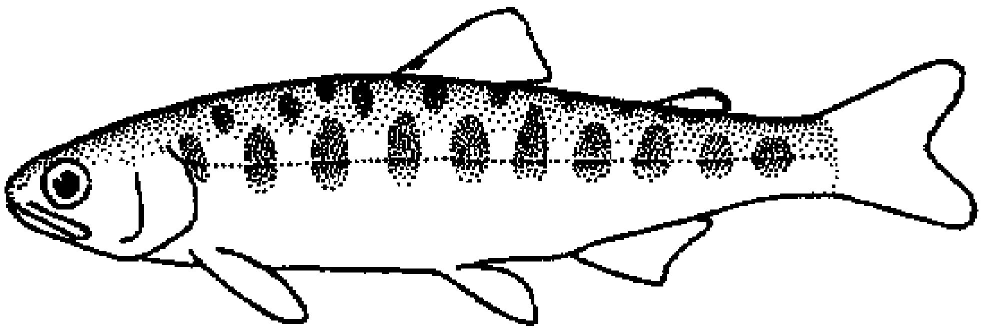
FLOW-HABITAT RELATIONSHIPS FOR JUVENILE SPRING-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT REARING IN CLEAR CREEK BETWEEN WHISKEYTOWN DAM AND CLEAR CREEK ROAD



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PREFACE

The following is the final report for the U.S. Fish and Wildlife Service's investigations on anadromous salmonid rearing habitat in Clear Creek between Whiskeytown Dam and Clear Creek Road, part of the Central Valley Project Improvement Act (CVPIA) Instream Flow and Fisheries Investigations, an effort which began in October, 2001.[1] Title 34, Section 3406(b)(1)(B) of the CVPIA, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service after consultation with the California Department of Fish and Game. The purpose of these investigations is to provide scientific information to the U.S. Fish and Wildlife Service CVPIA Program to assist in developing such recommendations for Central Valley rivers.

Written comments or information can be submitted to and raw data in digital format can be obtained from:

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[1] This program is a continuation of a 7-year effort, also titled the Central Valley Project Improvement Act Instream Flow Investigations, which ran from February 1995 through September 2001.

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ABSTRACT

Flow-habitat relationships were derived for spring-run Chinook salmon and steelhead/rainbow trout fry and juvenile rearing in Clear Creek between between Whiskeytown Dam and Clear Creek Bridge. A 2-dimensional hydraulic and habitat model (River2D) was used for this study to model available habitat. Habitat was modeled for 11 sites which were representative of the mesohabitat types available in the study segments for spring-run Chinook salmon and steelhead/rainbow trout fry and juvenile rearing. Bed topography was collected for these sites using a total station, wading in dry and shallow portions of the sites and using a single person cataraft for deeper pools. Additional data were collected to develop stage-discharge relationships at the upstream and downstream end of the sites as an input to River2D. Velocities measured at locations throughout the site were used to validate the velocity predictions of River2D. The raw topography data were refined by defining breaklines going up the channel along features such as thalwegs, tops of bars and bottoms of banks. A finite element computational mesh was then developed to be used by River2D for hydraulic calculations. River2D hydraulic data were calibrated by adjusting bed roughnesses until simulated water surface elevations matched measured water surface elevations. The calibrated files for each site were used in River2D to simulate hydraulic characteristics for 23 simulation flows. Habitat suitability criteria (HSC) were developed from depth, velocity, adjacent velocity and cover measurements collected at the locations of 202 spring-run Chinook salmon fry, 426 steelhead/rainbow trout fry and 191 spring-run Chinook salmon and steelhead/rainbow trout juvenile observations. Logistic regression was used to develop the HSC. The 2-D model predicts the highest total weighted usable area values (WUA) for: 1) spring-run Chinook salmon fry at 600 cubic feet/second (cfs) in the Upper Alluvial Segment and 900 cfs in the Canyon Segment; 2) steelhead/rainbow trout fry at 700 cfs in the Upper Alluvial Segment and 900 cfs in the Canyon Segment; and 3) spring-run Chinook salmon and steelhead/rainbow trout juveniles at 900 cfs in the Upper Alluvial Segment and 650 cfs in the Canyon Segment. The results of this study suggest that the flow recommendations in the CVPIA Anadromous Fish Restoration Program during the spring-run Chinook salmon and steelhead/rainbow trout rearing period of October-September (150-200 cfs) may not be close to achieving maximum habitat availability and productivity for rearing spring-run Chinook salmon and steelhead/rainbow trout in Clear Creek (50 to 64 % of maximum WUA).

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act provided for enactment of all reasonable efforts to double sustainable natural production of anadromous fish stocks including the four races of Chinook salmon (fall, late-fall, winter, and spring-runs), steelhead, white and green sturgeon, American shad and striped bass. Clear Creek is a tributary of the Sacramento River, located in the Sacramento River basin portion of the Central Valley of California. For Clear Creek, the Central Valley Project Improvement Act Anadromous Fish Restoration Plan calls for a release from Whiskeytown Dam of 200 cfs from October through June and a release of 150 cfs or less from July through September (U. S. Fish and Wildlife Service 2001) as a high priority action to restore anadromous fish populations in Clear Creek. The Clear Creek study was planned to be a 5-year effort, the goals of which were to determine the relationship between stream flow and physical habitat availability for all life stages of Chinook salmon (fall- and spring-run) and steelhead/rainbow trout. There were four phases to this study based on the life stages to be studied and the number of segments delineated for Clear Creek from downstream of Whiskeytown Reservoir to the confluence with the Sacramento River[2]. Rearing habitat study sites for the second phase of the study were selected that encompassed the upper two segments of the creek. The goal of this report was to produce models predicting the availability of physical habitat in Clear Creek between Whiskeytown Dam and Clear Creek Road for spring-run Chinook salmon and steelhead/rainbow trout rearing over a range of stream flows that meet, to the extent feasible, the levels of accuracy specified in the methods section. Flow-habitat relationships for Chinook salmon and steelhead/rainbow trout fry and juvenile rearing in the Lower Alluvial Segment will be addressed in a future report. The tasks and their associated objectives are given in Table 1.

To develop a flow regime which will accommodate the habitat needs of anadromous species inhabiting streams, it is necessary to determine the relationship between streamflow and habitat availability for each life stage of those species. We are using the models and techniques contained within the Instream Flow Incremental Methodology (IFIM) to establish these relationships. The IFIM is a habitat-based tool developed by the U.S. Fish and Wildlife Service to assess instream flow problems (Bovee 1996). The decision variable used by the IFIM is total habitat, in units of Weighted Useable Area (WUA), for each life stage (fry, juvenile and rearing) of each evaluation species (or race as applied to Chinook salmon). Habitat incorporates both macro- and microhabitat features. Macrohabitat features include longitudinal changes in channel characteristics, base flow, water quality, and water temperature. Microhabitat features include

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[2] There are three segments: the Upper Alluvial segment, the Canyon segment, and the Lower Alluvial segment. Spring-run Chinook salmon spawn in the upper two segments, fall-run Chinook salmon spawn in the lower segment and steelhead/rainbow trout spawn in all three segments.

Table 1. Study tasks and associated objectives.

Task	Objective
study segment selection	determine the number and aerial extent of study segments
habitat mapping	delineate the aerial extent and habitat type of mesohabitat units
field reconnaissance and study site selection	select study sites which adequately represent the mesohabitat types present in the study segments
transect placement (study site setup)	delineate the upstream and downstream boundaries of the study sites, coinciding with the boundaries of the mesohabitat units selected for study
hydraulic and structural data collection	collect the data necessary to develop stage-discharge relationships at the upstream and downstream boundaries of the site, to develop the site topography and cover distribution, and to use in validating the velocity predictions of the hydraulic model of the study sites
hydraulic model construction and calibration	predict depths and velocities throughout the study sites at a range of simulation flows
habitat suitability criteria data collection	collect depth, velocity, adjacent velocity and cover data for spring-run Chinook salmon and steelhead/rainbow trout to be used in developing habitat suitability criteria
habitat suitability criteria development	develop indices to translate the output of the hydraulic models into habitat quality
habitat simulation	compute weighted useable area for each study site over a range of simulation flows using the habitat suitability criteria and the output of the hydraulic model

the hydraulic and structural conditions (depth, velocity, substrate or cover) which define the actual living space of the organisms. The total habitat available to a species/life stage at any streamflow is the area of overlap between available microhabitat and suitable macrohabitat conditions.

A conceptual model of the link between rearing habitat and population change may be described as follows. Changes in flows result in changes in depths and velocities. These changes, in turn, along with the distribution of cover, alter the amount of habitat area for fry and juvenile rearing for anadromous salmonids. Changes in the amount of habitat for fry and juvenile rearing could affect rearing success through alterations in the conditions that favor fry and juvenile growth and promote survival. These alterations in rearing success could ultimately result in changes in salmonid populations.

There are a variety of alternative techniques available to evaluate fry and juvenile rearing habitat, but they can be broken down into three general categories: 1) biological response correlations; 2) demonstration flow assessment; and 3) habitat modeling (Annear et al. 2002). Biological response correlations can be used to evaluate rearing habitat by examining juvenile production estimates at different flows (Hvidsten 1993). Disadvantages of this approach are: 1) difficulty in separating out effects of flows from year to year variation in escapement and other factors; 2) the need for many years of data; 3) the need to assume a linear relationship between juvenile production and flow between each observed flow; and 4) the inability to extrapolate beyond the observed range of flows. Demonstration flow assessments (CIFGS 2003) use direct observation of river habitat conditions at several flows; at each flow, polygons of habitat are delineated in the field. Disadvantages of this approach are: 1) the need to have binary habitat suitability criteria; 2) limitations in the accuracy of delineation of the polygons; 3) the need to assume a linear relationship between habitat and flow between each observed flow; and 4) the inability to extrapolate beyond the observed range of flows (Gard 2009). Modeling approaches are widely used to assess the effects of instream flows on fish habitat availability despite potential assumption, sampling, and measurement errors that, as in the other methods described above, can contribute to the uncertainty of results. Based on the above discussion, we selected habitat modeling as the technique to be used for evaluating anadromous salmonid rearing habitat in Clear Creek.

Flows that are being evaluated for management range from a minimum of 50 cubic feet per second (cfs) (the minimum required release from Whiskeytown Dam) to a maximum of 900 cfs (75% of the outlet capacity of the controlled flow release from Whiskeytown Dam). Accordingly, the range of study flows encompasses the range of flows that are being evaluated for management. The assumptions of this study are: 1) physical habitat is the limiting factor for salmonid populations in Clear Creek between Whiskeytown Dam and Clear Creek Bridge; 2) rearing habitat quality can be characterized by depth, velocity, adjacent velocity and cover; 3) the 11 study sites are representative of anadromous salmonid rearing habitat in Clear Creek between Whiskeytown Dam and Clear Creek Bridge; and 4) theoretical equations of physical processes along with a description of stream bathymetry and roughness and a stage-discharge relationship provide sufficient input to simulate velocity distributions through a study site.

METHODS

Approach

A two-dimensional model, River2D Version 0.93 November 11, 2006 by P. Steffler, A. Ghanem, J. Blackburn and Z. Yang (Steffler and Blackburn 2002) was used for predicting Weighted Useable Area (WUA), instead of the Physical Habitat Simulation (PHABSIM[3]). River2D inputs include the bed topography and bed roughness, and the water surface elevation at the downstream end of the site. The amount of habitat present in the site is computed using the depths and velocities predicted by River2D, and the substrate and cover present in the site. River2D avoids problems of transect placement, since data are collected uniformly across the entire site. River2D also has the potential to model depths and velocities over a range of flows more accurately than would PHABSIM because River2D takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's Equation (Leclerc et al. 1995) and a velocity adjustment factor. Other advantages of River2D are that it can explicitly handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions (Ghanem et al. 1996, Crowder and Diplas 2000, Pasternack et al. 2004). With appropriate bathymetry data, the model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. River2D, with compact cells, should be more accurate than PHABSIM, with long rectangular cells, in capturing longitudinal variation in depth, velocity and substrate. River2D should do a better job of representing patchy microhabitat features, such as gravel patches. The data for two-dimensional modeling can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate and cover. Bed topography and substrate/cover mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the up- and downstream ends of the site and flow, and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

The upstream and downstream transects were modeled with the PHABSIM component of IFIM to provide water surface elevations as an input to the 2-D hydraulic and habitat model (River2D, Steffler and Blackburn 2002) used in this study (Figure 1). By calibrating the upstream and downstream transects with PHABSIM using the collected calibration water surface elevations

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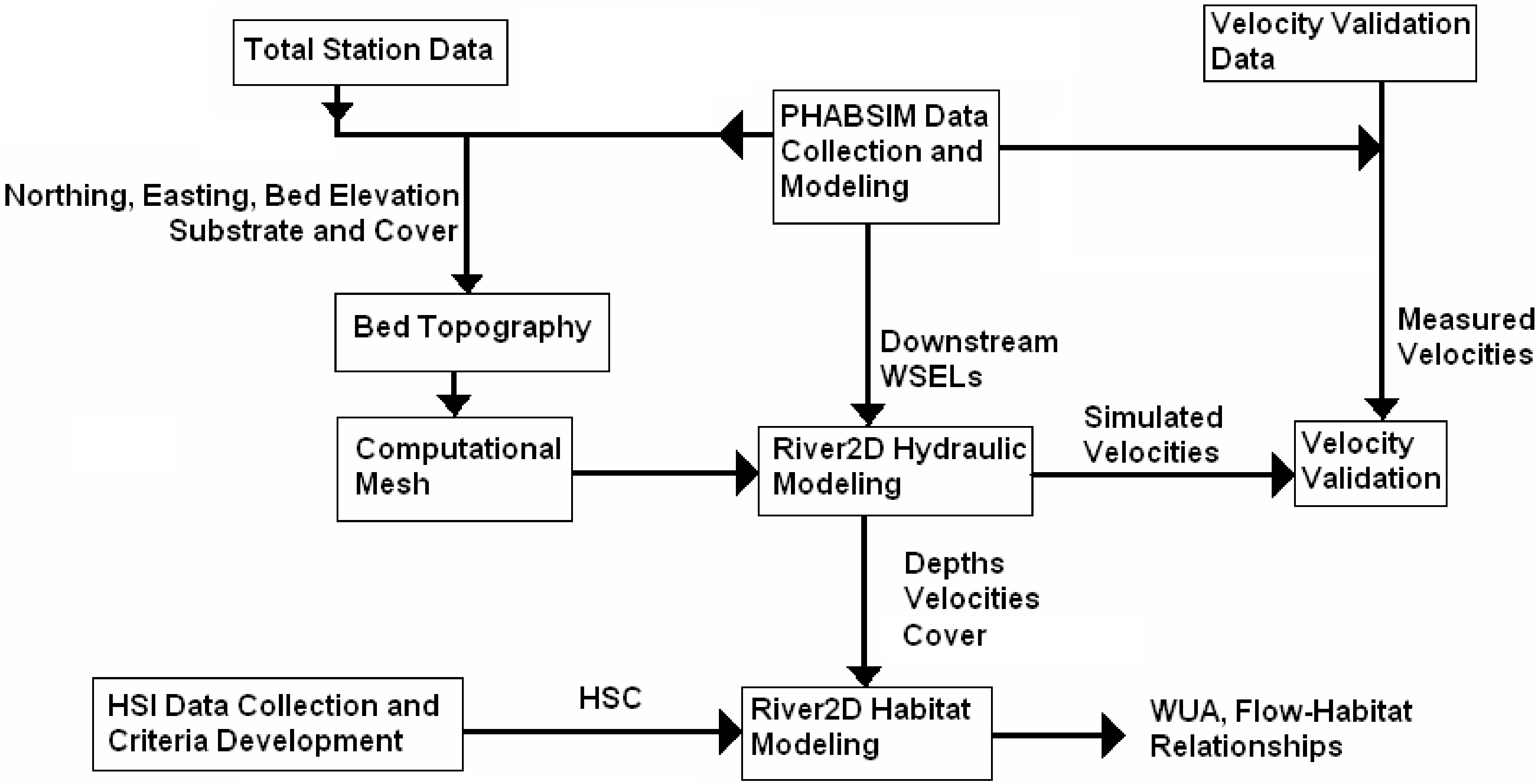
[3] PHABSIM is the collection of one dimensional hydraulic and habitat models which can be used to predict the relationship between physical habitat availability and streamflow over a range of river discharges. PHABSIM was used to develop the stage-discharge relationships at the study site boundaries.

