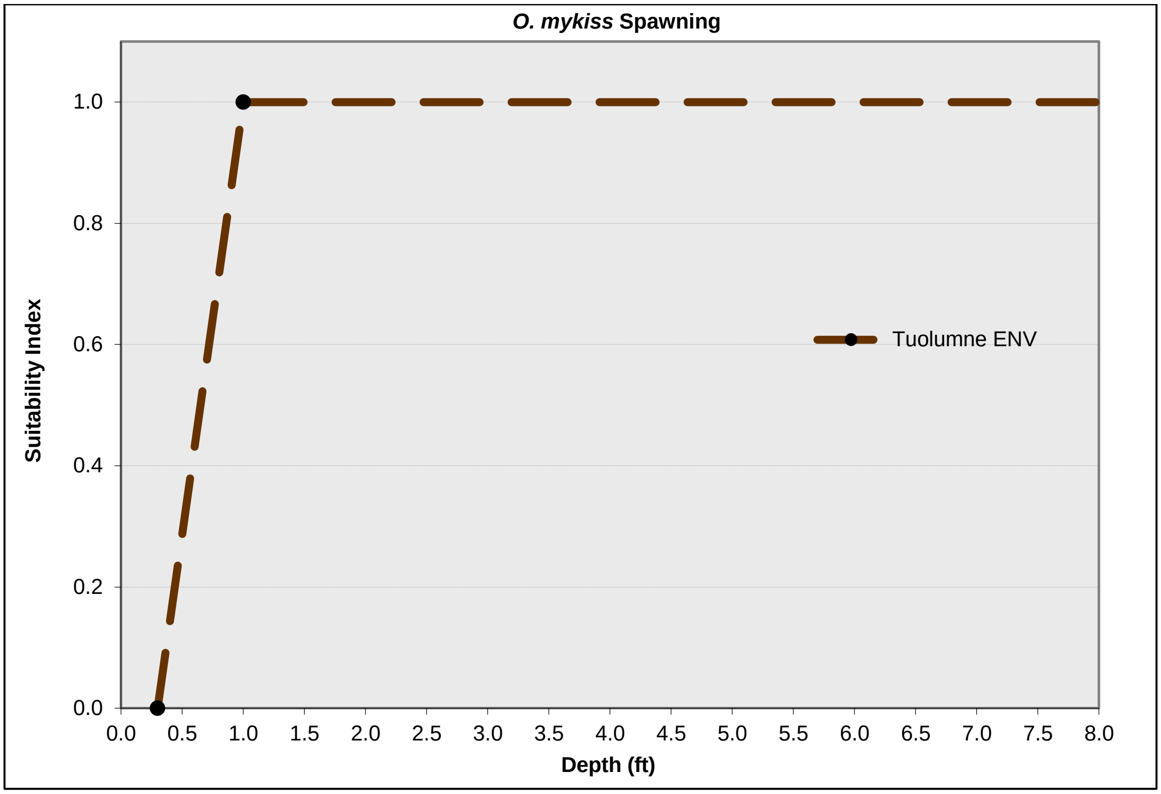

Figure 16. *O. mykiss* spawning depth suitability criteria for the lower Tuolumne River.

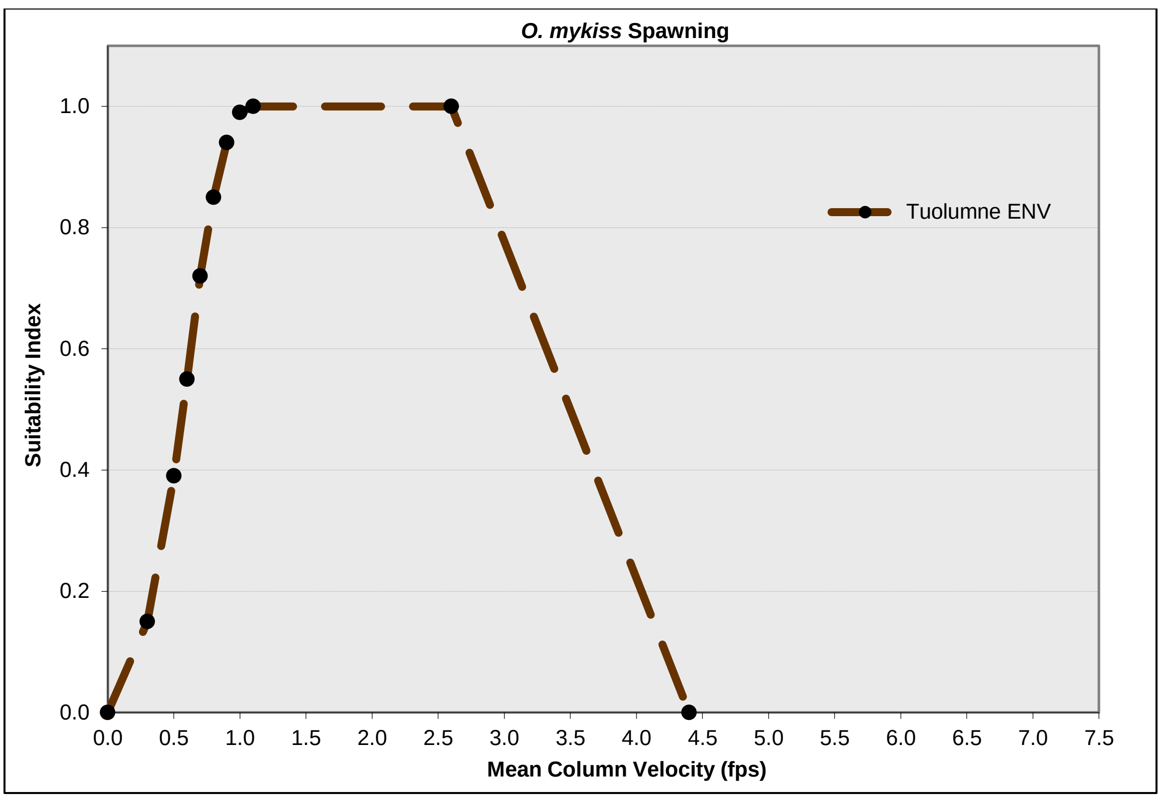

Figure 17. *O. mykiss* spawning velocity suitability criteria for the lower Tuolumne River.

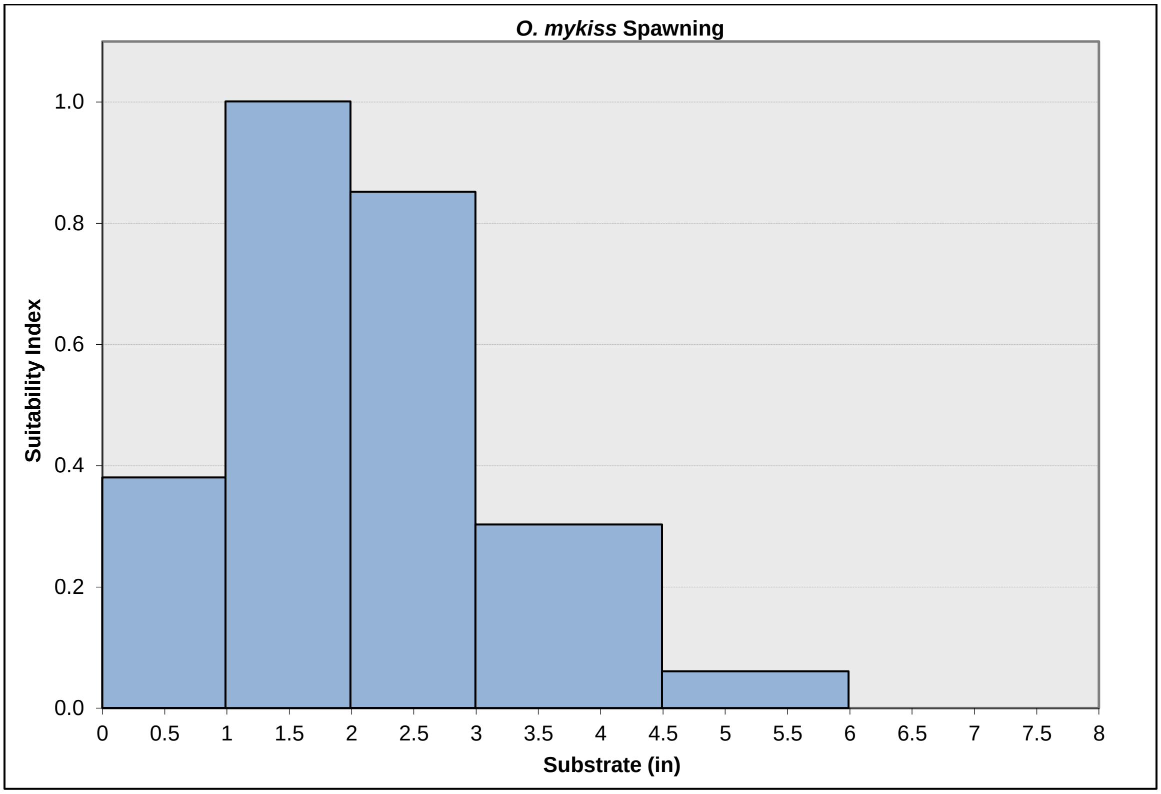

Figure 18. *O. mykiss* spawning substrate suitability criteria for the lower Tuolumne River.