Figure 1. Flow diagram of data collection and modeling.



(WSELs), we could then predict the WSELs for these transects for the various simulation flows that were to be modeled using River2D. We then calibrated the River2D models using the highest simulation flow. The highest simulation WSELs predicted by PHABSIM for the upstream and downstream transects could be used for the upstream boundary condition (in addition to flow) and the downstream boundary condition. The PHABSIM-predicted WSEL for the upstream transect at the highest simulation flow was used to ascertain calibration of the River2D model at the highest simulation flow. After the River2D model was calibrated at the highest simulation flow, the WSELs predicted by PHABSIM for the downstream transect for each simulation flow were used as an input for the downstream boundary condition for River2D model production files for the simulation flows.

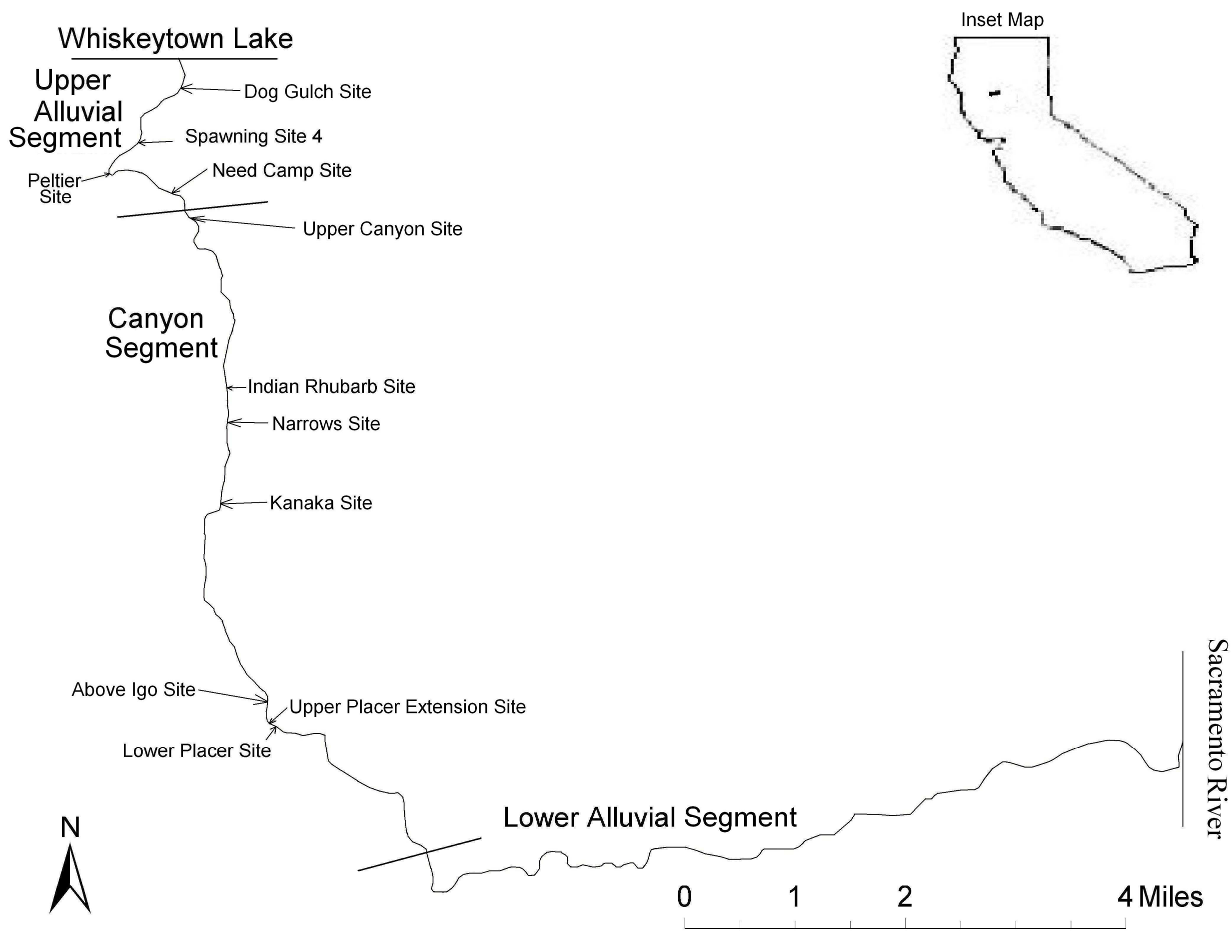
Study Segment Delineation

Study segments were delineated within the study reach of Clear Creek between Whiskeytown Dam and the Clear Creek Bridge (Figure 2) based on hydrology and other factors. Study segments were originally delineated in U.S. Fish and Wildlife Service (2007).

Habitat Mapping

Mesohabitat mapping for the two study segments was performed in August and September of 2004 by biologists from the Red Bluff Fish and Wildlife Office. This work consisted of walking downstream the entire length of the study segments, delineating the mesohabitat units using an adaptation of habitat-typing protocols developed by the California Department of Fish and Game (CDFG). The CDFG habitat typing protocols designates 12 mesohabitat types: Main Channel glides, Main Channel pools, Main Channel riffles, Main Channel runs, flatwater glides, flatwater pools, flatwater riffles, flatwater runs, side channel glides, side channel pools, side channel riffles, and side channel runs (Snider et al. 1992). However, we decided to combine the "flatwater" and "Main Channel" primary habitat types into "main channel", as this simplification of the classification system seemed appropriate for a stream the size of Clear Creek. Definitions of the habitat types are given in Table 2. Aerial photos from June 2003 flown at 1:4200 were used in conjunction with direct observations to determine the aerial extent of each habitat unit. The habitat units were delineated on the aerial photos and the length of the habitat units was measured using a laser range finder, or a tape measure if the unit was less than 12 feet (3.6 m) in length. In October 2004, we accompanied the biologists that had conducted the mesohabitat mapping in a reconnaissance of the mesohabitats identified for the Upper Alluvial Reach to help verify that the mesohabitat mapping process had been done to our specifications. Following the completion of the mesohabitat mapping on October 20, 2004, the mesohabitat types and number of each habitat type in each segment were enumerated, and shapefiles of the mesohabitat units were created in a Geographic Information System (GIS) using the GPS data and the aerial photos. The area of each mesohabitat unit was computed in GIS from the above shapefiles.

Figure 2. Clear Creek stream segments and rearing study sites.



Field Reconnaissance and Study Site Selection

Based on the results of the mesohabitat mapping and field reconnaissance, a list of potential study sites was developed. A number of the potential study sites on this list were eliminated based on access difficulty and safety considerations. Based on the results of habitat mapping, we selected six juvenile habitat study sites that, together with five spawning habitat study sites, adequately represent the mesohabitat types present in each segment. Details on the five spawning study sites are given in U.S. Fish and Wildlife Service (2007). The six new study sites were placed in mesohabitat types that were not adequately represented in the five spawning study sites. We attempted to randomly select the six new study sites from eleven areas that were found to have reasonable and safe access to ensure unbiased selection of the study sites. In November 2004 and February 2005, we visited the potential study sites that had been selected through this process to ascertain their suitability for 2-D modeling. However, on revisiting two of the selected study sites in preparation for study site selection, it was determined that the extreme

Table 2. Habitat type definitions.

Habitat Type	Definition
Main Channel	More than 20 percent of total flow.
Side Channel	Less than 20 percent of total flow.
Pool	Primary determinant is downstream control - thalweg gets deeper as go upstream from bottom 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 Main Channel 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 moderately turbulent 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.

difficulty of accessing the sites and the amounts of poison oak present around the sites made data collection unpractical and unsafe. As a result, two other study sites were selected as replacements. For the sites selected for modeling, the landowners along both riverbanks were identified and temporary entry permits were sent, accompanied by a cover letter, to acquire permission for entry onto their property during the course of the study.

Transect Placement (study site set-up)

Five of the six study sites were established in June 2005. The sixth site was established in August 2005. Whenever possible, the study site boundaries (up- and downstream transects) were selected to coincide with the upstream and downstream ends of the mesohabitat unit. The location of these boundaries was established during site setup by going to the locations marked on aerial photos during the mesohabitat mapping. In some cases, the upstream or downstream boundary had to be moved upstream or downstream to a location where the hydraulic conditions were more favorable (e.g., more linear direction of flow, more consistent water surface elevations from bank to bank).

For each study site, a transect was placed at the upstream and downstream end of the site. The downstream transect was modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. The upstream transect was used in calibrating the 2-D model - bed roughnesses are adjusted until the WSEL at the top of the site matches the WSEL predicted by PHABSIM. Transect pins (headpins and tailpins) were installed on each river bank above the 1,000 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Habitat Data Collection

Vertical benchmarks were established at each site to serve as the reference elevations to which all elevations (streambed and water surface) were tied. Vertical benchmarks consisted of lag bolts driven into trees or painted bedrock points. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site for total station placement to serve as the reference locations to which all horizontal locations (northings and eastings) were tied when collecting bed topography data.

Hydraulic and structural data collection began in June 2005 and was completed in October 2007. The precision and accuracy of the field equipment used for the hydraulic and structural data collection is given in Table 3. The data collected at the inflow and outflow transects included: 1) WSELs measured to the nearest 0.01 foot (0.0031 m) at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot (0.031 m); 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate[4] and cover classification at these same locations (Tables 4 and 5) and also where dry ground elevations were surveyed.

When conditions allowed, WSELs were measured along both banks and in the middle of each transect. Otherwise, the WSELs were measured along both banks. If the WSELs measured for a transect were within 0.1 foot (0.031 m) of each other, the WSELs at each transect were then derived by averaging the two to three values. If the WSEL differed by greater than 0.1 foot (0.031 m), the WSEL for the transect was selected based on which side of the transect was considered most representative of the flow conditions. For sites where there was a gradual gradient change in the vicinity of the downstream transect, there could be a point in the thalweg downstream of the downstream transect that was higher than that measured at the downstream

[4] Substrate was only used to calculate bed roughness.

Table 3. Precision and accuracy of field equipment. A blank means that that information is not available.

Equipment	Parameter	Precision	Accuracy
Marsh-McBirney	Velocity		± 2% + 1.5 cm/s
Price AA	Velocity		± 6% at 7.6 cm/s to
			± 1.5% at vel > 46 cm/s
Total Station	Slope Distance	± (5ppm + 5) mm	
Total Station	Angle		4 sec
Electronic Distance Meter	Slope Distance		1.5 cm
Autolevel	Elevation		0.3 cm

Table 4. Substrate codes, descriptors and particle sizes.

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1 (0.25 cm)
1	Small Gravel	0.1 – 1 (0.25 – 2.5 cm)
1.2	Medium Gravel	1 – 2 (2.5 – 5 cm)
1.3	Medium/Large Gravel	1 – 3 (2.5 – 7.5 cm)
2.3	Large Gravel	2 – 3 (5 – 7.5 cm)
2.4	Gravel/Cobble	2 – 4 (5 – 10 cm)
3.4	Small Cobble	3 – 4 (7.5 – 10 cm)
3.5	Small Cobble	3 – 5 (7.5 – 12.5 cm)
4.6	Medium Cobble	4 – 6 (10 – 15 cm)
6.8	Large Cobble	6 – 8 (15 – 20 cm)
8	Large Cobble	8 – 10 (20 – 25 cm)
9	Boulder/Bedrock	> 12 (30 cm)
10	Large Cobble	10 – 12 (25 – 30 cm)

Table 5. Cover coding system.

Cover Category	Cover Code
No cover	0
Cobble	1
Boulder	2
Fine woody vegetation (< 1" diameter)	3
Fine woody vegetation + overhead	3.7
Branches	4
Branches + overhead	4.7
Log (> 1' diameter)	5
Log + overhead	5.7
Overhead cover (> 2' above substrate)	7
Undercut bank	8
Aquatic vegetation	9
Aquatic vegetation + overhead	9.7
Rip-rap	10

transect thalweg. This Stage of Zero Flow (SZF) downstream of the downstream transect acts as a control on the water surface elevations at the downstream transect. Because the true SZF is needed to accurately calibrate the water surface elevations on the downstream transect, this SZF in the thalweg downstream of the downstream transect was surveyed in using differential leveling. Depth and velocity measurements were made using a wading rod equipped with a Marsh-McBirney[R] model 2000 or Price AA velocity meter. Most measurements were taken by wading, however, a one-person cataraft was necessary for some portions of the transects on three sites in the Canyon Segment. The distance intervals of each depth and velocity measurement from the headpin or tailpin were measured using a tape or hand held laser range finder[5].

[5] The stations for the dry ground elevation measurements were also measured using the tape or hand held laser range finder.

Data collected between the transects included: 1) bed elevation; 2) northing and easting (horizontal location); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the sites, wading in dry and shallow portions of the sites and using a single person cataraft for deeper pools. Bed elevation and horizontal location of individual points were obtained with a total station[6], while the cover and substrate were visually assessed at each point.

To validate the velocities predicted by the 2-D model, depth, velocity, substrate and cover measurements were collected throughout each site, primarily by wading, with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. Again, in deeper portions of several sites, a one-person cataraft was necessary. The validation velocities and the velocities measured on the transects described previously were collected at 0.6 of the depth for 20 seconds. The horizontal locations and bed elevations were recorded by sighting from the total station to a stadia rod and prism held at each point where depth and velocity were measured. A minimum of 50 representative points were measured throughout each site.

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

All velocity, depth, and station data collected were compiled in an Excel spreadsheet for each site and checked before entry into PHABSIM files for the upstream and downstream transects. A table of substrate and cover ranges/values was created to determine the substrate and cover for each vertical/cell (e.g., if the substrate size class was 2-4 inches (5-10 cm) on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the WSEL of the highest flow to be modeled. An American Standard Code for Information Interchange (ASCII) file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton, U.S. Fish and Wildlife Service, 1998) to get the PHABSIM input file and then translated into RHABSIM Version 2.0[7] files. A separate PHABSIM file was constructed for each study site. A total of five to six sets of measured WSELs were used, all being checked as a quality control check to ensure that the WSELs from the upstream transect were greater than the WSELs from the downstream transect. The slope for each transect was computed for each WSEL flow as the difference in

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[6] A total station is an electronic/optical instrument used in modern surveying. The total station is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read distances from the instrument to a particular point. Data from the total station consist of the horizontal angle, vertical angle and slope distance to each point.

[7] RHABSIM is a commercially produced software (Payne and Associates 1998) that incorporates the modeling procedures used in PHABSIM.

WSELs between the two transects divided by the distance between the two. The slope used for each transect was calculated by averaging the slopes computed for each flow. If WSELs were available for several closely spaced flows, the WSEL that corresponded with the velocity set or the WSEL collected at the lowest flow was used in the PHABSIM files. Calibration flows in the PHABSIM files were the flows calculated from gage readings[8].

The SZF was determined for each transect and entered into the PHABSIM file. In habitat types without backwater effects (e.g., riffles and runs), this value generally represents the lowest point in the streambed across a transect. However, if a transect directly upstream contains a lower bed elevation than the adjacent downstream transect, the SZF for the downstream transect applies to both. In some cases, data collected in between the transects showed a higher thalweg elevation than either transect; in these cases the higher thalweg elevation was used as the SZF for the upstream transect.

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous et al. 1989) was run on the PHABSIM file to compare predicted and measured WSELs. This model produces a stage-discharge relationship using a log-log linear rating curve calculated from at least three sets of measurements taken at different flows. Besides *IFG4*, two other hydraulic models are available in PHABSIM to predict stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the geometry of the channel and the nature of the streambed controls WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects. *IFG4*, the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus measured discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus measured discharge; and 4) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs[9]. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

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[8] There were no tributaries or diversions between each gage used for a study site, and the study site.

[9] The first three criteria are from U.S. Fish and Wildlife Service (1994), while the fourth criterion was developed by the authors.

Velocity Adjustment Factors (VAFs) were examined for all of the simulated flows as a potential indicator of problems with the stage-discharge relationship. The acceptable range of VAF values is 0.2 to 5.0 and the expected pattern for VAFs is a monotonic increase with an increase in flows (U.S. Fish and Wildlife Service 1994).

River2D Model Construction

After completing the PHABSIM calibration process to arrive at the simulation WSELs that was used as inputs to the River2D model, the next step was to construct the River2D model using the collected bed topography data. The total station data and the PHABSIM transect data were combined in a spreadsheet to create the input files (bed and cover) for the 2-D modeling program. An artificial extension one channel-width-long was added upstream of the top of the site to enable the flow to be distributed by the model when it reached the study area, thus minimizing boundary conditions influencing the flow distribution at the upstream transect and within the study site.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point, while the cover files contain the horizontal location, bed elevation and the cover for each point. The initial bed roughness value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness values in Table 6, with the bed roughness value computed as the sum of the substrate bed roughness value and the cover bed roughness value. The bed roughness values for substrate in Table 6 were computed as five times the average particle size[10]. The bed roughness values for cover in Table 6 were computed as five times the average cover size, where the cover size was measured on the Sacramento River on a representative sample of cover elements of each cover-type. The bed and cover files were exported from Excel as ASCII files.

A utility program, R2D_BED (Steffler 2002), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines[11] going up the channel along features such as thalwegs, tops of bars and bottoms of banks. Breaklines were also added along lines of constant elevation. An additional utility program, R2D_MESH (Waddle and Steffler 2002), was used to define the inflow and outflow boundaries, to improve the fit between the mesh and the final bed file, and to improve the quality of the mesh, as measured by the Quality Index (QI) value. An ideal mesh (all equilateral triangles)

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[10] Five times the average particle size is approximately the same as 2 to 3 times the d85 particle size, which is recommended as an estimate of bed roughness height (Yalin 1977).

[11] Breaklines are a feature of the R2D_Bed program which force the TIN of the bed nodes to linearly interpolate bed elevation and bed roughness values between the nodes on each breakline and force the TIN to spring on the breaklines (Steffler 2002).

Table 6. Initial bed roughness values.

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05, 0.76, 2[12]	9	0.29
10	1.4	9.7	0.57
		10	3.05

would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Waddle and Steffler 2002). The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. The final step with the R2D_MESH software was to generate the computational (cdg) file.

[12] For substrate code 9, we used bed roughnesses of 0.76 and 2, respectively, for cover codes 1 and 2, and a bed roughness of 0.05 for all other cover codes. The bed roughness value for cover code 1 (cobble) was estimated as five times the assumed average size of cobble (6 inches [0.15 m]). The bed roughness values for cover code 2 (boulder) was estimated as five times the assumed median size of boulders (1.3 feet [0.4 m]). Bed roughnesses of zero were used for cover codes 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

River2D Model Calibration

Once a River2D model has been constructed, calibration is then required to determine that the model is reliably simulating the flow-WSEL relationship that was determined through the PHABSIM calibration process using the measured WSELs. The cdg files were opened in the River2D software, where the computational bed topography mesh was used together with the WSEL at the bottom of the site, the flow entering the site, and the bed roughnesses of the computational mesh elements to compute the depths, velocities and WSELs throughout the site. The basis for the current form of River2D is given in Ghanem et al. (1995). The computational mesh was run to steady state at the highest flow to be simulated, and the WSELs predicted by River2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the upstream transect. Calibration was considered to have been achieved when the WSELs predicted by River2D at the upstream transect were within 0.1 foot (0.031 m) of the WSEL predicted by PHABSIM. In cases where the simulated WSELs at the highest simulation flow varied across the channel by more than 0.1 foot (0.031 m), we used the highest measured flow within the range of simulated flows for River2D calibration. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by River2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect. The minimum groundwater depth was adjusted to a value of 0.05 to increase the stability of the model. The values of all other River2D hydraulic parameters were left at their default values (upwinding coefficient = 0.5, groundwater transmissivity = 0.1, groundwater storativity = 1, and eddy viscosity parameters $\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.5$ and $\varepsilon_3 = 0.1$).

We then calibrated the upstream transect using the methods described above, varying the BR Mult until the simulated WSEL at the upstream transect matched the measured WSEL at the upstream transect. A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than 1% (Steffler and Blackburn 2002). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than 1.0[13]. Finally, the WSEL predicted by the 2-D model should be within 0.1 foot (0.031 m) of the WSEL measured at the upstream transects[14].

[13] This criterion is based on the assumption that flow in low gradient streams is usually subcritical, where the Froude number is less than 1.0 (Peter Steffler, personal communication).

[14] We have selected this standard because it is a standard used for PHABSIM (U. S. Fish and Wildlife Service 2000).

River2D Model Velocity Validation

Velocity validation is the final step in the preparation of the hydraulic models for use in habitat simulation. Velocities predicted by River2D were compared with measured velocities to determine the accuracy of the model's predictions of mean water column velocities. The measured velocities used were those measured at the upstream and downstream transects and the 50 measurements taken between the transects. The criterion used to determine whether the model was validated was whether the correlation between measured and simulated velocities was greater than 0.6. A correlation of 0.5 to 1.0 is considered to have a large effect (Cohen 1992). The model would be in question if the simulated velocities deviated from the measured velocities to the extent that the correlation between measured and simulated velocities fell below 0.6.

River2D Model Simulation Flow Runs

After the River2D model was calibrated, the flow and downstream WSEL in the calibrated cdg file were changed to simulate the hydraulics of the site at the simulation flows. The cdg file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each cdg file was run in River2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions should usually have a Max F of less than one.

Habitat Suitability Criteria (HSC) Data Collection

Habitat suitability criteria (HSC) are used within 2-D habitat modeling to translate hydraulic and structural elements of rivers into indices (HSIs) of habitat quality (Bovee 1986). HSC refer to the overall functional relationships that are used to convert depth, velocity and substrate suitability into habitat quality (HSI). HSI refers to the independent variable in the HSC relationships. The primary habitat variables which were used to assess physical habitat suitability for Chinook salmon and steelhead/rainbow trout fry and juvenile rearing were depth, velocity, cover and adjacent velocity[15].

Traditionally, criteria are created from observations of fish use by fitting a nonlinear function to the frequency of habitat use for each variable (depth, velocity, and cover). One concern with this technique is the effect of availability of habitat on the observed frequency of habitat use. For example, if a cover type is relatively rare in a stream, fish will be found primarily not using that cover type simply because of the rarity of that cover type, rather than because they are

[15] Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed (Fausch and White 1981). Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth.

selecting areas without that cover type. Guay et al. (2000) proposed a modification of the above technique where depth, velocity, and cover data are collected both in locations where juveniles are present and in locations where juveniles are absent, and a logistic regression is used to develop the criteria. This approach to collecting juvenile habitat suitability criteria data and the development of HSC was employed in this study.

The collection of Chinook salmon and steelhead/rainbow trout fry and juveniles (YOY) rearing HSC data by the staff of the Red Bluff Fish and Wildlife Office began at the end of 2004 and was completed in 2008. Snorkel surveys were conducted along the banks and mid-channel of the habitat units. Depth, velocity, adjacent velocity[16] and cover data were also collected on locations which were not occupied by YOY Chinook salmon and steelhead/rainbow trout (unoccupied locations). This was done so that we could apply the method presented in Guay et al. (2000) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability).

Before going into the field, a data book was prepared with one line for each unoccupied location where depth, velocity, cover and adjacent velocity would be measured. Each line had a distance from the bank or mid-channel line, with a range of 0.5 to 10 feet (0.15 to 3 m) by 0.5 foot (0.15 m) increments, with the values produced by a random number generator. In areas that could be sampled up to 20 feet (6 m) from the bank or mid-channel line, the above distances were doubled.

If one person was snorkeling per habitat unit, the side of the creek to be snorkeled would alternate with each habitat unit and would also include snorkeling the middle portion of some units. As an example, the right bank was snorkeled for one habitat unit, the middle of the next habitat unit was then snorkeled, and then the left bank was snorkeled of the next habitat unit and then the process was repeated.[17] The habitat units were snorkeled working upstream, which is generally the standard for snorkel surveys. In some cases when snorkeling the middle of a habitat unit, the difficulty of snorkeling mid-channel required snorkeling downstream. If three

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[16] The adjacent velocity was measured within 2 feet (0.6 m) on either side of the location where the velocity was the highest. Two feet (0.6 m)was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon and steelhead/rainbow trout reside, taking into account that the size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, USGS, personal communication), and assuming that the mean depth of Clear Creek is around 4 feet (1.2 m, i.e., 4 feet [1.2 m] x ½ = 2 feet [0.6 m]).

[17]The Sacramento Fish and Wildlife Office Instream Flow Group designates left and right bank looking upstream.

people were going to snorkel each unit, one person snorkeled along each bank working upstream, while the third person snorkeled downstream through the middle of the unit. The snorkelers placed a weighted, numbered tag at each location where YOY spring-run Chinook salmon or steelhead/rainbow trout were observed. The snorkelers recorded the tag number, the species, the cover code[18] and the number of individuals observed in each 10-20 mm size class on a Poly Vinyl Chloride (PVC) wrist cuff. The distance to be snorkeled was delineated by laying out a tape along the bank as described previously for a distance of 150 or 300 feet (46 or 91 m). The average and maximum distance from the water's edge that was sampled, cover availability in the area sampled (percentage of the area with different cover types) and the length of bank sampled (measured with a 150 or 300-foot-long [46 or 91 m] tape) was also recorded. When three people were snorkeling, cover percentages were collected by each person snorkeling. After completing each unit, the percentages for each person were combined and averaged. The cover coding system used is shown in Table 5.

Three people went up the tape, one with a stadia rod and data book and the other two with a wading rod and velocity meter. At every 20-foot (6 m) interval along the tape, the person with the stadia rod measured out the distance from the bank given in the data book. If there was a tag within 3 feet (0.9 m) of the location, this was recorded on that line in the data book. If the location was beyond the sampling distance, based on the information recorded by the snorkeler, "beyond sampling distance" was recorded on that line and the recorder went to the next line at that same location, repeating until reaching a line with a distance from the bank within the sampling distance. If there was no tag within 3 feet (0.9 m) of that location, one of the surveyors with the wading rod measured the depth, velocity, adjacent velocity and cover at that location. The surveyors then proceeded to the next 20-foot (6 m) mark on the tape, using the distance from the bank on the next line. Depth was recorded to the nearest 0.1 foot (0.031 m) and average water column velocity and adjacent velocity were recorded to the nearest 0.01 ft/s (0.0031 m/s). Another individual retrieved the tags, measured the depth and mean water column velocity at the tag location, measured the adjacent velocity for the location, and recorded the data for each tag number. Data taken by the snorkeler and the measurer were correlated at each tag location.

For the one-snorkeler surveys, the unoccupied data (i.e. data from locations where juveniles were absent) for the mid-channel snorkel surveys was collected by establishing the distance to be snorkeled by laying out the tape on a bank next to the distance of creek that was to be snorkeled. After snorkeling that distance, the line snorkeled was followed down through the middle of the channel and the randomly selected distance at which the unoccupied data were to be collected was measured out toward the left or right bank, alternating with each 20 foot (6 m) location along the tape. For the three-snorkeler surveys, unoccupied data were collected for each habitat unit snorkeled in this manner by alternating left and right bank or mid-channel for each habitat unit

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[18] If there was no cover elements (as defined in Table 5) within 1 foot (0.3 m) horizontally of the fish location, the cover code was 0.1 (no cover).

snorkeled. As an example, for the first habitat unit snorkeled, unoccupied data would be collected along the left bank. At the next unit, data would be collected along the right bank. At the next unit, the data would be collected as described previously using the mid-channel line snorkeled.

Habitat Suitability Criteria (HSC) Development

In general, logistic regression is an appropriate statistical technique to use when data are binary (e.g., when a fish is either present or absent in a particular habitat type) and result in proportions that need to be analyzed (e.g., when 10, 20, and 70 percent of fish are found respectively in habitats with three different sizes of gravel; Pampel 2000). It is well-established in the literature (Knapp and Preisler 1999, Parasiewicz 1999, Geist et al. 2000, Guay et al. 2000, Pearce and Ferrier 2000, Filipe et al. 2002, Tiffan et al. 2002, McHugh and Budy 2004, Tirelli et al. 2009) that logistic regressions are appropriate for developing habitat suitability criteria. For example, McHugh and Budy (2004) state:

> "More recently, and based on the early recommendations of Thielke (1985), many researchers have adopted a multivariate logistic regression approach to habitat suitability modeling (Knapp and Preisler 1999; Geist et al. 2000; Guay et al. 2000)."

Accordingly, logistic regression has been employed in the development of the habitat suitability criteria (HSC) in this study. Criteria were developed by using a logistic regression procedure, with presence or absence of YOY as the dependent variable and depth, velocity, cover and adjacent velocity as the independent variables, with all of the data (in both occupied and unoccupied locations) used in the regression.

All YOY Chinook salmon observed in the Upper Alluvial and Canyon Segments were classified as spring-run because the barrier weir near the upstream end of the Lower Alluvial Segment excludes fall-run from the Upper Alluvial and Canyon Segments. Data were compiled on the length of each mesohabitat and cover type sampled to try to have equal effort in each mesohabitat and cover type and that each location was only sampled once at the same flow (to avoid problems with pseudo-replication). Generally, at least 150 observations are needed to develop habitat suitability criteria (Bovee 1986).

Separate salmonid YOY rearing HSC are typically developed for different size classes of YOY (typically called fry and juvenile). Since we recorded the size classes of the YOY, we were able to investigate three different options for the size used to separate fry from juveniles: <40 mm versus > 40 mm, <60 mm versus >60 mm, and <80 mm versus >80 mm. We used Mann-Whitney U tests to test for differences in depth, velocity and adjacent velocity, and Pearson's test for association to test for differences in cover, for the above categories of fry versus juveniles. Separate fry and juvenile HSC could be developed for each species (Chinook salmon and steelhead/rainbow trout). To determine if there were differences between species, we used Mann-Whitney U tests to test for differences in depth, velocity and adjacent velocity, and used Pearson's test for association to test for differences in cover, for fry and juveniles.

We used a polynomial logistic regression (SYSTAT 2002), with dependent variable frequency (with a value of 1 for occupied locations and 0 for unoccupied locations) and independent variable depth or velocity, to develop depth and velocity HSI. The logistic regression fits the data to the following expression:

$$\text{Frequency} = \frac{\text{Exp}\,(I + J * V + K * V^2 + L * V^3 + M * V^4)}{1 + \text{Exp}\,(I + J * V + K * V^2 + L * V^3 + M * V^4)}, \qquad (1)$$

where Exp is the exponential function; I, J, K, L and M are coefficients calculated by the logistic regression; and V is velocity or depth. The logistic regressions were conducted in a sequential fashion, where the first regression tried was a fourth order regression. If any of the coefficients or the constant were not statistically significant at $p = 0.05$, the associated terms were dropped from the regression equation, and the regression was repeated.