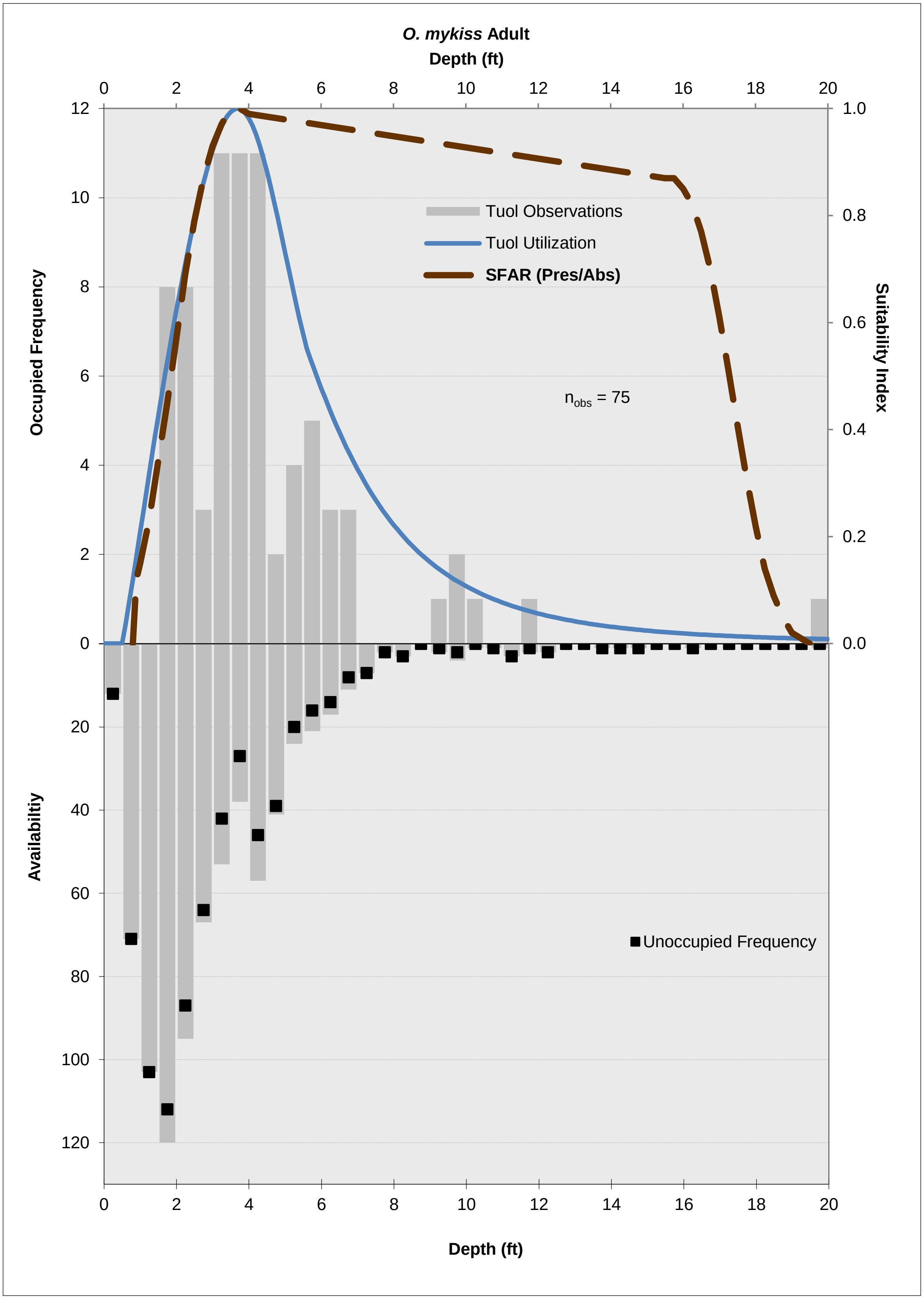

Figure 19. *O. mykiss* adult depth suitability criteria for the lower Tuolumne River; curve applied in the PHABSIM model was SFAR (Pres/Abs).

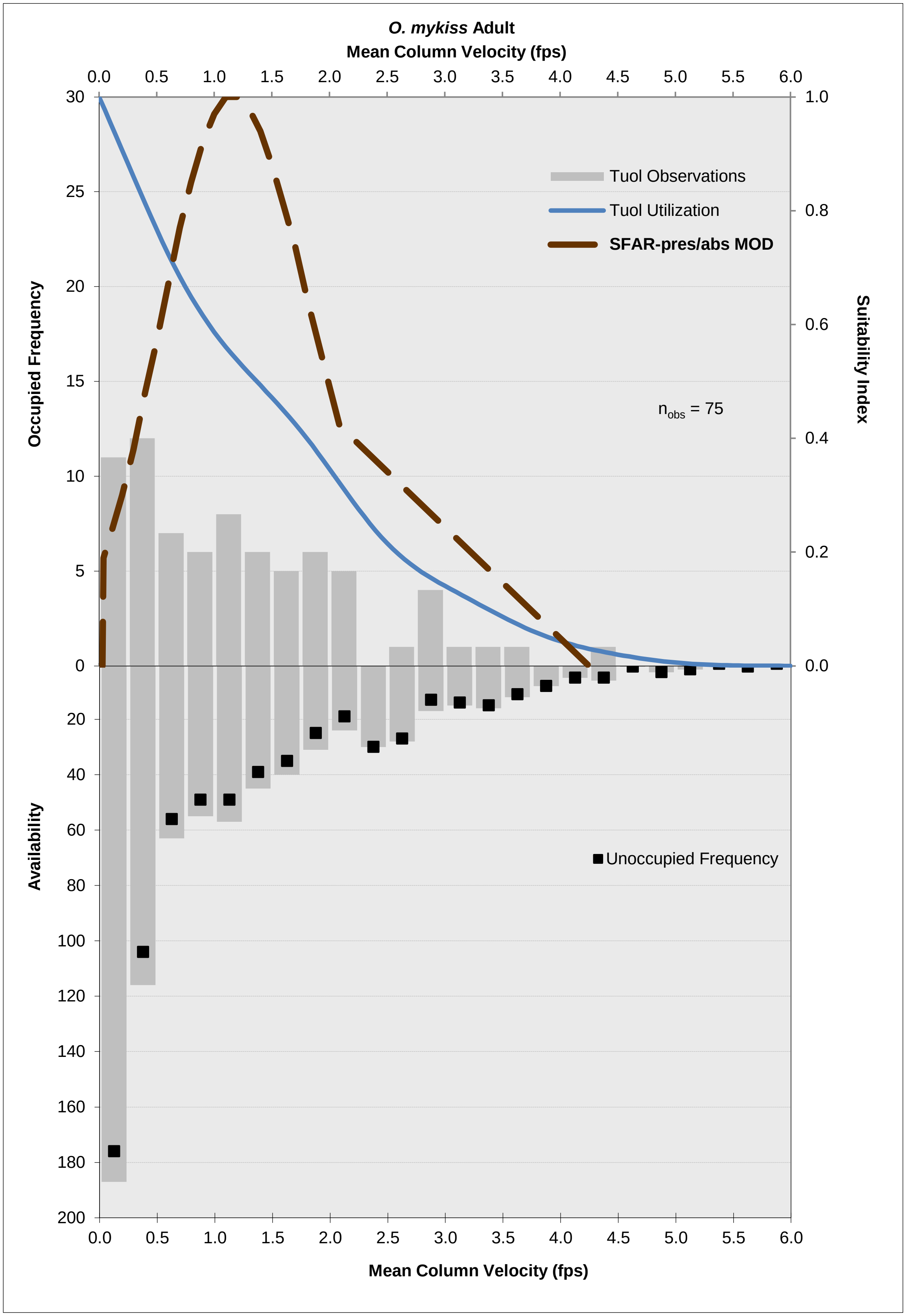

Figure 20. *O. mykiss* adult velocity suitability criteria for the lower Tuolumne River; curve applied in PHABSIM model was SFAR (pres/abs MOD).

3.1.3 Adjacent velocity

The results of the adjacent velocity analysis in the lower Tuolumne River are presented in Table 15. Adjacent velocities were significantly different ($p<0.05$) than fish observation point mean velocities for three of the five species and life stage combinations, although the fry life stage is not typically considered to use feeding lanes. However, the differences in mean column velocity were small (0.06 to 0.25 fps), suggesting limited use (or lack) of well-developed shear zones or feeding lanes (which is consistent with more homogenous morphological and hydraulic conditions observed in the Tuolumne or other large alluvial valley rivers). In addition, the magnitude of the adjacent velocities was well within the preferred velocity ranges (e.g., suitability indices of >0.5) for continuous occupation of the point location (i.e., the adjacent velocity was not in a much faster but less preferred location that was briefly and opportunistically used for feeding, but rather within a velocity range typical of positions more continuously occupied by the species and life stage). As a result, there appears to be limited application of adjacent velocity analytical methods to lower Tuolumne River conditions, and further analysis of adjacent velocities within the PHABSIM model was not warranted.

Table 15. Adjacent velocities observed during site-specific surveys in the lower Tuolumne River between February and July 2012.

Species	Life stage	Sample Size	Mean Column Velocity		Adjacent Velocity		Difference Between Averages	p[1]
			Average (fps)	Std. Dev.	Average (fps)	Std. Dev.		
Chinook salmon	fry	218	0.32	0.31	0.46	0.52	0.14	**0.000**
	juvenile	87	0.65	0.62	0.89	1.03	0.25	**0.001**
O. mykiss	fry	97	0.44	0.44	0.49	0.55	0.06	0.263
	juvenile	93	0.90	0.78	0.85	0.77	-0.06	0.431
	adult	75	1.58	1.10	1.79	1.31	0.21	**0.042**

[1] Statistically significant ($p<0.05$) values shown in bold.

3.2 Weighted Usable Area

Results of the PHABSIM analysis of WUA versus flow relationships for each species and life stage are presented in Figures 21 and 22. In order to facilitate comparison and analysis, the results are presented with a normalized y-axis scale representing "percent of maximum" WUA. Results presenting raw WUA values along the y-axis are provided in Appendix H, along with results of some ancillary analyses of substrate and cover. Photographs of each transect location at each measured flow are included in Appendix I.

Results for Chinook salmon fry show peak WUA values (e.g., ≥95% of maximum) at approximately 50-100 cfs, with relatively high WUA values (e.g., ≥80% of maximum) below 125 cfs (Figure 21). Results for Chinook salmon juveniles show peak WUA values at approximately 75–225 cfs, with relatively high WUA values below 400 cfs. Results for Chinook salmon spawning show peak WUA values at approximately 250–350 cfs, with relatively high WUA values from 175 to 475 cfs.