The results of the regression equations were rescaled so that the highest value of suitability was 1.0. The resulting HSC were modified by truncating at the slowest/shallowest and deepest/fastest ends, so that the next shallower depth or slower velocity value below the shallowest observed depth or the slowest observed velocity had a SI (suitability index) value of zero, and so that the next larger depth or faster velocity value above the deepest observed depth or the fastest observed velocity had an SI value of zero; and eliminating points not needed to capture the basic shape of the curves.

Because adjacent velocities were highly correlated with velocities, a logistic regression of the following form was used to develop adjacent velocity criteria:

$$\text{Frequency} = \frac{\text{Exp}\,(I + J * V + K * V^2 + L * V^3 + M * V^4 + N * AV)}{1 + \text{Exp}\,(I + J * V + K * V^2 + L * V^3 + M * V^4 + N * AV)}, \qquad (2)$$

where Exp is the exponential function; I, J, K, L, M and N are coefficients calculated by the logistic regression; V is velocity and AV is adjacent velocity. The I and N coefficients from the above regression were then used in the following equation:

$$\text{HSI} = \frac{\text{Exp}\,(I + N * AV)}{1 + \text{Exp}\,(I + N * AV)}. \qquad (3)$$

We then computed values of equation 3 for the range of occupied adjacent velocities, and then rescaled the values so that the largest value was 1.0. We then used a linear regression on the rescaled values to determine, using the linear regression equation, HSI_0 (the HSI where the AV is zero) and AV_{LIM} (the AV at which the HSI is 1.0). The final adjacent velocity criteria started at HSI_0 for an adjacent velocity of zero, ascended linearly to an HSI of 1.0 at an adjacent velocity of AV_{LIM} and stayed at an HSI of 1.0 for adjacent velocities greater than AV_{LIM}.

We addressed the availability of cover using the following process: 1) ranking the sites sampled in descending order by the percentage of cover group 1; 2) calculating the cumulative feet sampled of cover groups 0 and 1 going down through the sites until we reached an equal number of cumulative feet of cover groups 0 and 1 sampled; and 3) continuing the development of cover criteria using only the above subset of sites. This process allowed us to maximize the amount of area sampled to include in development of the cover criteria while equalizing the amount of area sampled in cover groups 0 and 1. The first step in the development of the cover criteria was to group cover codes within each species and life stage, so that there were no significant differences within the groups and a significant difference between the groups, using Pearson’s test for association using the number of observations where fish were present and absent. We then combined together the fish observations in each group of cover types and calculated the HSI for each group by dividing the number of observations in each group by the number of observations in the most frequent group.

Habitat Simulation

The final step was to simulate available habitat for each mesohabitat type present in each site. Preference curve files were created containing the digitized fry and juvenile rearing HSC developed for the Clear Creek spring-run Chinook salmon and steelhead/rainbow trout. The final cdg files, the cover file and the preference curve file were used in River2D to calculate the combined suitability of depth, velocity and cover for each mesohabitat type present in each site. The resulting data were exported into a comma-delimited file for each flow, species, life stage, and each mesohabitat type present in each site. These files were then run through a GIS post-processing software[19] to incorporate the adjacent velocity criteria into the habitat suitability, and

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[19] The software calculates the direction of flow for each node from the magnitude of the x and y components of flow at each node. The direction of flow is used along with the distance parameter of the adjacent velocity (2 feet [0.6 m]) to determine the locations at which the adjacent velocity will be computed. These locations, together with a TIN of the velocities at all nodes, are used to calculate the adjacent velocity for each node. The adjacent velocity criteria is then used to calculate the adjacent velocity suitability index for that node. This index is then multiplied by the combined depth, velocity and cover suitability indices. This product is then multiplied by the area represented by each node to calculate the WUA for each node, with the WUA for all nodes summed to determine the total WUA for each mesohabitat type, flow, life stage and species.

to calculate the WUA values for each mesohabitat type in each site over the desired range of flows for all twelve sites. We then multiplied the WUA values for each mesohabitat unit modeled by the ratios of the total area of each mesohabitat type present in a given segment to the area of each mesohabitat type that was modeled in that segment, and then summed the resulting products to calculate the total WUA for each segment.

RESULTS

Study Segment Delineation

We have divided the Clear Creek study area into three stream segments: Upper Alluvial Segment (Whiskeytown Dam to NEED Camp Bridge); Canyon Segment (NEED Camp Bridge to Clear Creek Road Bridge); and Lower Alluvial Segment (Clear Creek Road Bridge to Sacramento River). The first two segments address spring-run Chinook salmon and steelhead/rainbow trout while the last segment addresses fall-run Chinook salmon and steelhead/rainbow trout.

Habitat Mapping

A total of 73 mesohabitat units (50,621 m^2) were mapped for the Upper Alluvial Segment of Clear Creek and 202 mesohabitat units (179,909 $m^{2)}$ for the Canyon Segment. Table 7 summarizes the habitat types, area and numbers of each type recorded during the habitat mapping process, while Appendix A gives a complete list of the habitat units.

Field Reconnaissance and Study Site Selection

The reconnaissance work narrowed the list of potential sites to the six additional juvenile rearing sites that were modeled (Table 8, Appendix B). These sites are as follows from upstream to downstream: Dog Gulch, Upper Canyon, Narrows, Kanaka, Above Igo and Upper Placer Extension. The Dog Gulch site is in the Upper Alluvial Segment, while the rest are located in the Canyon Segment. The presence of only one study site in the Upper Alluvial Segment was the result of the spawning sites (U.S. Fish and Wildlife Service 2007) in that segment having already adequately represented most of the habitat types for that segment.

The study site boundaries (up- and downstream transects) were selected, as near as possible, to coincide with the upstream and downstream ends of the mesohabitat unit. However, only the Narrows, Kanaka and Above Igo sites were entirely within a single habitat unit (main channel pool). On the other sites it was necessary to establish the transects slightly up or downstream of the habitat unit boundary, in locations where the hydraulic conditions were more favorable (e.g., more linear direction of flow, with more consistent water surface elevations from bank to bank).

Table 7. Clear Creek mesohabitat mapping results by segment.

Mesohabitat Type	Upper Alluvial		Canyon	
	Area (100 m^2)	Number of Units	Area (100 m^2)	Number of Units
Main Channel Cascade (MCC)	-	-	135.9	31
Main Channel Glide (MCG)	7.2	2	14.9	4
Main Channel Pool (MCP)	186.2	14	832.2	76
Main Channel Riffle (MCR)	131.6	21	174.2	46
Main Channel Run (MCRU)	160.6	17	202.4	42
Side Channel Glide (SCG)	4.4	2	-	-
Side Channel Pool (SCP)	1.7	3	-	-
Side Channel Riffle (SCRi)	7.9	8	3.9	2
Side Channel Run (SCRu)	6.6	6	1.2	1

In August 2005, the downstream transect of Upper Canyon site was re-established as a result of plans for gravel injection in the vicinity of the original downstream transect location. The downstream transect was moved upstream to a location where influences of the gravel injection on water surface elevations and bed topography would be avoided. However, this significantly reduced the length of creek comprising the study site and significantly reduced the amount of riffle habitat that was to be modeled for that site.

Hydraulic and Structural Habitat Data Collection

Water surface elevations were measured at high (779-793 cfs), medium (431-441 cfs) and low (79-290 cfs) flows for the six study sites. Depth and velocity measurements on the transects were collected at the Dog Gulch transect at 200 cfs, Upper Canyon transects at 227 cfs, Narrows transects at 86 cfs, and the Kanaka transects at 79 cfs. For Above Igo, the depth and velocity measurements were made on the upstream transect at 155 cfs and on the downstream transect at 290 cfs. For Upper Placer Extension, the depth and velocity measurements were made on the upstream transect at 253 cfs and on the lower transect at 255 cfs. The number and density of the points collected for each site is given in Table 9.

Table 8. Sites selected for modeling spring-run Chinook salmon and steelhead/rainbow trout rearing. Lack of a number in parentheses indicates one unit for that mesohabitat type in the site.

Site Name	Segment	Site Mesohabitat Types
Dog Gulch	Upper Alluvial	MCG, MCP, MCRi(2), MCRu, SCG, SCP, SCRi
Spawning Site 4	Upper Alluvial	MCP, MCRI, MCRU, SCRI, SCRU
Peltier	Upper Alluvial	MCP(4), MCRI(3), MCRU(3), SCRI, SCRU(2)
Need Camp	Upper Alluvial	MCRI(2), MCRU(2)
Upper Canyon	Canyon	MCRi, MCRu
Indian Rhubarb	Canyon	MCP
Narrows	Canyon	MCP
Kanaka	Canyon	MCP
Above Igo	Canyon	MCP
Upper Placer Ext.	Canyon	MCP(2), MCRi(2), MCRu, SCRi
Lower Placer	Canyon	MCRi

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

Calibration flows (the initial creek discharge values from Whiskeytown Dam for Dog Gulch, combined Whiskeytown Dam and Page-Boulder Creek gage discharge values for Upper Canyon, Narrows, and Kanaka, and IGO gage discharge values for Above Igo and Upper Placer Extension) are given in Table 10. For time periods where gage values were not available for Page-Boulder Creek, flows for Page-Boulder Creek were calculated using the following equation[20]:

Page-Boulder Creek Flow = 0.23 x (IGO Flow – Whiskeytown Flow) (4)

For high flow releases, the appropriate Whiskeytown flow to use for Upper Canyon, Narrows, and Kanaka was determined by travel time from Whiskeytown to each of these sites.

[20] This equation was derived from a linear regression of Page-Boulder Creek gage flows and the difference between IGO and Whiskeytown gage flows. This regression equation had an R^2 value of 0.96 (n = 83).

Table 9. Number and density of topography, substrate and cover data points collected for each site.

Site Name	Number of Points: Points on Transects	Number of Points: Points Between Transects	Density of Points (points/100 m^2)
Dog Gulch	60	1331	17.7
Upper Canyon	82	233	10.7
Narrows	54	761	111.8
Kanaka	49	1987	127.2
Above Igo	69	587	10.8
Upper Placer Ext.	130	2854	24.8

Table 10. Gage measured and calculated calibration flows for the six study sites (cfs). *Calculated flows are given in italics*. For entries with two flows separated by a forward slash, the first flow is for cross-section one and the second flow is for cross-section two.

Date	Dog Gulch	Upper Canyon	Narrows	Kanaka	Above Igo	Up. Placer Ext.
6/13/2005	150					
6/14/2005			*162*	*162*		
6/15/2005						
6/16/2005						214
8/23/2005	120	*122*	*122*	*122*	127	127
9/19/2005		*202*			207	
11/16/2005	779	*781*	*779/784*	*784*	793	793
11/17/2005	431	*433/438*	*432/437*	*432*	441	441
1/24/2006	200					
1/25/2006					290	
5/2/2006		*227*				
6/13/2006					155	155
7/11/2006			*86*	*86*		
7/13/2006					91	91
8/09/2006				*79*		

A total of five sets (Dog Gulch, Upper Canyon and Narrows) or six sets (Kanaka, Above Igo, and Upper Placer Extension) of measured WSELs at low, medium, and high flows were used in the WSEL calibration. However, in the case of Upper Placer Extension, the downstream transect was the same as the upstream transect of the Upper Placer spawning study site and the calibration used for that transect in the spawning study was applied here. See U.S. Fish and Wildlife (2007) for more details on the Upper Placer spawning study site and transects. The SZFs used for each transect are given in Appendix C. Calibration flows in the PHABSIM files are given in Appendix C. For all of the transects, *IFG4* met the criteria described in the Methods section (Appendix C).

Velocity Adjustment Factors (VAFs) were examined for all of the simulated flows (Appendix D). None of the transects deviated significantly from the expected pattern of VAFs. In addition, VAF values (ranging from 0.42 to 4.96) were within an acceptable range of 0.2 to 5.0, with the exception of the three highest flow VAFs for the Kanaka downstream transect and the highest flow VAF for the Kanaka upstream transect. The three highest flow VAFs for the Kanaka downstream transect of 5.31, 5.75, and 6.17 and the highest flow VAF for the Kanaka upstream transect of 5.28, respectively, were somewhat above the acceptable range of 5.0.

River2D Model Construction

The bed topography for each site is shown in Appendix E. The finite element computational mesh (TIN) for each of the study sites are shown in Appendix F. As shown in Appendix G, the meshes for all sites had QI values of at least 0.30. The percentage of the original bed nodes for which the meshes differed by 0.1 foot (0.031 m) or less from the elevation of the original bed nodes ranged from 80-94% (Appendix E).

River2D Model Calibration

Calibration was conducted at the highest simulation flow, 900 cfs (25.5 m^3/s), for all sites[21]. The calibrated cdg files all had a solution change of less than 0.000001, with the net Q for all sites less than 1% (Appendix G). The calibrated cdg file for all study sites had a maximum Froude Number greater than 1.0 (Appendix G). Three of the six study sites, Dog Gulch, Upper Canyon and Upper Placer Extension, had calibrated cdg files within 0.1 foot (0.031 m) of the PHABSIM WSEL. Five of the six study sites (with the exception of Narrows site) had average WSEL values that were within the 0.1 (0.031 m) criterion. Above Igo had average WSELs that were well within that criterion value (Appendix G). For Above Igo and Kanaka, the WSELs next to the locations of the left and right banks on the upstream transect were both within the 0.1 foot

[21] Our general rule is that it is more accurate to calibrate sites using the WSELs simulated by PHABSIM at the highest simulated flow because the RIVER2D model is more sensitive to the bed roughness multiplier at higher flows, versus lower flows.

(0.031 m) criterion value. For Narrows, the WSEL on the left bank was within the 0.1 foot (0.031 m) criterion value but the WSEL on the right bank greatly exceeded the 0.1 foot (0.031 m) criterion value.

River2D Model Velocity Validation

The correlation between predicted and measured velocities ranged from moderately strong to very strong, with the exception of Narrows site, (Appendix H), with there being some significant differences between individual measured and predicted velocities for all sites. The hydraulic models for Dog Gulch, Upper Canyon, Kanaka, Above Igo, and Upper Placer Extension sites were validated, since the correlation between the predicted and measured velocities was greater than 0.6 for these sites. However, we were unable to validate the model for Narrows site with regards to velocity simulation, since the correlation values were considerably less than 0.6. As a result, the model for this site is in question. In general, the simulated and measured cross-channel velocity profiles at the upstream and downstream transects (Appendix H[22]) were relatively similar in shape. Unless noted as follows, the simulated velocities for the six sites were relatively similar to the measured velocities for the transects.

River2D over-predicted the simulated velocities for the Upper Canyon downstream (XS1) transect on the west side of the channel and under-predicted the velocities for much of the rest of the channel. For the Upper Canyon upstream (XS2) transect, River2D under-predicted the simulated velocities on the west side of the channel. In the case of the Narrows downstream (XS1) and upstream (XS2) transects, River2D under-predicted the velocities on the west side of the channel. River2D also under-predicted the simulated velocities for the Narrows downstream (XS1) transect on the east side of the channel, while over-predicting the simulated velocities for the mid-channel portion of the upstream (XS2) transect. In the case of Kanaka, River2D over-predicted the simulated velocities on the south side of the downstream (XS1) and upstream (XS2) transects and under-predicted the velocities on the north sides of those transects. For Above Igo site, River2D under-predicted the velocities for the west side of the upstream (XS2) transect, while over-predicting the simulated velocities for the east side of the channel. River2D over-predicted the simulated velocities for the Upper Placer Extension downstream (XS1) transect on the west side of the channel, while under-predicting the simulated velocities on the east side of the channel. In the case of the upstream transect, River2D under-predicted the simulated velocities on the west side of the channel, while over-predicting the simulated velocities on the east side of the channel (Appendix H).

[22] Velocities were plotted versus easting for transects that were oriented primarily east-west, while velocities were plotted versus northing for transects that were primarily north-south.

River2D Model Simulation Flow Runs

The simulation flows were 50 cfs to 300 cfs by 25 cfs increments and 300 cfs to 900 cfs by 50 cfs increments. The production cdg files all had a solution change of less than 0.00001, but the net Q was greater than 1% for 1 flow for Upper Canyon, 4 flows for Narrows, 1 flow for Kanaka, 5 flows for Above Igo, and 1 flow for Upper Placer Extension (Appendix I). The maximum Froude Number was greater than 1.0 for all 23 simulated flows for Dog Gulch, 19 of the 23 simulated flows for Upper Canyon, all 23 simulated flows for Narrows, 16 of the 23 simulated flows for Kanaka, 7 of the 23 simulated flows for Above Igo, and all 23 simulated flows for Upper Placer Extension (Appendix I).

Habitat Suitability Criteria Data Collection

The sampling dates and Clear Creek flows are shown in Table 11. There were 774 measurements of depth, adjacent velocity and cover and 773 measurements of velocity at locations where YOY Chinook salmon and steelhead/rainbow trout were observed. All but 46 of these measurements were made near the stream banks. There were 214 observations of spring-run Chinook salmon and 566 observations of steelhead/rainbow trout[23]. There were 308 observations of fish less than 40 mm, 224 observations of 40-60 mm fish, 191 observations of 60-80 mm fish and 190 observations of fish greater than 80 mm. A total of 1,175 mesohabitat units were surveyed. A total of 29.7 miles of near-bank habitat and 6.3 miles of mid-channel habitat were sampled. Table 12 summarizes the number of feet of different mesohabitat types sampled and Table 13 summarizes the number of feet of different cover types sampled. To evaluate whether we have spent equal effort sampling areas with and without woody cover, we have developed two different groups of cover codes based on snorkel surveys we conducted on the Sacramento River: Cover Group 1 (cover codes 4 and 7 and composite [3.7, 4.7, 5.7 & 9.7, i.e. instream+overhead] cover), and Cover Group 0 (all other cover codes). A total of 18.6 miles (11.2 km) of Cover Group 0 and 10.6 miles (6.4 km) of Cover Group 1 in near-bank habitat[24], and 6.2 miles (3.7 km) of Cover Group 0 and 750 feet (229 m) of Cover Group 1 in mid-channel habitat, were sampled.

Habitat Suitability Criteria Development

The results of the Mann-Whitney U tests and Pearson's test for association to test for differences between fry and juvenile salmonids, as shown in Table 14, showed significant differences (at $p = 0.05$) between fry and juvenile habitat use for all four variables for all three criteria to separate fry from juveniles. However, there was the greatest difference between fry and juvenile

[23] These numbers total more than 774 because a few of the observations included both spring-run Chinook salmon and steelhead/rainbow trout YOY and only one measurement was made per group of closely associated individuals.

[24] These numbers are less than the total miles sampled because cover data were not recorded for all areas sampled.

Table 11. Spring-run Chinook salmon and steelhead/rainbow trout YOY HSC sampling dates and flows. For multiple dates, flows are averages.

Sampling Dates	Clear Creek Flows[25] (cfs)
September 24, 2004	213
January 14, 21, and 26-27, 2005	283
February 15, 2005	238
April 6 and 20, 2005	250
May 5, 11-13, 16, 23 and 26, 2005	264
June 7, 10, 13 and 23-24, 2005	198
July 28-29, 2005	154
November 22, 2005	199
December 7-8 and 14-16, 2005	216
January 25-26, 2006	194
February 10, 17 and 23, 2006	272
March 9-10, 15-17, 20-21, 27 and 29, 2006	378
April 6, 20-21, 24 and 26, 2006	333
May 1, 5-6, 9-10, 16-17, 24-25 and 30-31, 2006	262
June 6-7, 2006	136
July 5 and 14, 2006	95
August 8, 2006	89
December 7, 15, 18-20 and 29, 2006	240
January 5, 8, 10, 17-19, 25-26 and 30-31, 2007	217
February 1, 5-7, 13-15, 21 and 27, 2007	261
March 7, 2007	255
April 3, 5, 10, 13, 17 and 26-27, 2007	235
May 1, 11, 15-18 and 23-24, 2007	227
June 7, 19 and 21, 2007	167
July 10, 12 and 19-20, 2007	106
January 16-17 and 30, 2008	253
April 29-30, 2008	224

[25] U.S. Geological Survey Gage Number 11372000 on Clear Creek near Igo, CA.

Table 12. Distances sampled for YOY spring-run Chinook salmon and steelhead/rainbow trout HSC data - mesohabitat types

Mesohabitat Type	Near-bank habitat distance sampled (ft)	Mid-channel habitat distance sampled (ft)
Main Channel Glide	4,071 (1,241 m)	744 (227 m)
Main Channel Pool	66,804 (20,362 m)	12,993 (3,960 m)
Main Channel Riffle	31,292 (9,538 m)	7,011 (2,137 m)
Main Channel Run	52,065 (15,869 m)	10,395 (3,168 m)
Side Channel Glide	0 (0 m)	550 (168 m)
Side Channel Pool	1,180 (360 m)	520 (158 m)
Side Channel Riffle	200 (61 m)	365 (111 m)
Side Channel Run	0 (0 m)	664 (202 m)
Cascade	1,129 (344 m)	282 (86 m)

Table 13. Distances sampled for YOY spring-run Chinook salmon and steelhead/rainbow trout HSC data - cover types.

Cover Type	Near-bank habitat distance sampled (ft)	Mid-channel habitat distance sampled (ft)
None	48,623 (14,820 m)	18,372 (5,600 m)
Cobble	14,901 (4,542 m)	8,763 (2,671 m)
Boulder	7,835 (2,388 m)	4,558 (1,389 m)
Fine Woody	48,153 (14,677 m)	465 (142 m)
Branches	23,518 (7,168 m)	376 (115 m)
Log	1,700 (518 m)	38 (12 m)
Overhead	1,461 (445 m)	26 (8 m)
Undercut	3,049 (929 m)	73 (22 m)
Aquatic Vegetation	5,115 (1,559 m)	616 (188 m)
Rip Rap	0 (0 m)	0 (0 m)
Overhead + instream	45,101 (13,747 m)	611 (186 m)

Table 14. Differences in YOY salmonid habitat use as a function of size.

Variable	<40 mm Versus > 40 mm	<60 mm Versus > 60 mm	< 80 mm Versus > 80 mm
Depth	χ^2 = 77.92, p < 0.000001, n = 308, 530	χ^2 = 141.65, p < 0.000001, n = 468, 344	χ^2 = 172.71, p < 0.000001, n = 623, 190
Velocity	χ^2 = 78.06, p < 0.000001, n = 307, 530	χ^2 = 119.28, p < 0.000001, n = 467, 344	χ^2 = 142.08, p < 0.000001, n = 622, 190
Adjacent Velocity	χ^2 = 116.6, p < 0.000001, n = 308, 530	χ^2 = 183.55, p < 0.000001, n = 468, 344	χ^2 = 140.35, p < 0.000001, n = 623, 190
Cover	C = 62, p < 0.000001, n = 308, 530	C = 115, p < 0.000001, n = 468, 344	C = 147, p < 0.000001, n = 623, 190

habitat use for depth, velocity and cover for the < 80 mm versus > 80 mm criteria to separate fry from juveniles (see Z and C values in Table 14), while there was greatest difference between fry and juvenile habitat use for adjacent velocity for the < 60 mm versus > 60 mm criteria to separate fry from juveniles (see Z values in Table 14). Since there was the greatest difference between fry and juvenile habitat use for the < 80 mm versus > 80 mm criteria for three of the four parameters, we selected 80 mm as the criteria to separate fry from juveniles. Hereafter, fry refers to YOY less than 80 mm, while juvenile refers to YOY greater than 80 mm.

The results of the Mann-Whitney U tests and Pearson's test for association to test for differences between spring-run Chinook salmon and steelhead/rainbow trout, are shown in Table 15. There were significant differences (at p = 0.05) between species for fry for depth and velocity and for juveniles for all four parameters (See χ^2 and C values in Table 22), but there were no significant differences (at p = 0.05) between species for fry for adjacent velocity or cover. For fry, we lumped together data for both species for depth and velocity, but developed separate criteria for each species for adjacent velocity and cover. For juveniles, we lumped data for both species for all four parameters.

Based on observations, spring-run Chinook salmon fry were present between November 22 and June 30, and steelhead/rainbow trout fry were present between January 26 and November 22. As a result, we only used unoccupied data collected between November 22 and June 30 (1,665 observations) to develop spring-run Chinook salmon fry adjacent velocity and cover criteria, and only used unoccupied data collected between January 26 and November 22 (1,718 observations) to develop steelhead/rainbow trout adjacent velocity and cover criteria. We used all of the unoccupied observations when we combined together fry of both species, since either spring-run Chinook salmon or steelhead rainbow trout fry were observed on all sampling dates (November 22 through September 24). For juvenile salmonids, we only used unoccupied data collected between March 7 and September 24 (1,495 observations), since all but one of the observations of

Table 15. Differences in YOY habitat use as a function of species.

Variable	< 80 mm Fish	> 80 mm Fish
Depth	χ^2 = 0.01, p = 0.903, n = 202, 426	χ^2 = 0.45, p = 0.50, n = 17, 174
Velocity	χ^2 = 1.53, p = 0.216, n = 201, 426	χ^2 = 0.73, p = 0.39, n = 17, 174
Adjacent Velocity	χ^2 = 23.22, p < 0.000001, n = 202, 426	χ^2 = 3.73, p = 0.053, n = 17, 174
Cover	C = 24, p = 0.018, n = 202, 426	C = 6, p = 0.77, n = 17, 174

either juvenile spring-run Chinook salmon or steelhead/rainbow trout were made during this time period[26]. The number of occupied and unoccupied locations for each parameter, species and life-stage are shown in Table 16.

The coefficients for the final logistic regressions for depth and velocity for each size class are shown in Table 17. The logistic regression and associated parameters were statistically significant, with the exception of the V^3 coefficient for juvenile salmonids. We still used the V^3 coefficient for juvenile salmonids because the p-value (0.054) was just slightly higher than 0.05 and was lower than p-values for V^2 (0.075) or V^4 (0.072) coefficients. The V term was eliminated after the first logistic regression, since it had a p-value of 0.34. The logistic regression equation for salmonid fry velocity initially peaked at 0 feet/second (0 m/s), reached a minimum SI of 0.10 at 1.9 feet/second (0.58 m/s), and then increased to a SI of 0.57 at 3.6 feet/second (1.10 m/s, the maximum velocity at which spring-run Chinook salmon or steelhead/ rainbow trout fry were found in Clear Creek). There were 10 occupied (1.6%) and 399 unoccupied (20%) locations with velocities greater than 1.9 feet/second (0.58 m/s), indicating that the results of the logistic regression for velocities greater than 1.9 feet/second (0.58 m/s) were not supported by the underlying data. As a result, we set the SI to 0.10 for velocities of 1.9 to 3.6 feet/second (0.58 to 1.10 m/s). The final depth and velocity criteria, along with the frequency distributions of occupied and unoccupied locations, are shown in Figures 3 through 6 and Appendix J.

Adjacent velocities were highly correlated with velocities (Table 18). For spring-run fry, the [J * V] and [M * V^4] terms were dropped from the regressions because the p-values for J and M were greater than 0.05. For steelhead/rainbow trout fry adjacent velocity, the [L * V^3] and [M * V^4]

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[26] The only observation of a juvenile salmonid outside of this time period (on January 26) was of a fish classified as a winter-run Chinook salmon by the CDFG race tables.

Table 16. Number of occupied and unoccupied locations.

		Depth	Velocity	Adjacent Velocity	Cover
Spring-run Chinook fry	**Occupied**	N/A	N/A	201	201
	Unoccupied	N/A	N/A	1665	1665
Steelhead/rainbow trout fry	**Occupied**	N/A	N/A	426	426
	Unoccupied	N/A	N/A	1718	1718
Salmonid fry	**Occupied**	628	627	N/A	N/A
	Unoccupied	2012	2012	N/A	N/A
Juvenile salmonid	**Occupied**	191	191	191	191
	Unoccupied	1495	1495	1495	1495

Table 17. Logistic regression coefficients. A blank for a coefficient or constant value indicates that term or the constant was not used in the logistic regression, because the p-value for that coefficient or for the constant was greater than 0.05. The coefficients in this table were determined from Equation 2. The logistic regression and all associated parameters were statistically significant[27].

Species/life stage	Parameter	I	J	K	L	M	R^2
Salmonid fry	depth	0.4302	-1.2582				0.132
Salmonid fry	velocity		-3.2386	0.9297		-0.0282	N/A[28]
Juvenile salmonid	depth	-3.1069	0.9686	-0.1668			0.014
Juvenile salmonid	velocity	-1.9889			-0.0101		0.004

terms were dropped from the regressions because the p-values for L and M were greater than 0.05. For juvenile salmonid adjacent velocity, the [K * V^2], [L * V^3] and [M * V^4] terms were dropped from the regressions because the p-values for K, L and M were greater than 0.05. The logistic regression and remaining coefficients were statistically significant. The I and N coefficients from equation 3 are given in Table 18. We were unable to develop adjacent velocity criteria for spring-run Chinook salmon fry because the coefficients in Table 18 produced a relationship in which suitability decreased with increasing adjacent velocity. Such a relationship is inconsistent with the biological mechanism for adjacent velocity of turbulent mixing

[27] The only exception to this was for the coefficient for the V^3 term for salmonid fry, where the p value was 0.054.

[28] There are no R^2 values for logistic regressions that do not include a constant, since the R^2 value is calculated by comparing the logistic regression with a constant-only model.

Figure 3. Spring-run Chinook salmon and steelhead/rainbow trout fry rearing depth HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout fry rearing has a non-zero suitability for depths of 0.1 to 4.0 feet (0.031 to 1.22 m) and an optimum suitability at a depth of 0.1 feet (0.031 m).