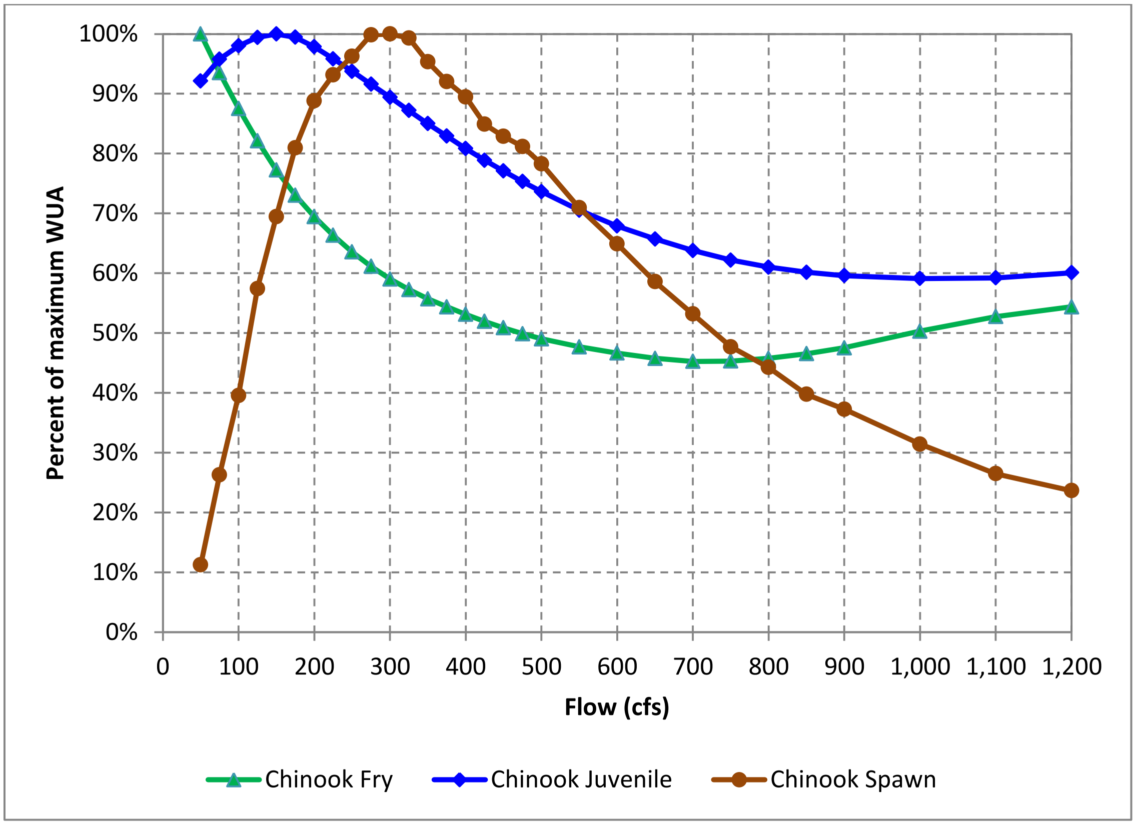

Figure 21. Chinook salmon WUA results for the lower Tuolumne River.

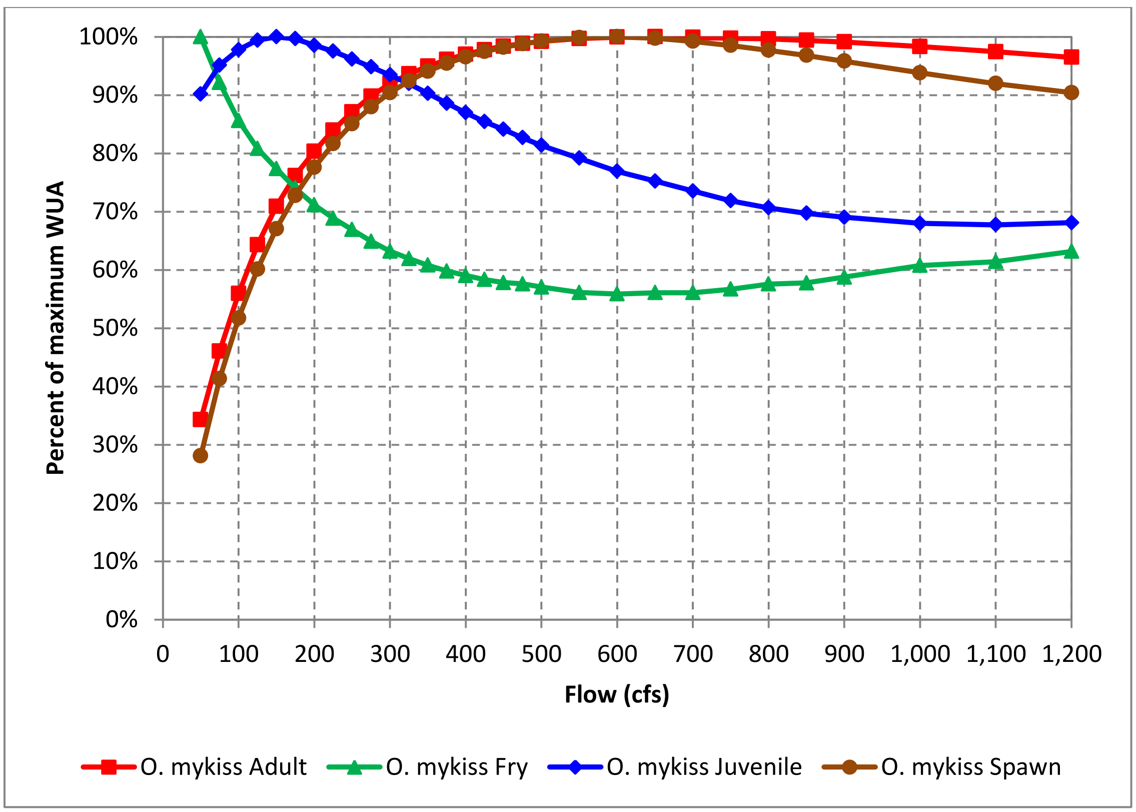

Figure 22. *O. mykiss* WUA results for the lower Tuolumne River.

Results for *O. mykiss* fry show peak WUA values below approximately 75 cfs, with relatively high WUA values at flows ≤125 cfs. Results for *O. mykiss* juveniles show peak WUA values at approximately 75–275 cfs, with relatively high WUA values at flows ≤500 cfs. Results for *O. mykiss* adults show peak WUA values at flows ≥350 cfs, with relatively high WUA values at flows ≥200 cfs. Results for *O. mykiss* spawning show peak WUA values at ≥375 cfs, with relatively high WUA values at flows ≥225 cfs.

3.3 Habitat Time Series

Habitat time series results for each of five water year types (using the San Joaquin River 60-20-20 Index) and five species and life stage combinations are presented in Figures 23 to 32. The time periods used in the habitat time series analysis when individual lifestages are most typically observed, or expected to be present, within the study reach are summarized in Table 16.

Under a Critical year scenario, Chinook salmon WUA values and flows stay relatively stable through the year, with two exceptions: 1) spawning habitat increases significantly in mid-October in association with a change in the spawning flow, and 2) fry and juvenile WUA drops in late spring in association with increased run-off or flood control releases (Figure 23). *O. mykiss* fry and juvenile WUA shows a similar pattern of WUA declines during spring flow peaks, but *O. mykiss* adults show a pattern of WUA changing in step with flows (i.e., higher when flows go up in the fall and spring, lower when they decline in summer) (Figure 24).

Under a Dry year scenario, a similar pattern to Critical years appears for Chinook salmon WUA, except that a relatively high spike in fall flows at the beginning of the spawning season actually depressed spawning WUA briefly (Figure 25). *O. mykiss* habitat for fry and juveniles declines with flow peaks in the spring and fall, and adult habitat varies up and down with flow (Figure 26).

Under a Below Normal year scenario, the same patterns as observed in drier years occur (Figures 27 and 28).

The Above Normal year exhibits an earlier and longer depression of Chinook salmon fry and juvenile WUA than drier years, in association with earlier and longer high spring flows or flood releases (Figure 29). *O. mykiss* WUA remains more stable (and higher for the adult life stage) than in other year types, except for drops in juvenile WUA in the spring (Figure 30).

The Wet year scenario creates stable, and lower, WUA areas for Chinook salmon fry and juveniles, with little change in spawning habitat (Figure 31). *O. mykiss* WUA is the most stable under Wet year flows, at higher WUA levels for adults and lower ones for fry and juveniles (Figure 32).

Figures 33 and 34 present HTS across all water year types for Chinook salmon and *O. mykiss*, respectively, and facilitate comparisons of patterns between water year types. Figure 33 documents that Chinook salmon WUA exhibits a similar pattern of annual fluctuation across all year types, except for juvenile and fry habitat that declines in wet years. Figure 34 shows that *O. mykiss* WUA displays a similar trend as Chinook salmon, although juvenile and fry WUA tends to be lower in both Above Normal and Wet water years. Adult *O. mykiss* WUA is typically higher and more stable in Above Normal and Wet years.

Table 16. Seasonal periodicity of Chinook salmon and *O. mykiss* life stages applied for the lower Tuolumne River habitat time series analysis.