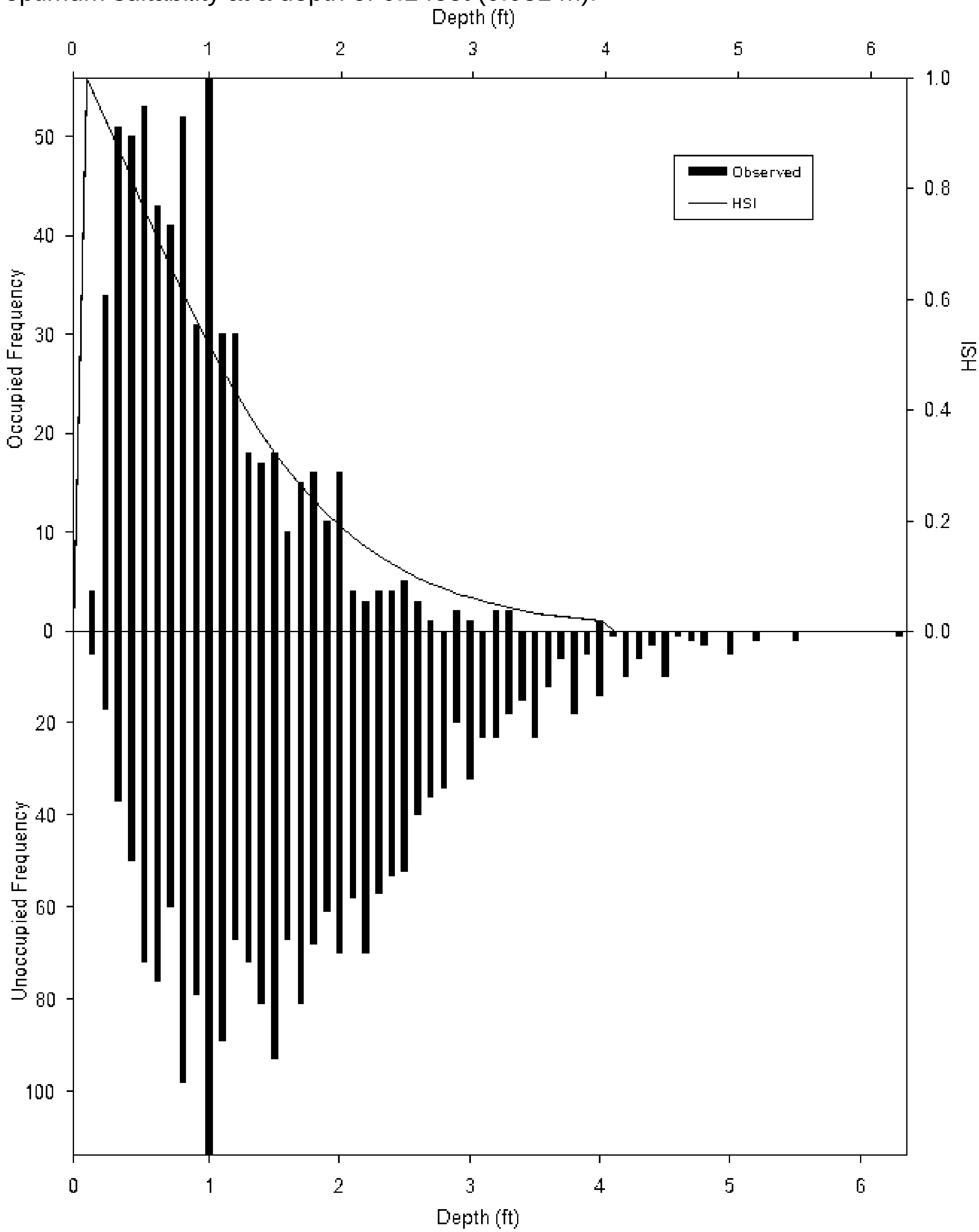


Figure 4. Spring-run Chinook salmon and steelhead/rainbow trout fry rearing velocity HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout fry rearing has a non-zero suitability for velocities of 0 to 3.60 feet/sec (0 to 1.097 m/s) and an optimum suitability at a velocity of zero.

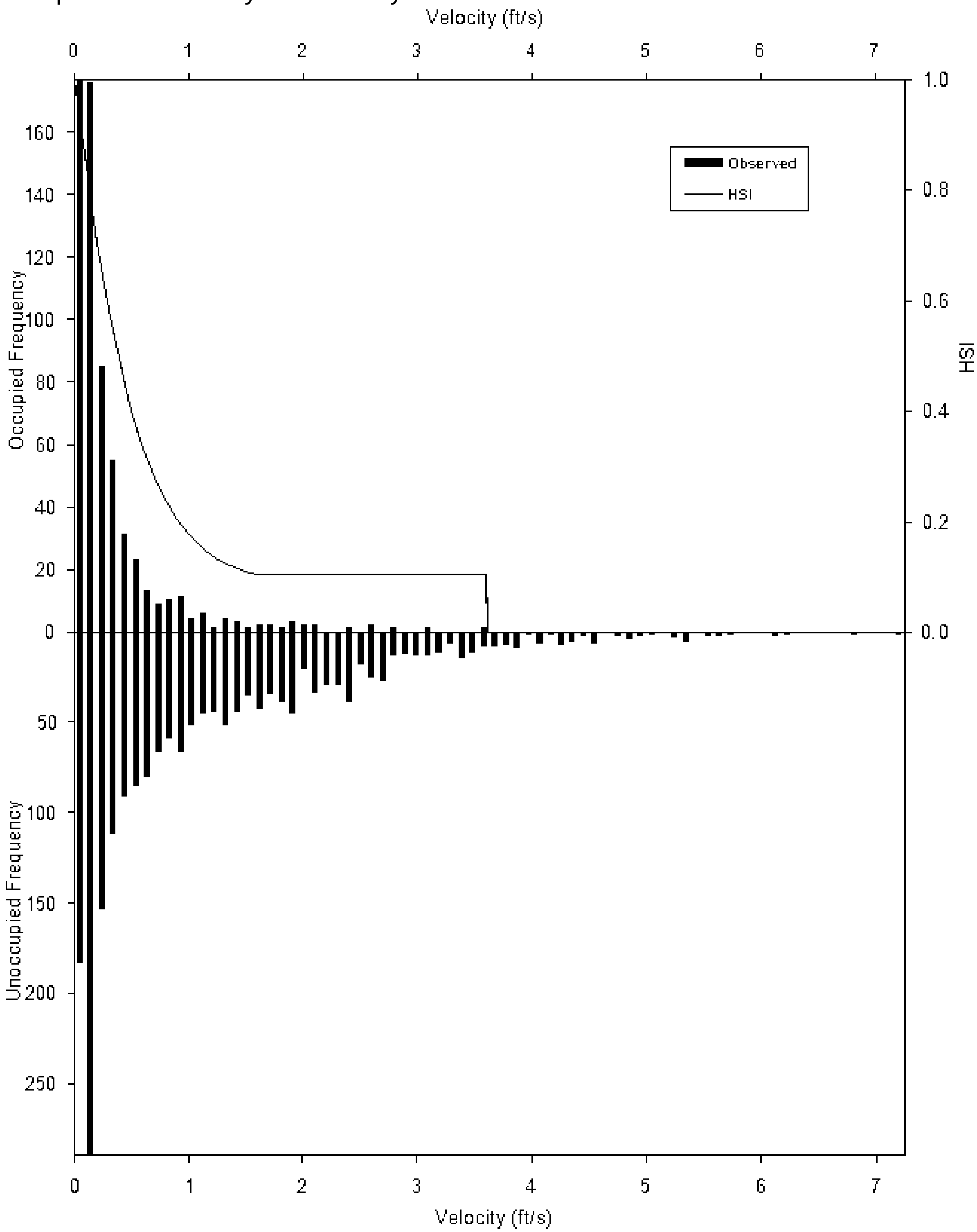


Figure 5. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing depth HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing has a non-zero suitability for depths of 0.3 to 5.5 feet (0.09 to 1.68 m) and an optimum suitability at depths of 2.8 to 3.0 feet (0.85 to 0.91 m).

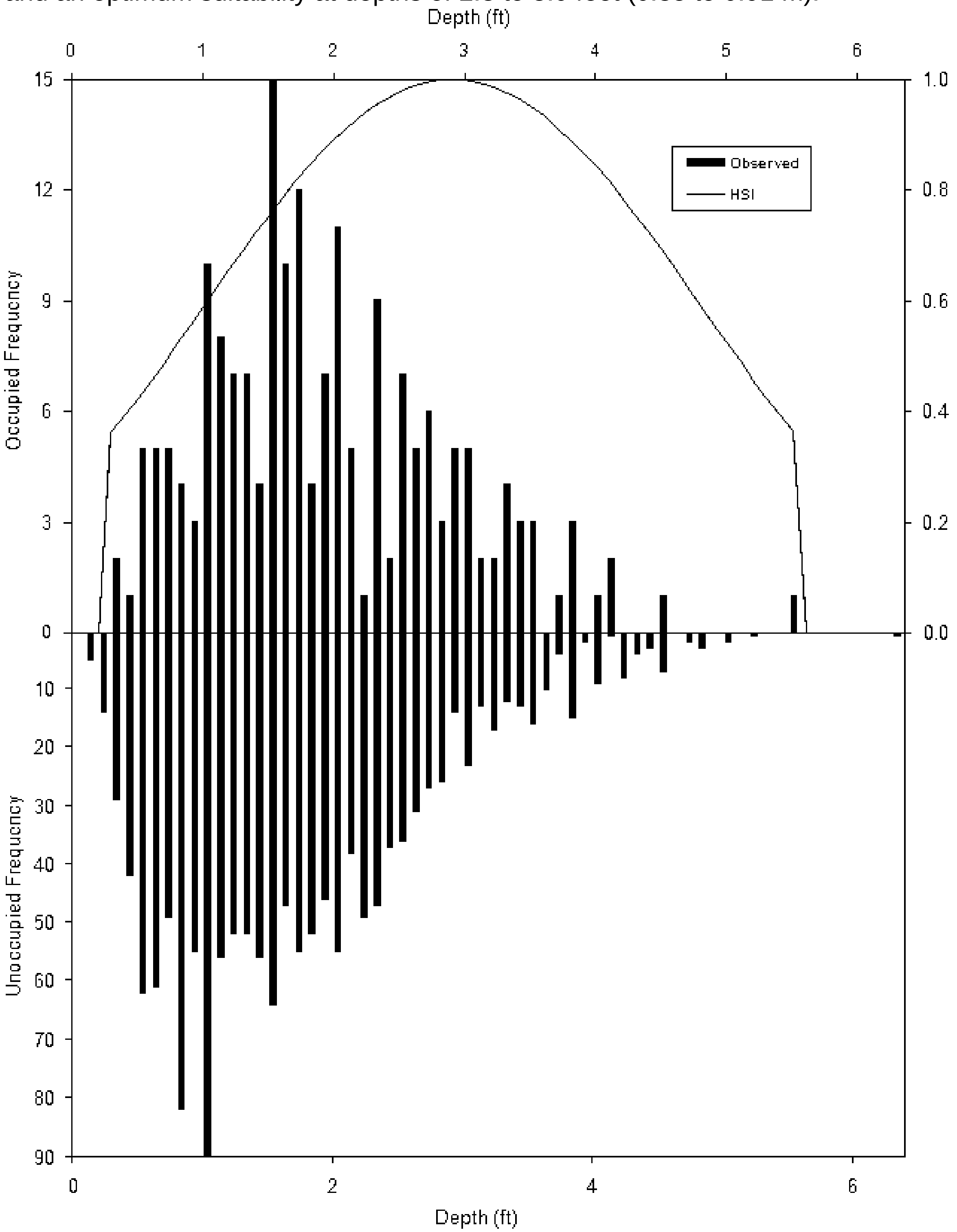


Figure 6. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing velocity HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing has a non-zero suitability for velocities of 0 to 5.53 feet/sec (0 to 1.685 m/s) and an optimum suitability at velocities of 0 to 0.8 feet/sec (0 to 0.244 m).

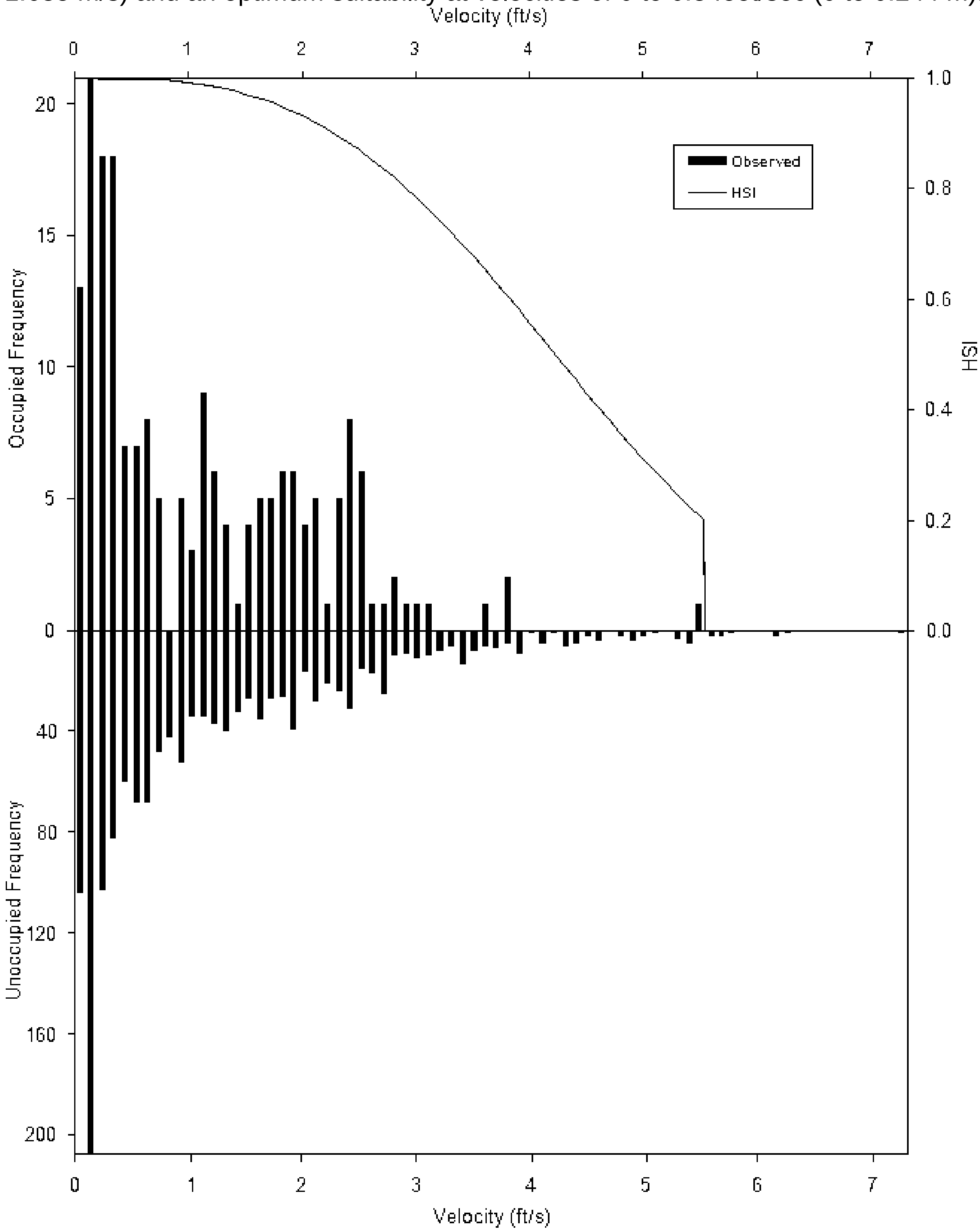


Table 18. Adjacent velocity logistic regression coefficients and R^2 values. The R^2 values are McFadden's Rho-squared values. The coefficients in this table were determined from Equation 2.

Species/Life Stage	Velocity/Adjacent Velocity Correlation	I	N	R^2
Chinook fry	0.84	-1.1362	-0.6875	0.145
Steelhead/rainbow trout fry	0.82	-0.4596	0.1608	0.153
Juvenile salmonids	0.80	-2.3488	0.4880	0.036

transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon and steelhead/rainbow trout reside. The results of equation 3 and the derivation of the final adjacent velocity criteria (Appendix K) are shown in Figures 7 and 8.

The subset of sites used to develop cover criteria consisted of a total of 20.6 miles (12.4 km) of channel (10.3 miles [6.2 km] of cover group 0 and 10.3 miles [6.2 km] of cover group 1), or 58% of the total area sampled. The subset of sites included 2,021 feet (616 m) of mid-channel habitat and 20.2 miles (12.1 km) of near-bank habitat. The subset of sites included 543 occupied observations (70% of the total number of occupied locations) and 1,402 unoccupied locations (67% of the unocccupied locations). The statistical tests are presented in Tables 19 and 20. For Table 19, an asterisk indicates that presence/absence of fish for those cover codes were significantly different at $p = 0.05$. For Table 20, an asterisk indicates that fish presence/absence was significantly different between groups at $p = 0.05$. Our analysis indicated that there were two distinct groups of cover types for spring-run Chinook salmon fry and spring-run Chinook salmon/steelhead/rainbow trout juveniles and three distinct groups for steelhead/rainbow trout fry. This was the minimum number of groups for which there were significant differences between groups but no significant differences among the cover codes in each group. For all three sets of criteria there were no occupied or unoccupied observations of cover code 10; we assigned cover code 10 the same HSI as cover code 2, since most rip-rap consists of boulder-sized rock. The final cover HSC values for both species and life stages are shown in Figures 9 to 11 and in Appendix J.