		Fall			Winter			Spring			Summer		
Species	**Life stage**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Chinook salmon	Spawn	■	■	■									
	Fry				■	■	■						
	Juvenile					■	■	■	■	■			
O. mykiss	Spawn					■	■						
	Fry							■	■	■	■	■	■
	Juvenile	■	■	■	■	■	■	■	■	■	■	■	■

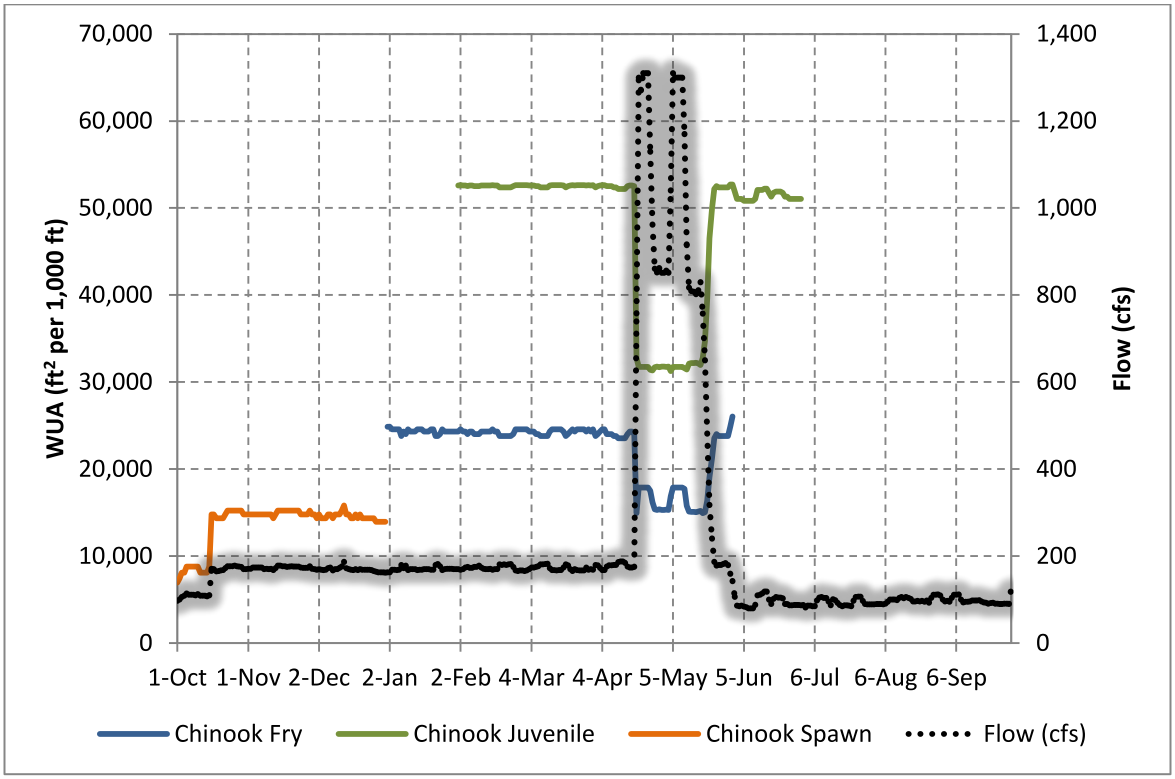

Figure 23. Habitat Time Series results for lower Tuolumne River Chinook salmon in a Critical water year (2008).

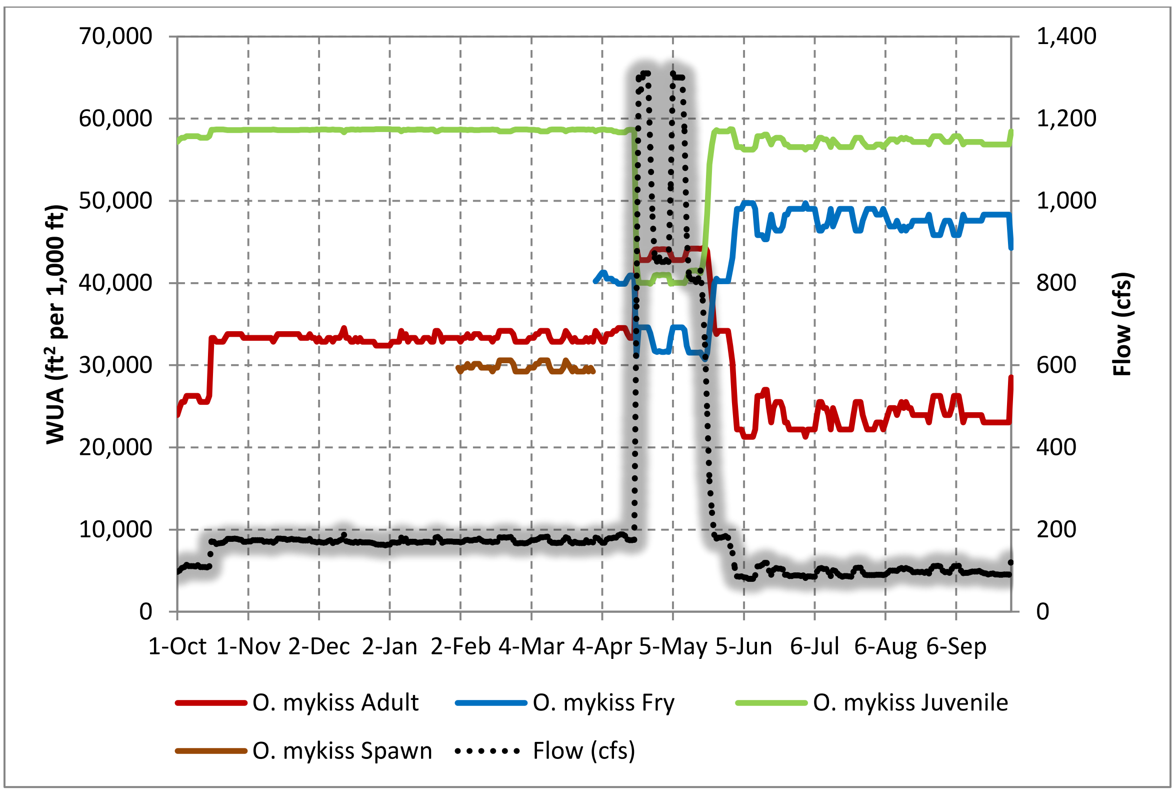

Figure 24. Habitat Time Series results for lower Tuolumne River *O. mykiss* in a Critical water year (2008).

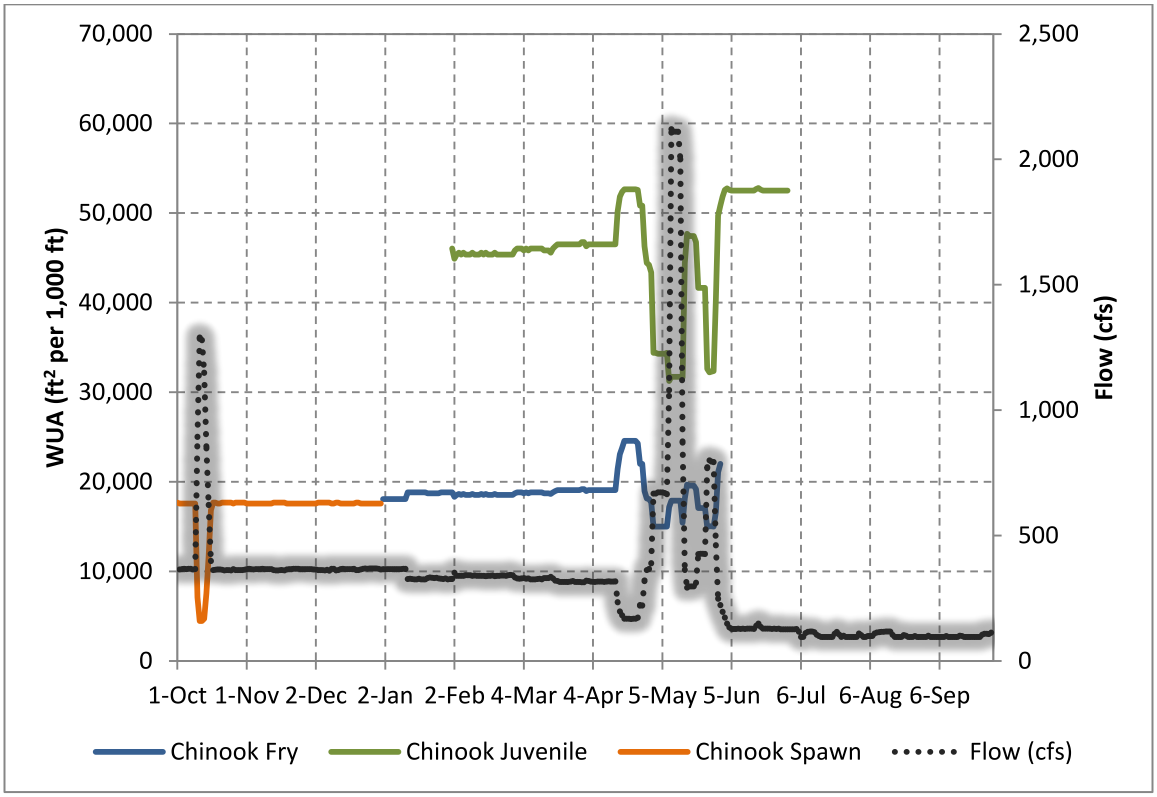

Figure 25. Habitat Time Series results for lower Tuolumne River Chinook salmon in a Dry water year (2012).

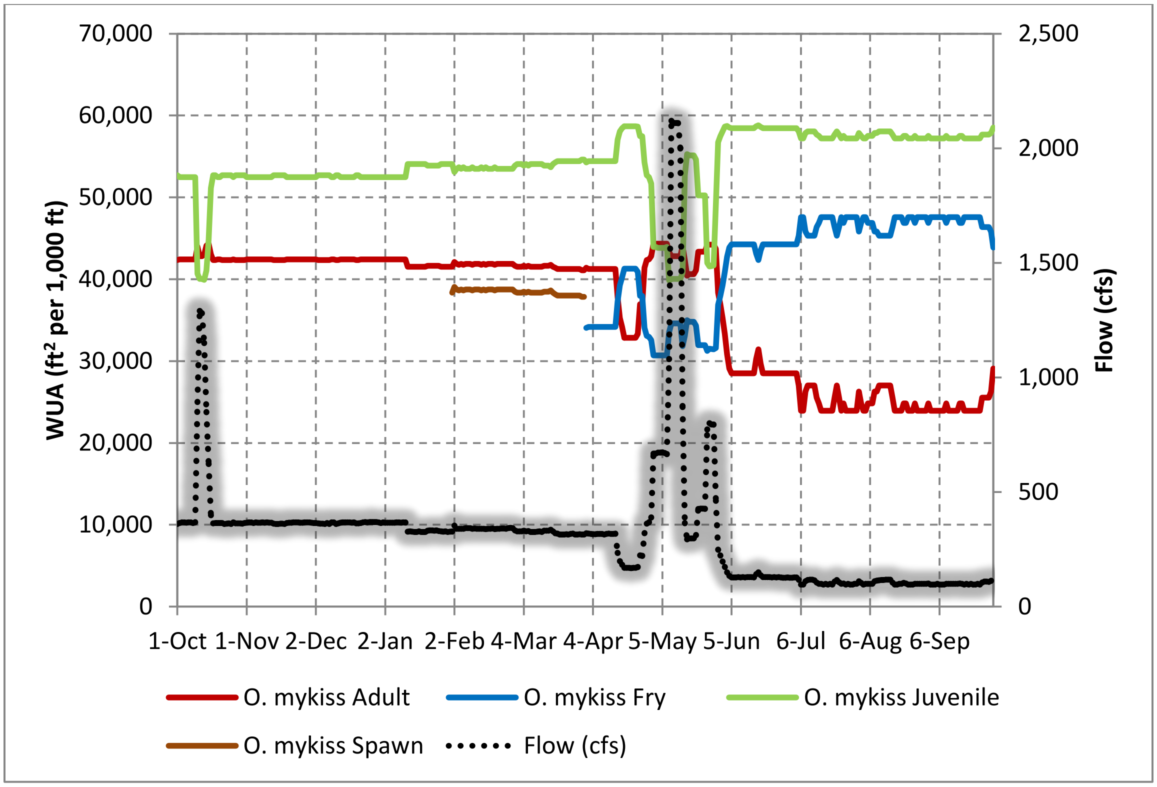

Figure 26. Habitat Time Series results for lower Tuolumne River *O. mykiss* in a Dry water year (2012).

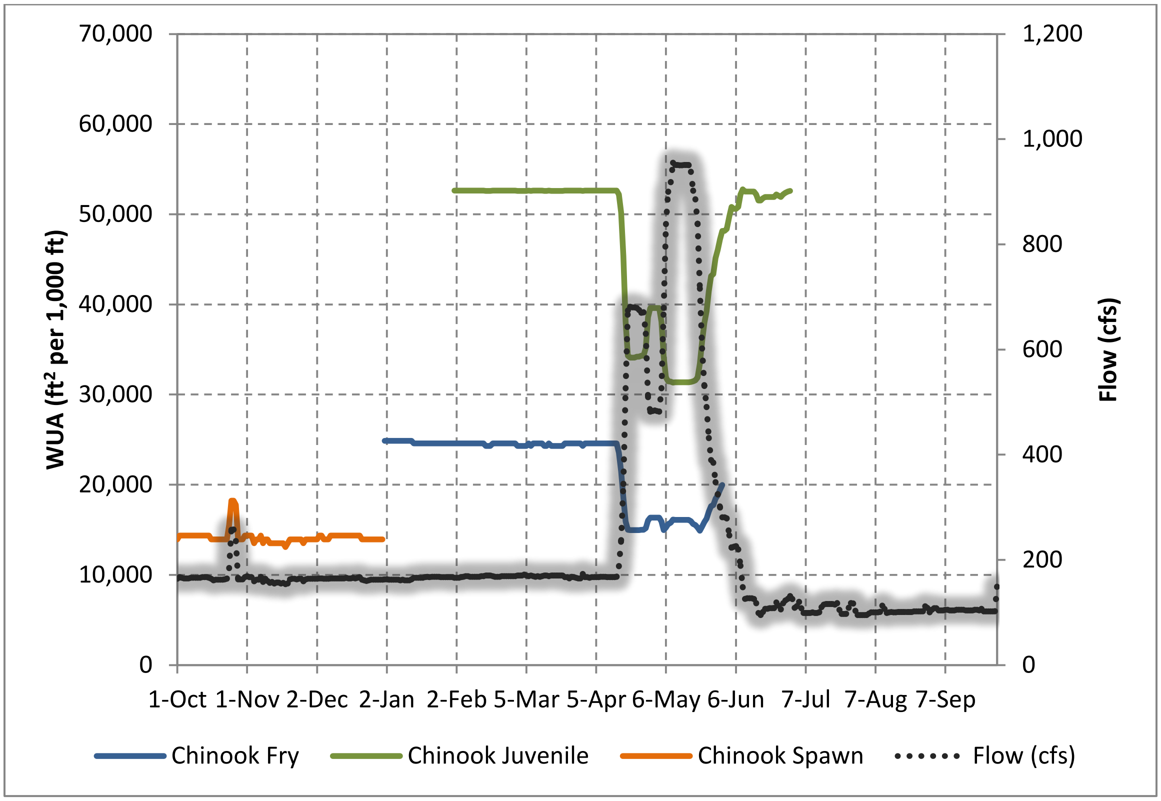

Figure 27. Habitat Time Series results for lower Tuolumne River Chinook salmon in a Below Normal water year (2009).

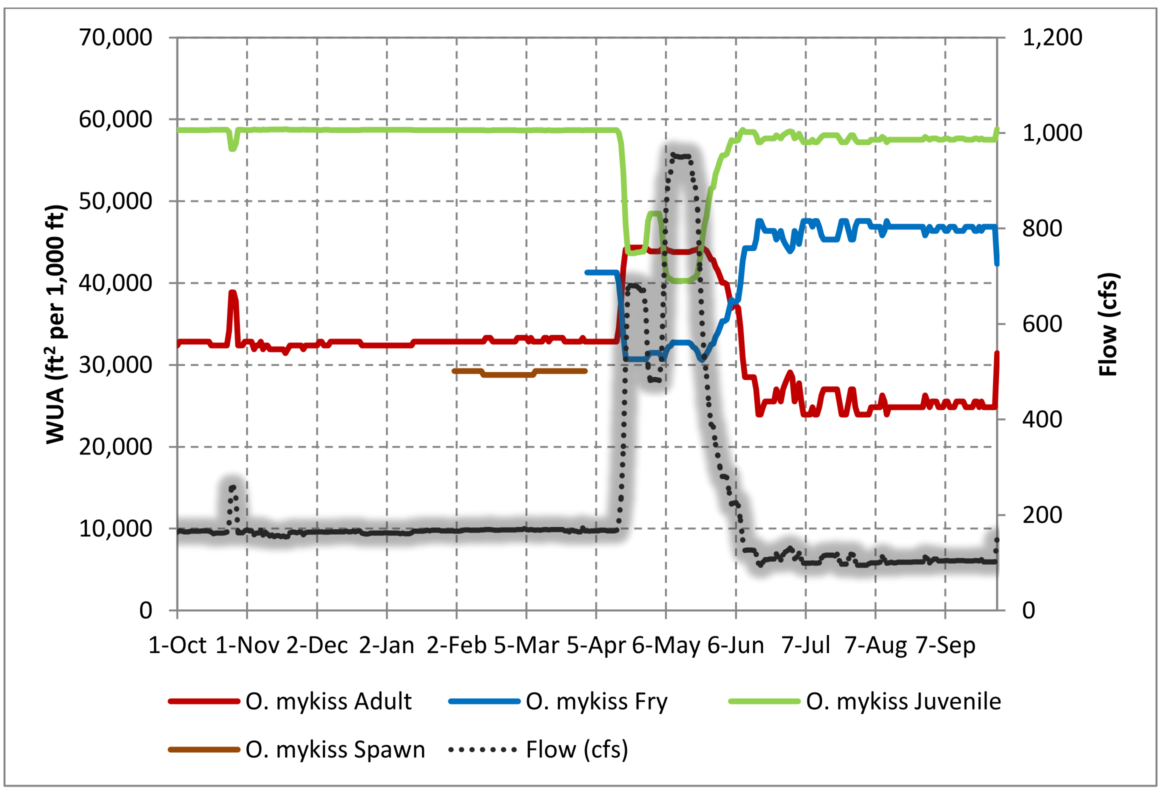

Figure 28. Habitat Time Series results for lower Tuolumne River *O. mykiss* in a Below Normal water year (2009).

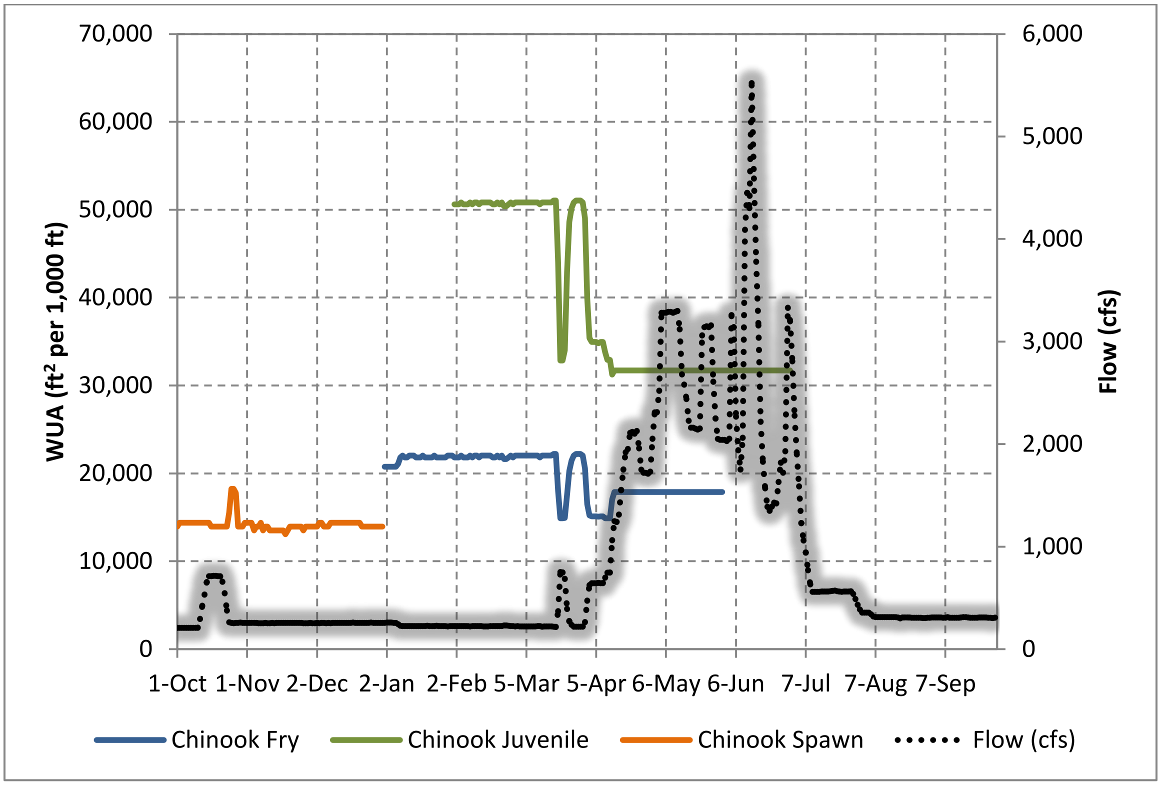

Figure 29. Habitat Time Series results for lower Tuolumne River Chinook salmon in an Above Normal water year (2010).