Habitat Simulation

The WUA values calculated for each site are contained in Appendix K. The ratios of the total area of each habitat type present in a given segment to the area of each habitat type that was modeled in that segment are given in Table 21.

The flow habitat relationships for spring-run Chinook salmon fry rearing are shown in Figures 12 and 13 and Appendix K. In the Upper Alluvial Segment, the 2-D model predicts the highest total WUA for spring-run Chinook salmon fry at 600 cfs. In the Canyon Segment, the 2-D model predicts the highest total WUA for spring-run Chinook salmon fry at 900 cfs.

Figure 7. Steelhead/rainbow trout fry rearing adjacent velocity HSC.

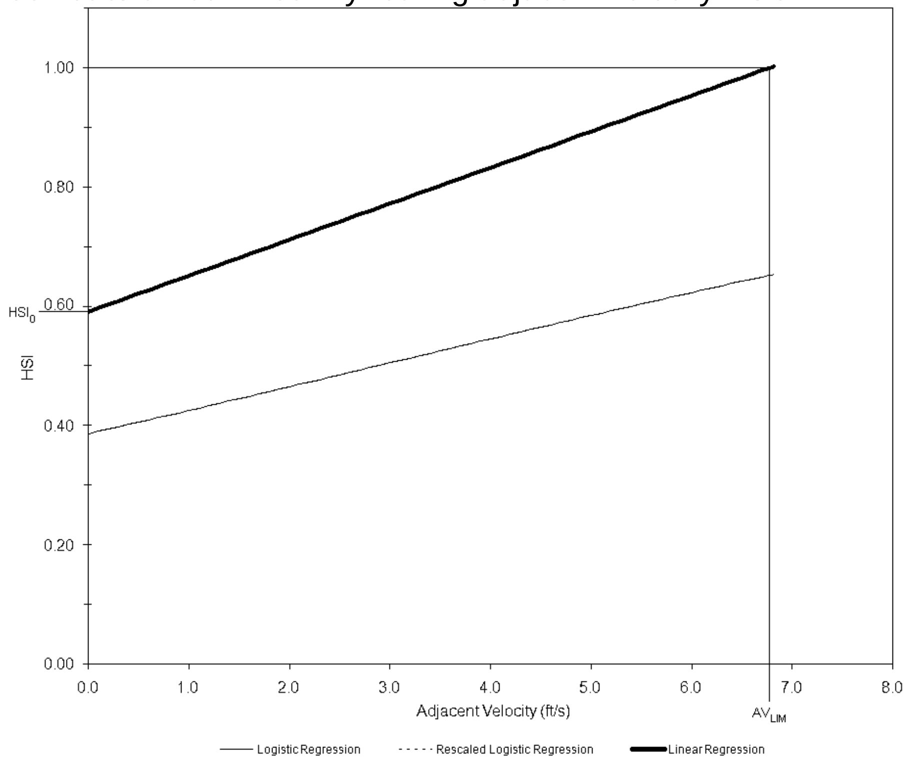


Figure 8. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing adjacent velocity HSC.

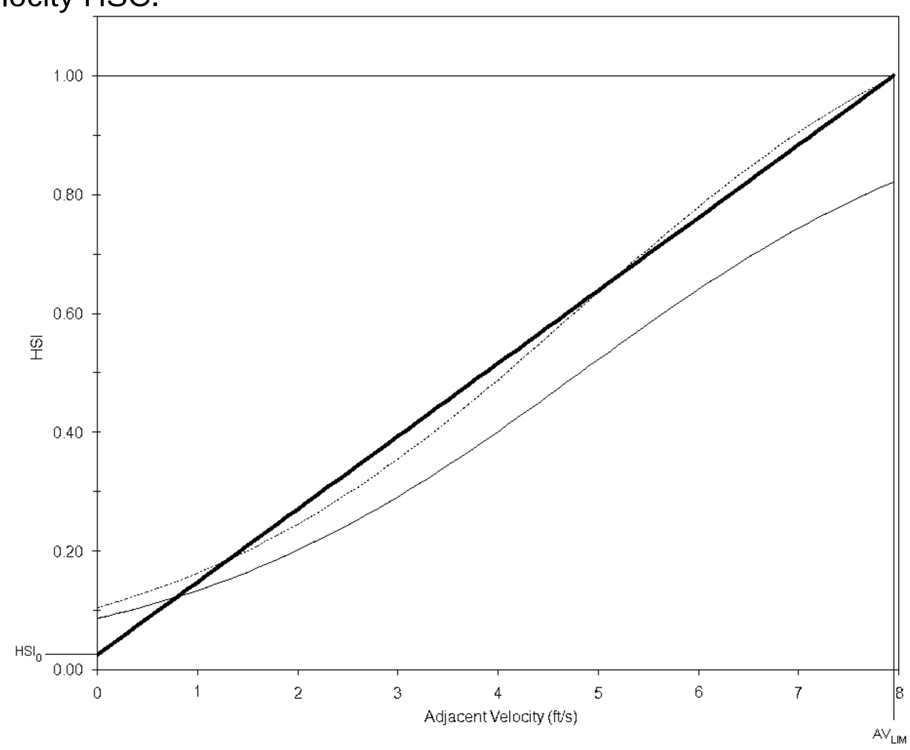


Table 19. Statistical tests of difference between cover codes, using the number of observations where fish were present and absent. An asterisk indicates that presence/absence of fish for those cover codes were significantly different at p = 0.05.

Species/life stage	Cover Codes	c-value
Chinook salmon fry	3.7, 3, 4.7, 8, 9, 2, 0, 4, 7, 5, 5.7, 9.7	132 *
Chinook salmon fry	9, 2, 0, 4, 7, 5, 5.7, 9.7	9.6
Chinook salmon fry	3.7, 3, 4.7, 8	4.3
Steelhead/rainbow trout fry	5, 5.7, 4.7, 8, 3.7, 9, 3, 4, 7, 9.7, 0, 2, 1	270 *
Steelhead/rainbow trout fry	5, 5.7, 4.7, 8, 3.7	1.6
Steelhead/rainbow trout fry	9, 3, 4, 7, 9.7	6.7
Steelhead/rainbow trout fry	0, 2, 1	1.4
Juvenile	8, 5, 4, 3.7, 7, 1, 4.7, 3, 2, 0, 5.7, 9, 9.7	39 *
Juvenile	8, 5, 4, 3.7, 7, 1, 4.7	10.5
Juvenile	3, 2, 0, 5.7, 9, 9.7	1.7

Table 20. Statistical tests of differences between cover code groups, using the number of observations where fish were present and absent. An asterisk indicates that fish presence/absence was significantly different between groups at p = 0.05.

	Cover Codes In Group			
Species/life stage	Group A	Group B	Group C	c-value
Chinook fry	9, 2, 0, 4, 7, 5, 5.7, 9.7	3.7, 3, 4.7, 8		118.7 *
Steelhead fry	5, 5.7, 4.7, 8, 3.7	9, 3, 4, 7, 9.7	0, 2, 1	258.3 *
Juvenile	8, 5, 4, 3.7, 7, 1, 4.7	3, 2, 0, 5.7, 9, 9.7		24.3 *

Figure 9. Spring-run Chinook salmon fry rearing cover HSC.

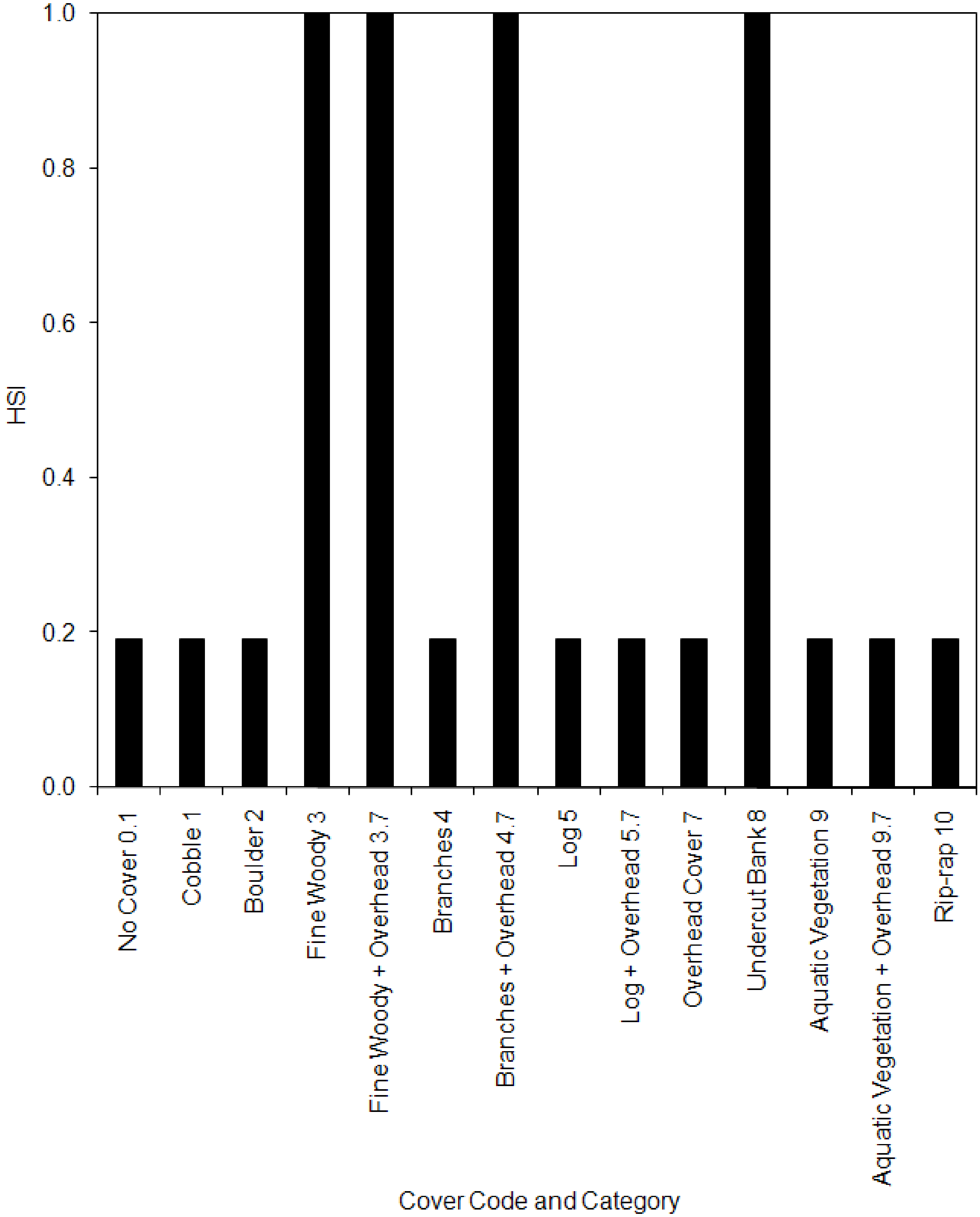


Figure 10. Steelhead/rainbow trout fry rearing cover HSC.

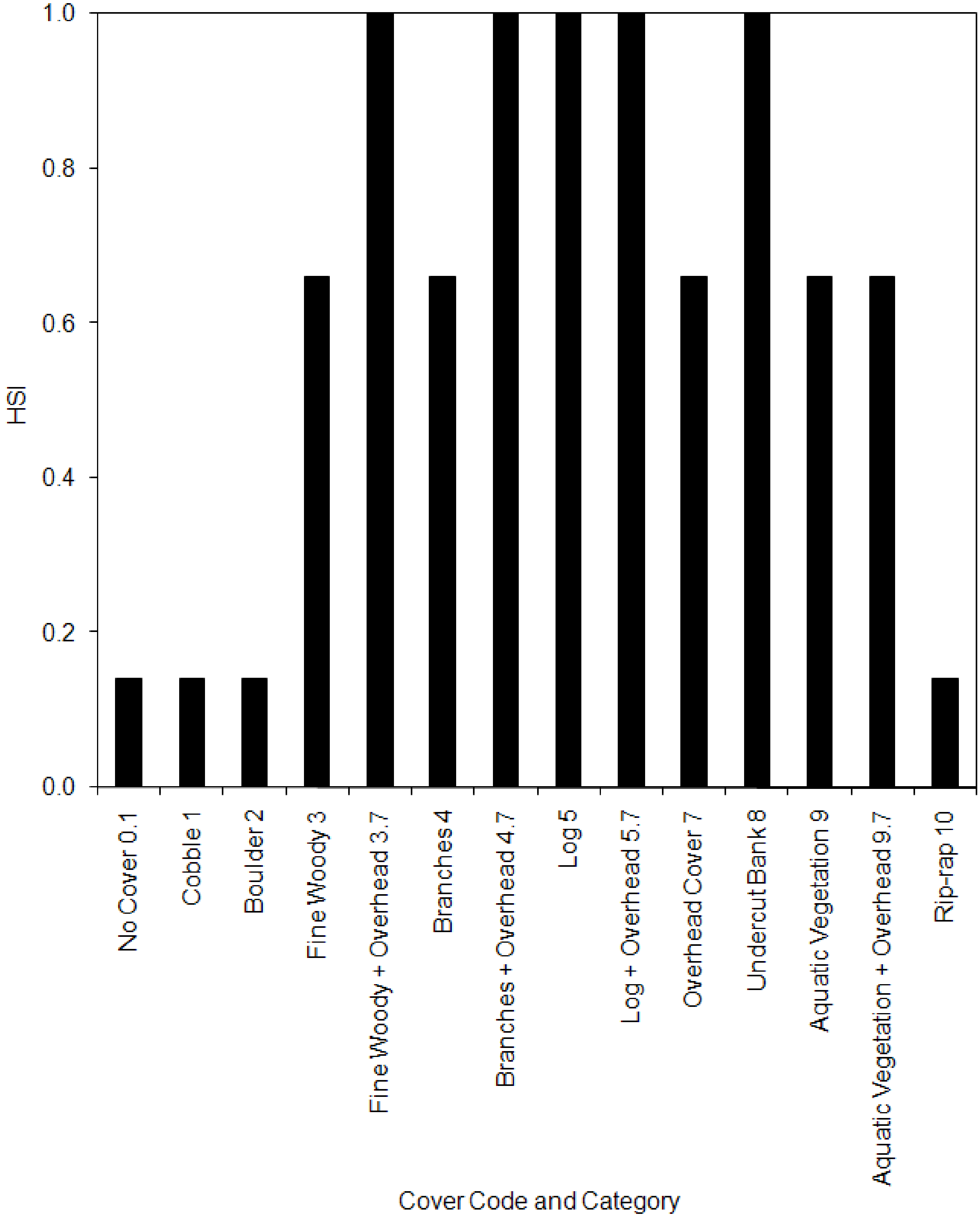


Figure 11. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing cover HSC.