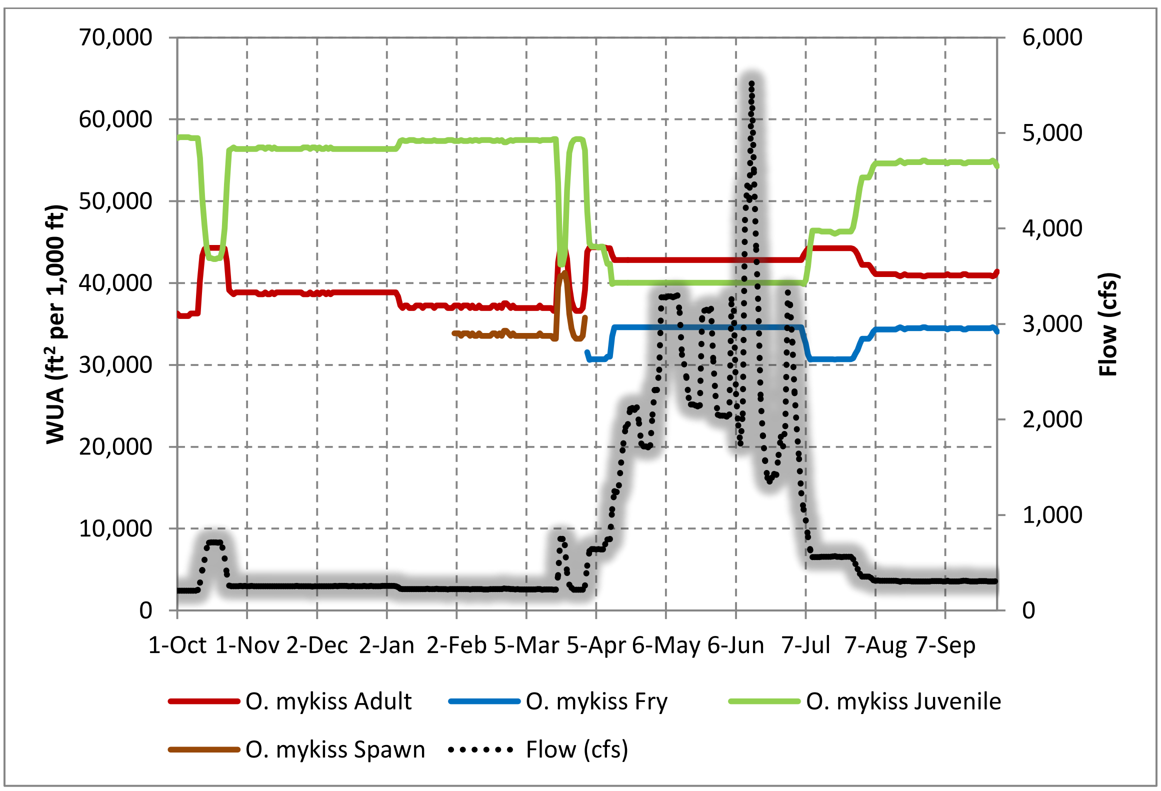

Figure 30. Habitat Time Series results for lower Tuolumne River *O. mykiss* in an Above Normal water year (2010).

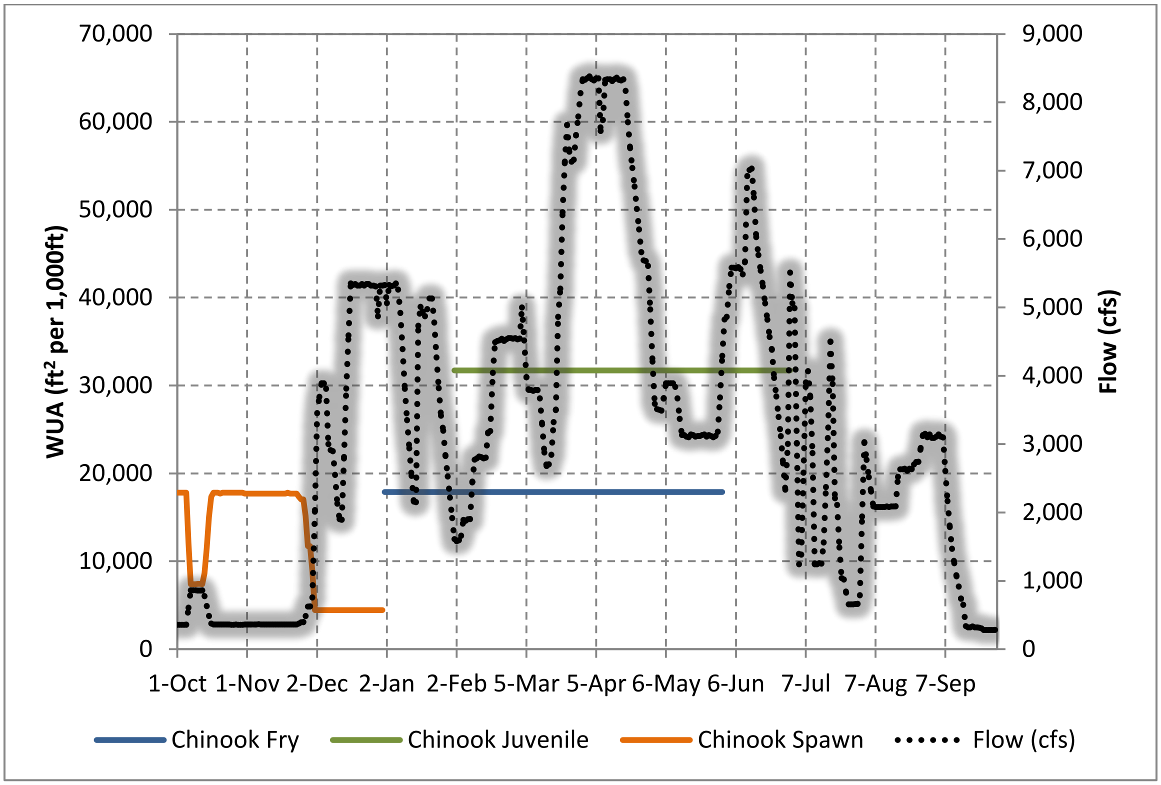

Figure 31. Habitat Time Series results for lower Tuolumne River Chinook salmon in a Wet water year (2011).

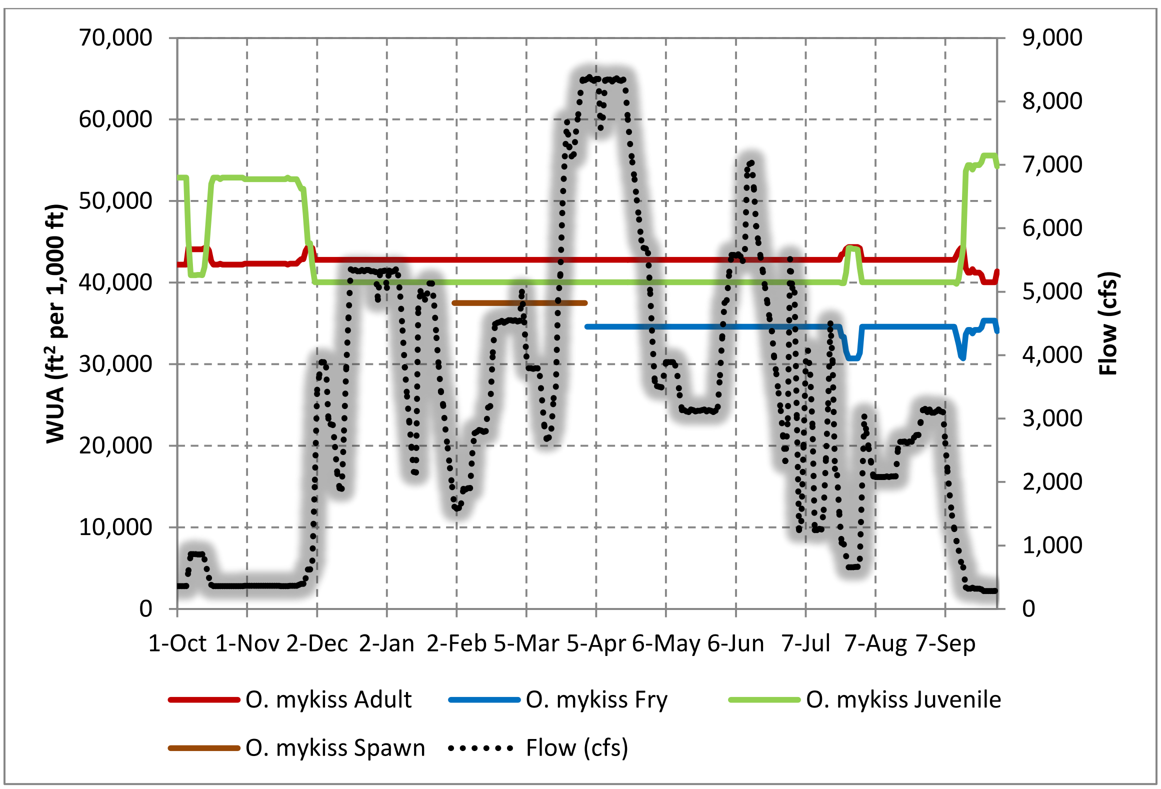

Figure 32. Habitat Time Series results for lower Tuolumne River *O. mykiss* in a Wet water year (2011).

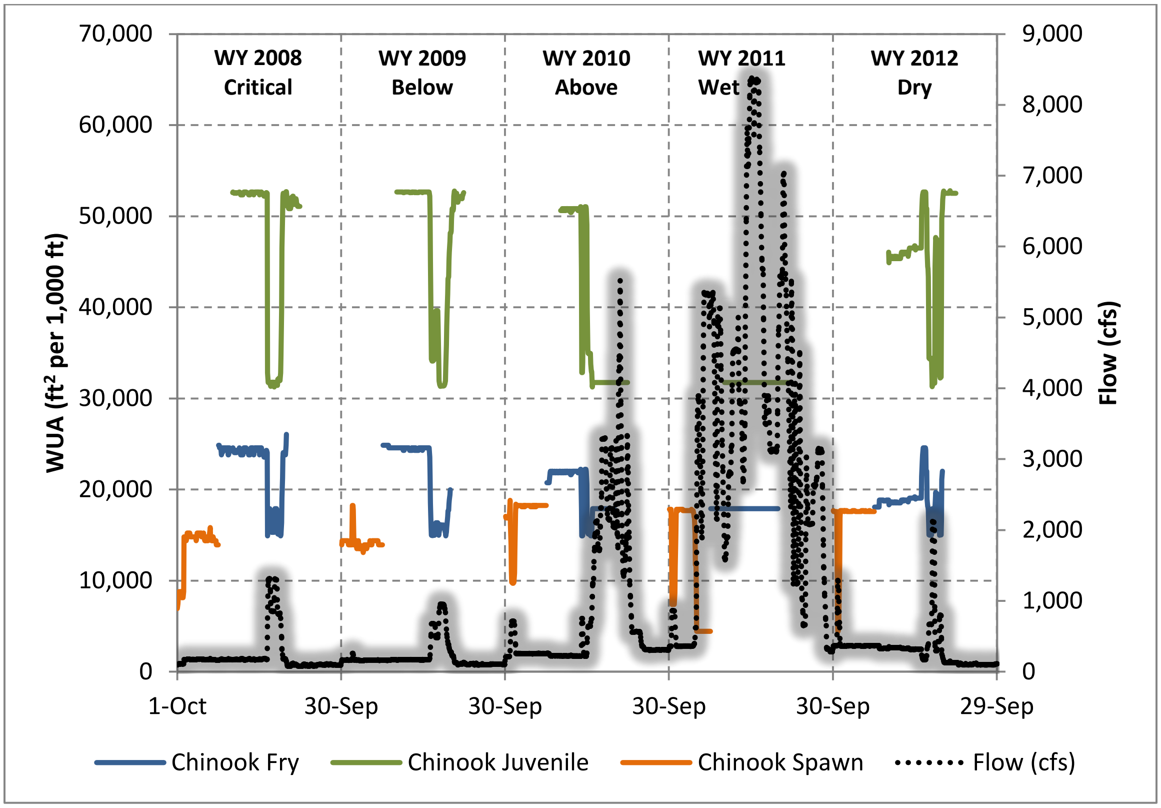

Figure 33. Habitat Time Series results for lower Tuolumne River Chinook salmon across all water year types.

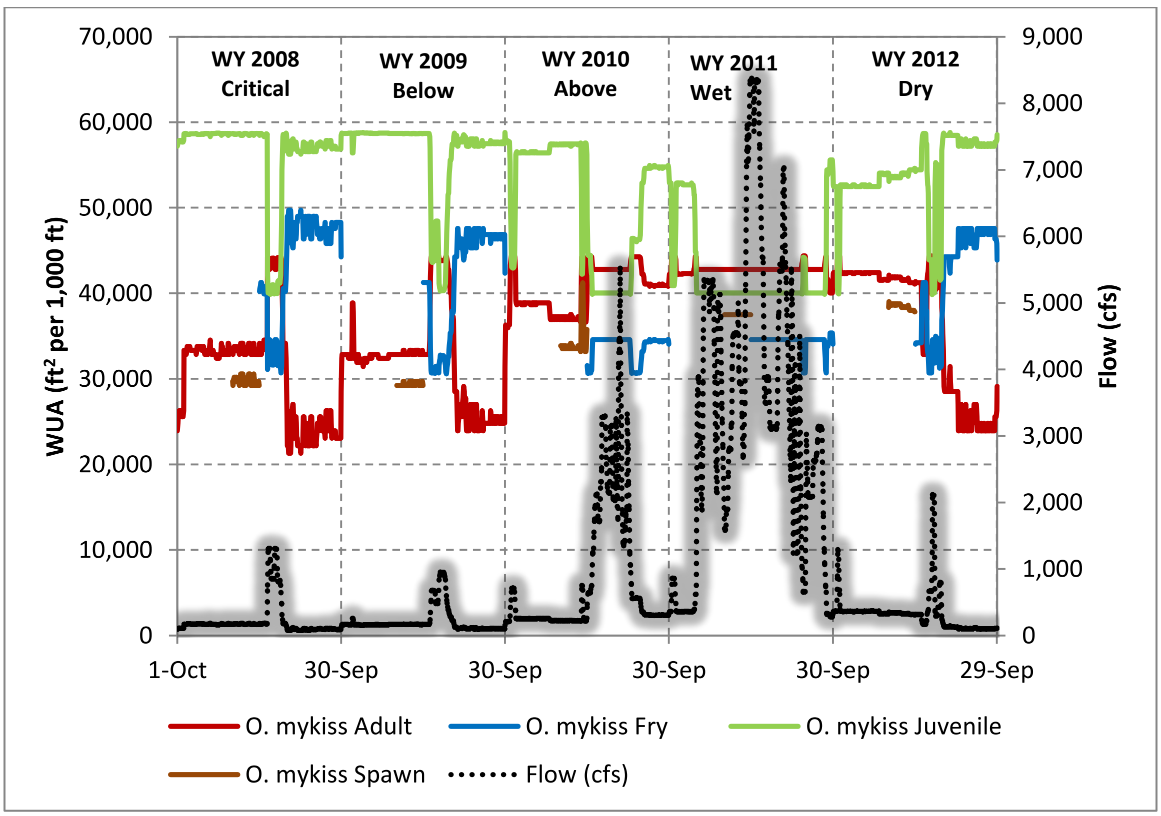

Figure 34. Habitat Time Series results for lower Tuolumne River *O. mykiss* across all water year types.

4 DISCUSSION

4.1 Habitat Suitability Criteria

4.1.1 Curve development

A variety of methods can be used for smoothing habitat suitability data and generating the resulting functions. The field data were collected in a manner that allows for alternative analytical techniques (such as logistic regression), as requested by technical workgroup participants and FERC. A primary advantage of the more traditional preference calculation methods from Bovee (1986) used here is that similar types of methods were used in the published studies that were included in the existing HSC data compilation and selection process. Thus, for validation purposes, the results calculated from the Tuolumne River site-specific data were most comparable to the other studies. Another advantage of the employed method is that it is non-parametric; the shape of the resulting preference curve is determined by the data, whereas the logistic regression approach (Guay et al. 2000) produces a parametric curve (a curve of a particular algebraic form, in this case 1/(1+exp(-P(substrate, velocity, depth))), where P is a polynomial) that may result in a less precise match to the underlying observations.

The kernel density approach used for this study is simply an implementation of the Bovee (1986) preference calculation method. The use of the kernel density estimation (versus an assessment using histograms) produces smooth curves instead of step functions, which is particularly helpful with small sample sizes (i.e., n<150).

4.1.2 Unlimited Depth Suitability

During the technical workgroup discussions of habitat suitability criteria, existing depth criteria for *O. mykiss* spawning and adults were selected that maintain maximum suitability to large or unlimited depths (Figures 16 and 19, respectively). Part of the reasoning behind these HSC is that, as a species that uses both riverine and lacustrine environments, *O. mykiss* are assumed to find any or most depths above some minimum to be suitable, as long as the velocities are sufficient. What is not known, or easily testable in the real world (because great depths with faster velocities rarely occur), is whether suitability is actually maximized at these greater depths, or whether deeper habitat is simply suitable at some lower index value.

In order to test the implications of this assumption, depth-limited criteria were applied to the *O. mykiss* adult and spawning life stages (and paired with existing velocity and substrate HSC, as applicable) to test whether a depth limitation substantively affected the WUA versus flow results. The depth-limited *O. mykiss* spawning HSC were from Bovee (1978), and adult depth HSC from an envelope curve drawn over a database from two dozen other studies (Appendix G, Figures 22 and 23).

The result of this comparison is presented in Figure 35. When depth limitations are applied, the spawning results for *O. mykiss* are significantly different, with a distinct WUA peak around 150 cfs (versus no distinct peak and maximum WUA at >350 cfs), a somewhat lower peak flow than observed for Chinook salmon spawning. Adult *O. mykiss* WUA peaks at 200-450 cfs versus >350 cfs without depth limitation.

These results suggest that if common depth limitations of alluvial rivers and the site-specific *O. mykiss* adult HSC data collected to date from the lower Tuolumne River are considered, the WUA versus flow relationship for the *O. mykiss* spawning and adult life stages are likely better represented by the results of this alternate analysis.

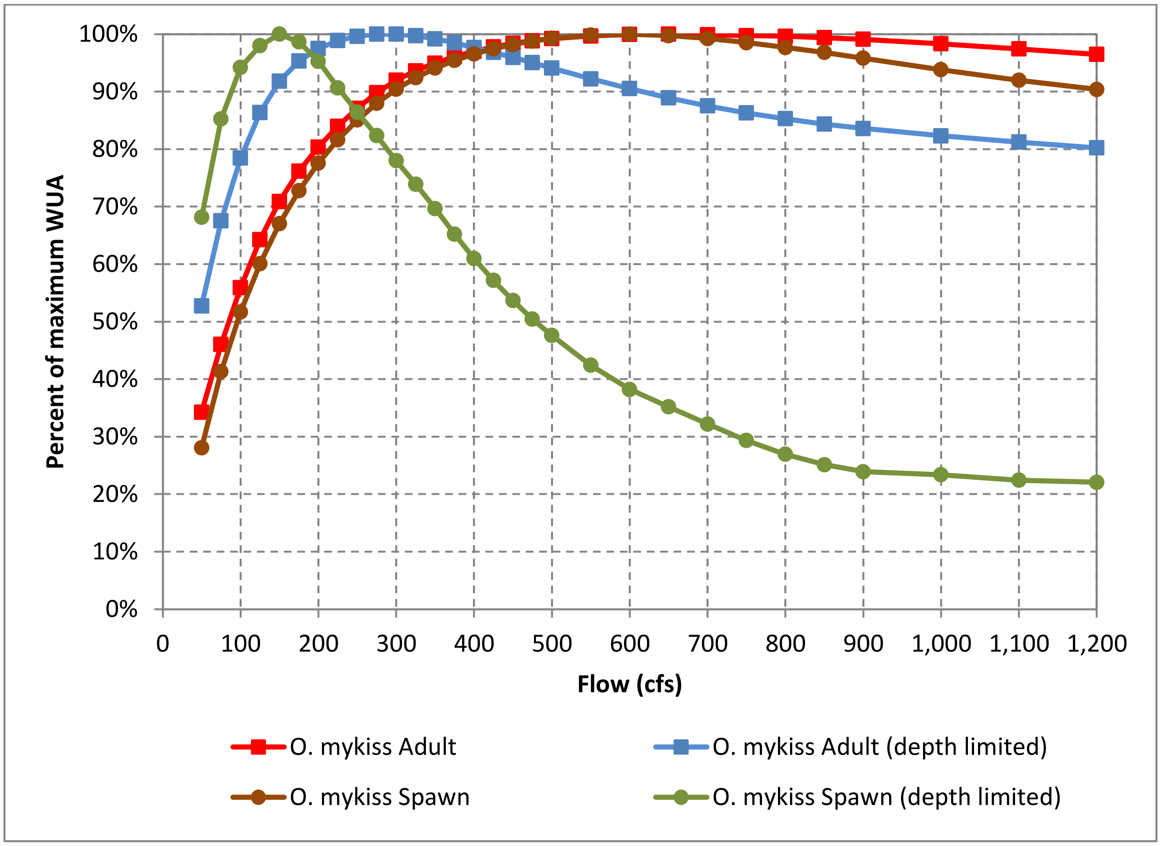

Figure 35. *O. mykiss* WUA results for the lower Tuolumne River using limited depth criteria.

4.1.3 Substrate and Cover Parameters

Both substrate (for spawning) and cover (for Chinook fry) parameters were included in the analysis. Use of a substrate parameter can sometimes give misleading results if the suitable substrate has a patchy distribution that is not well sampled with transect methods, leading to under-representation of available spawning substrate. To test for this scenario, the model was run with both substrate criteria and with “all substrates are suitable” criteria. The similarity of the results for Chinook salmon (Appendix H, Figure H-4) suggests that a lot of the sampled area with suitable hydraulic conditions for spawning also had suitable substrates; thus, the distribution of spawning gravels was not particularly patchy, and was well-sampled with transect methods. This is also consistent with the observations from other gravel mapping studies that document broad distribution of suitable Chinook spawning gravels in Tuolumne River riffle habitats (TID/MID 2013b). The larger disparity in results for *O. mykiss* spawning (Appendix H, Figure H-5) suggests that *O. mykiss* spawning gravels were less frequently encountered along the transects; however, the patchier distribution does not change the shape of the WUA versus flow relationship, but only its magnitude.

The importance of cover as a habitat parameter may vary considerably depending on the species, life stage, and river characteristics. In order to evaluate the effect of the cover parameter on the WUA results, the model was run both with and without cover for Chinook fry. The results presented in Appendix H (Figure H-3) suggest that cover has a relatively small influence in the magnitude of WUA, and no influence on the WUA versus flow relationship.

4.2 Comparison to Prior PHABSIM Study Results

Two prior instream flow studies of the lower Tuolumne River examined flow and habitat relationships for Chinook salmon and *O. mykiss*. Additionally, the current PHABSIM model was run using the same criteria included by USFWS in the 1995 study. Although the geographical extent, intensity of sampling, and habitat suitability criteria were different between the studies, a careful comparison of the results corroborates certain WUA versus flow relationships in the lower Tuolumne River (Table 17). See Appendix J for comparison graphics from these studies.

Results from all the studies indicate that WUA for the Chinook fry and juvenile is maximized at lower flows, with juveniles maintaining high habitat values up to around 300 cfs (Table 17). Similarly, there is agreement between the studies that Chinook salmon spawning WUA is maximized at flows between 175 and 400 cfs. There is more variation in the *O. mykiss* results; juvenile habitat is maximized in the 50-350 cfs range, and adult WUA is maximized in the 150-400 cfs range (Table 17 and Appendix J).

Although the current instream flow study is the most robust one to date, and uses current HSC, the results do not fundamentally conflict with those of prior studies.

Table 17. Lower Tuolumne River instream flow study result comparisons of maximum weighted usable area (WUA) results between 1981, 1995, and 2013.

Species/Life stage	TID/MID 2013	TID/MID 2013 (FWS 1995 HSC)[1]	FWS 1995[2]	CDFG 1981[3]
Chinook Fry	≤100 cfs	≤100 cfs	<75 cfs	40-280 cfs
Chinook Juvenile	50-300 cfs	50-400 cfs	75-225 cfs	80-340 cfs
Chinook Spawn	200-400 cfs	200-400 cfs	175-325 cfs	180-360 cfs
O. mykiss Fry	<125 cfs	--	--	--
O. mykiss Juvenile	50-350 cfs	100-300 cfs	50-170 cfs	40-140 cfs
O. mykiss Adult	>275 cfs	>200 cfs	50-425 cfs	140-280 cfs
O. mykiss Spawn	>225 cfs	--	--	--

[1] These results reflect the current PHABSIM model run with the HSC used in the FWS 1995 study.
[2] The USFWS 1995 study did not include *O. mykiss* fry and spawning criteria and limited the simulations for rainbow trout to 500 cfs, primarily as a means of evaluating summer conditions. Rainbow trout results were reported separately by habitat type only (i.e., riffle, run/glide, and pool) with significant habitat indicated as being primarily associated with riffle and run/glide types.
[3] The CDFG 1981 study simulated results to 600 cfs and did not include *O. mykiss* fry and spawning criteria. This study showed contrasting results for Chinook fry and juvenile between the two study reaches, with a 1991 reanalysis (TID/MID 1992b) documenting that the lower reach (Reach 2) results were disproportionally due to the influence of a single transect. As a consequence, only the results from Reach 1 are included above in order to maximize comparability of the data.

4.3 Effective Habitat

An "effective" habitat analysis was originally included in the study plan in order to examine the relationship between water temperature suitability and WUA.[6] The intent of the analysis was to

[6] "Effective Habitat" as discussed in Bovee (1982) often refers to an evaluation of habitat bottlenecks for particular life stages, and is applied as a type of population modeling exercise using habitat ratios. In this context, effective habitat is being used to refer to the moderating influence of water temperature on the WUA vs. flow relationship. For example, a longer reach of suitable temperature with a lower WUA value per unit length can have more "effective habitat" than a shorter reach with higher WUA. Since flow affects

better understand the tradeoffs between flow, WUA, and water temperature, since prior investigations and ongoing studies indicate that there may be an optimum balance between these parameters. For example, higher flows (presuming cold water releases) can push colder water temperatures further downstream, thereby increasing thermally suitable habitat area for salmonids. At the same time, WUA (which is largely based on hydraulics) for younger life stages typically decreases with higher flows, and can result in a net decrease in the combined hydraulic/thermal suitability of the habitat. Conversely, lower flows may provide higher WUA, but the combined hydraulic/thermal suitability can be compromised if the water temperature is unsuitable over too large a portion of the reach.

Study results to date provide the WUA information to pursue an effective habitat analysis. However, water temperature models of the lower Tuolumne River are currently being updated and reviewed for use in a variety of analyses. In order to use the most current temperature model (and a consistent one between studies) for the effective habitat analysis, further evaluations will be completed following the completion of the latest temperature model (relicensing Study W&AR-16). Completion of this analysis is anticipated by September 30, 2013, using the methods described in section 2.9.

4.4 Other Factors

Weighted usable area results are one consideration in the evaluation of factors affecting overall production of salmon and *O. mykiss* in the Tuolumne River. In addition to these results, numerous other factors such as geomorphic processes, water temperature, population dynamics, predation, spawning conditions, ocean harvest and other out-of-basin effects, and a variety of other factors affect fish and flow management options for the lower Tuolumne River. The most important in-river factors are the subject of detailed studies being conducted as part of the Don Pedro Project Relicensing process (TID/MID 2013a), which include:

- W&AR-4 Spawning Gravel Study
- W&AR-5 Salmonid Population Synthesis
- W&AR-6 Chinook Salmon Population Model
- W&AR-7 Predation Study
- W&AR-8 Salmonid Redd Mapping
- W&AR-10 *O. mykiss* Population Model
- W&AR-11 Chinook Salmon Otolith Study
- W&AR-12 *O. mykiss* Habitat Study
- W&AR-16 Temperature Model
- W&AR-20 *O. mykiss* Age Determination Study

These study results and other information will be used in developing recommendations for fish and flow management in the lower Tuolumne River as part of the relicensing process.

4.5 Next Steps

This report complies with requirements of the original July 16, 2009 FERC Order and subsequent directives to conduct a study "to determine instream flows necessary to maximize fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* production and survival throughout their various life stages." The information provided herein can be used, along with other

both the WUA and temperature parameter suitability in opposing directions for some life stages, the effective habitat is moderated by the balance between these parameters.

information being developed as part of ongoing relicensing studies, to examine potential flow-related effects on these species and understand the implications of various flow regime management actions.

Observations during the conduct of this study, and results of prior studies, indicate that there are flow-related WUA and water temperature trade-offs at some times of the year for some life stages. This relationship will be examined as part of an effective habitat analysis described previously in section 4.3.

Additionally, FERC included an instream flow study requirement within the December 22, 2011 Relicensing Study Plan Determination, which expanded the scope of this study to include instream flow habitat relationships for Sacramento splittail and Pacific lamprey (if existing HSC are available). The results of that assessment, using HSC provided by the USFWS on April 8, 2013, are expected to be available by July 30, 2013.

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