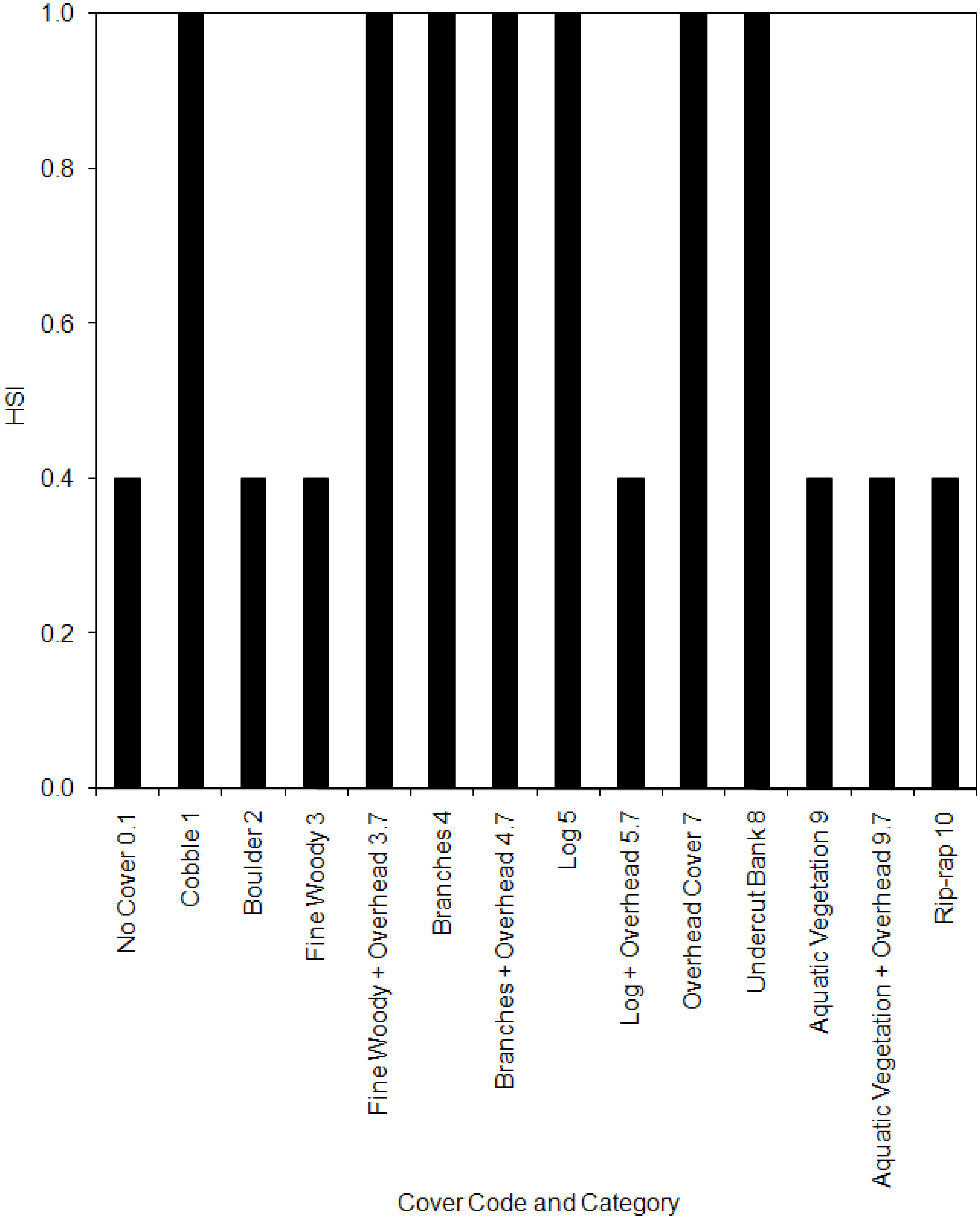


Table 21. Ratio of habitat areas in segment to habitat areas in modeled sites. Entries with an asterisk indicate that the habitat type was not modeled in that reach. Entries with two asterisks indicate that the habitat type was not present in that reach. The ratios were adjusted to account for study sites where the site boundary did not coincide with the boundary of a habitat unit, so that the area of the habitat type only included the portion of the habitat unit that was within the study site.

Habitat Type	Upper Alluvial Segment	Canyon Segment
Main Channel Glide	1.55	*
Main Channel Pool	6.27	13.40[29]
Main Channel Riffle	2.76	13.68
Main Channel Run	6.17	15.79
Side Channel Pool	54.55	**
Side Channel Riffle	18.12	**
Side Channel Run	7.40	1.60
Side Channel Glide	1.94	*

The flow habitat relationships for steelhead/rainbow trout fry rearing are shown in Figures 14 and 15 and Appendix K. In the Upper Alluvial Segment, the 2-D model predicts the highest total WUA for steelhead/rainbow trout fry at 700 cfs. In the Canyon Segment, the 2-D model predicts the highest total WUA for steelhead/rainbow trout fry at 900 cfs.

The flow habitat relationships for spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing are shown in Figures 16 and 17 and Appendix K. In the Upper Alluvial Segment, the 2-D model predicts the highest total WUA for spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing at 900 cfs. In the Canyon Segment, the 2-D model predicts the highest total WUA for spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing at 650 cfs.

[29] Excluding Narrows site increases this ratio to 14.52.

Figure 12. Spring-run Chinook salmon fry rearing flow-habitat relationship in the Upper Alluvial Segment. The flow with the predicted maximum spring-run Chinook salmon fry rearing habitat was 600 cfs.

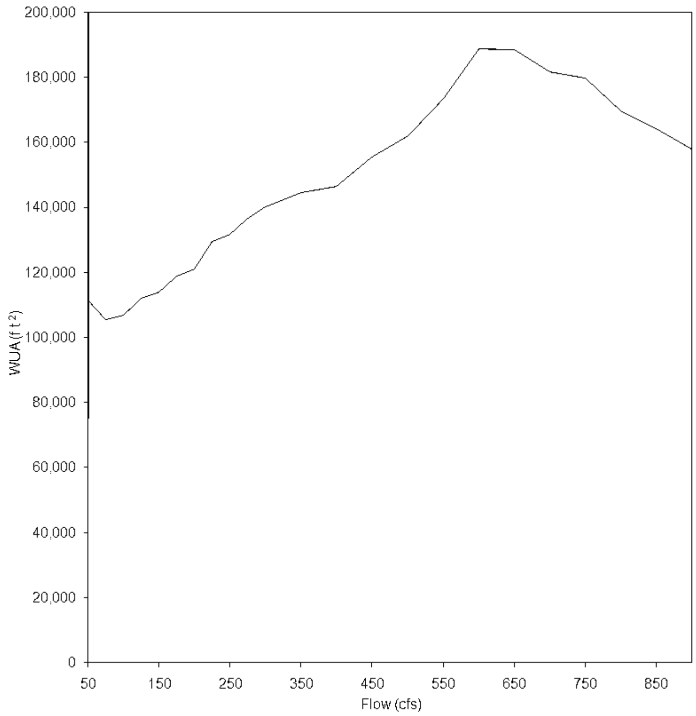


Figure 13. Spring-run Chinook salmon fry rearing flow-habitat relationship in the Canyon Segment. The flow with the predicted maximum spring-run Chinook salmon fry rearing habitat was 900 cfs.

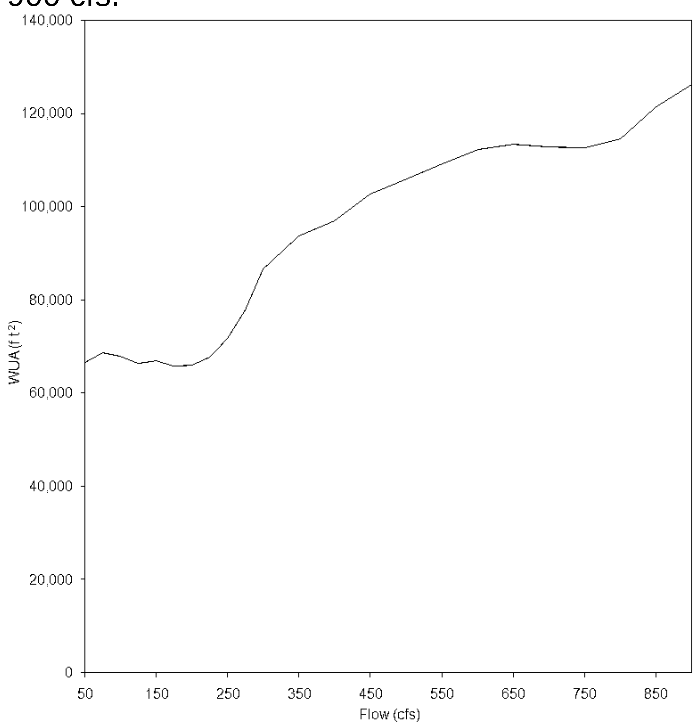


Figure 14. Steelhead/rainbow trout fry rearing flow-habitat relationship in the Upper Alluvial Segment. The flow with the predicted maximum steelhead/rainbow trout fry rearing habitat was 700 cfs.

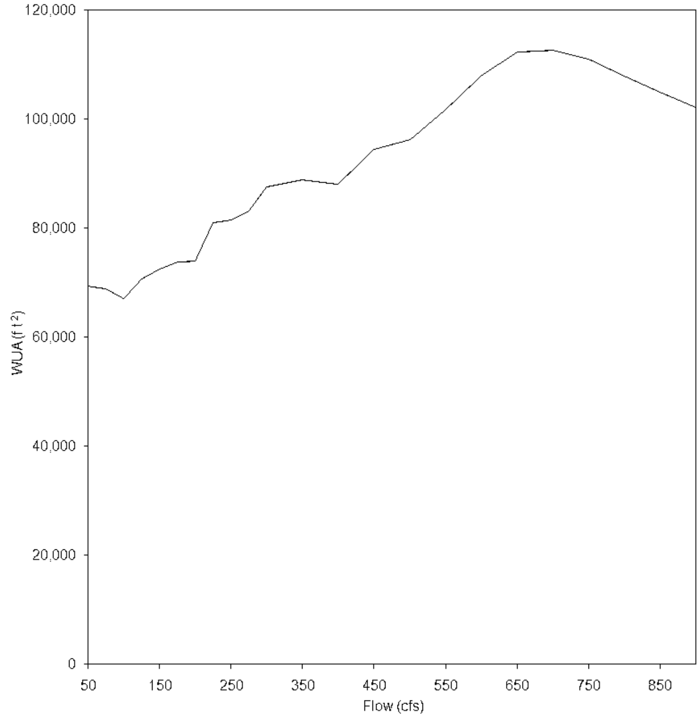


Figure 15. Steelhead/rainbow trout fry rearing flow-habitat relationship in the Canyon Segment. The flow with the predicted maximum steelhead/rainbow trout fry rearing habitat was 900 cfs.

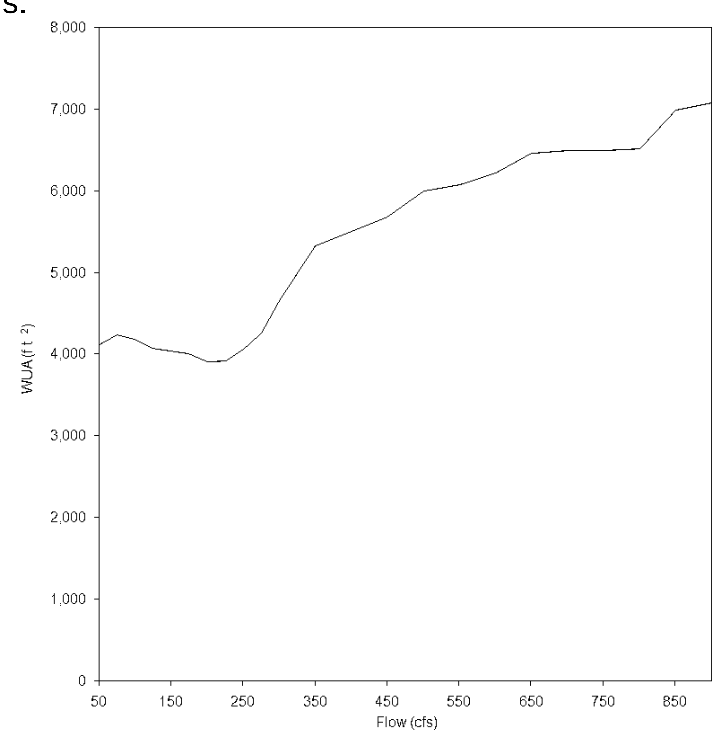


Figure 16. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing flow-habitat relationship in the Upper Alluvial Segment. The flow with the predicted maximum spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing habitat was 900 cfs.

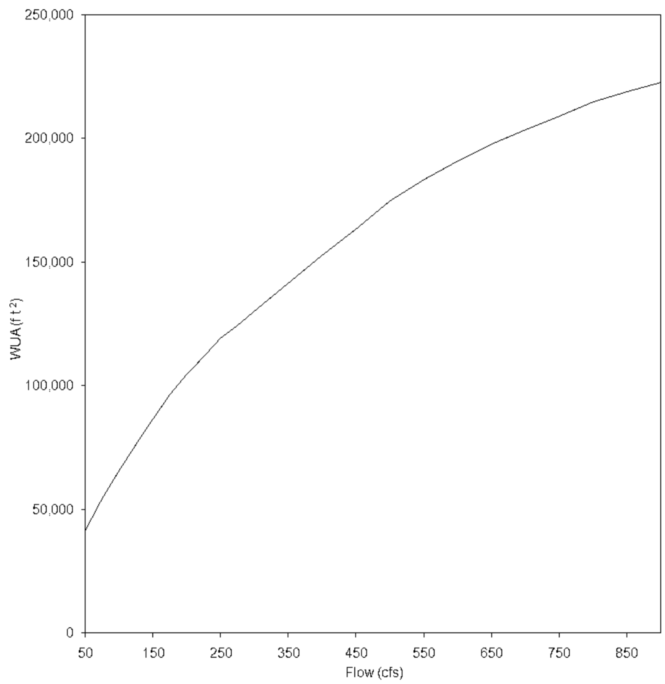
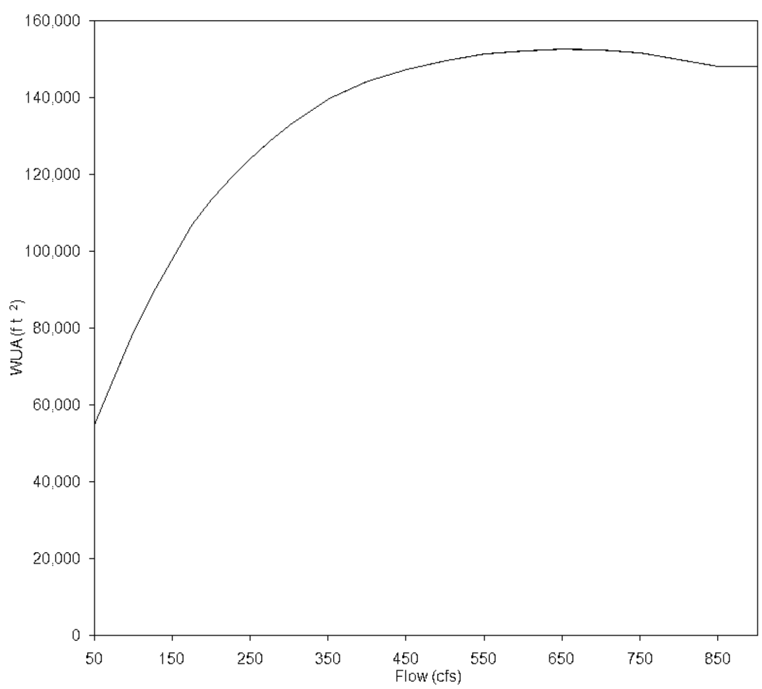


Figure 17. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing flow-habitat relationship in the Canyon Segment. The flow with the predicted maximum spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing habitat was 650 cfs.



DISCUSSION

Habitat Mapping

Traditionally habitat mapping is done in a linear fashion going downstream. The two-dimensional habitat mapping used in this study is more consistent with a two-dimensional-based hydraulic and habitat modeling of habitat availability. In addition, as shown in Figure 18, two-dimensional habitat mapping better captures the complexity of mesohabitat units in Clear Creek.

Hydraulic and Structural Habitat Data Collection

All of the measurements were accurate to 1 foot (0.31 m) horizontally and 0.1 foot (0.031 m) vertically. We conclude that measurement error would have a minimal effect on the final result.

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

We did not regard the slightly high VAF values for the highest three simulation flows of 700 to 900 cfs for the Kanaka downstream transects and for the highest simulation flow of 900 cfs for the Kanaka upstream transect as problematic since RHABSIM was only used to simulate WSELs and not velocities.

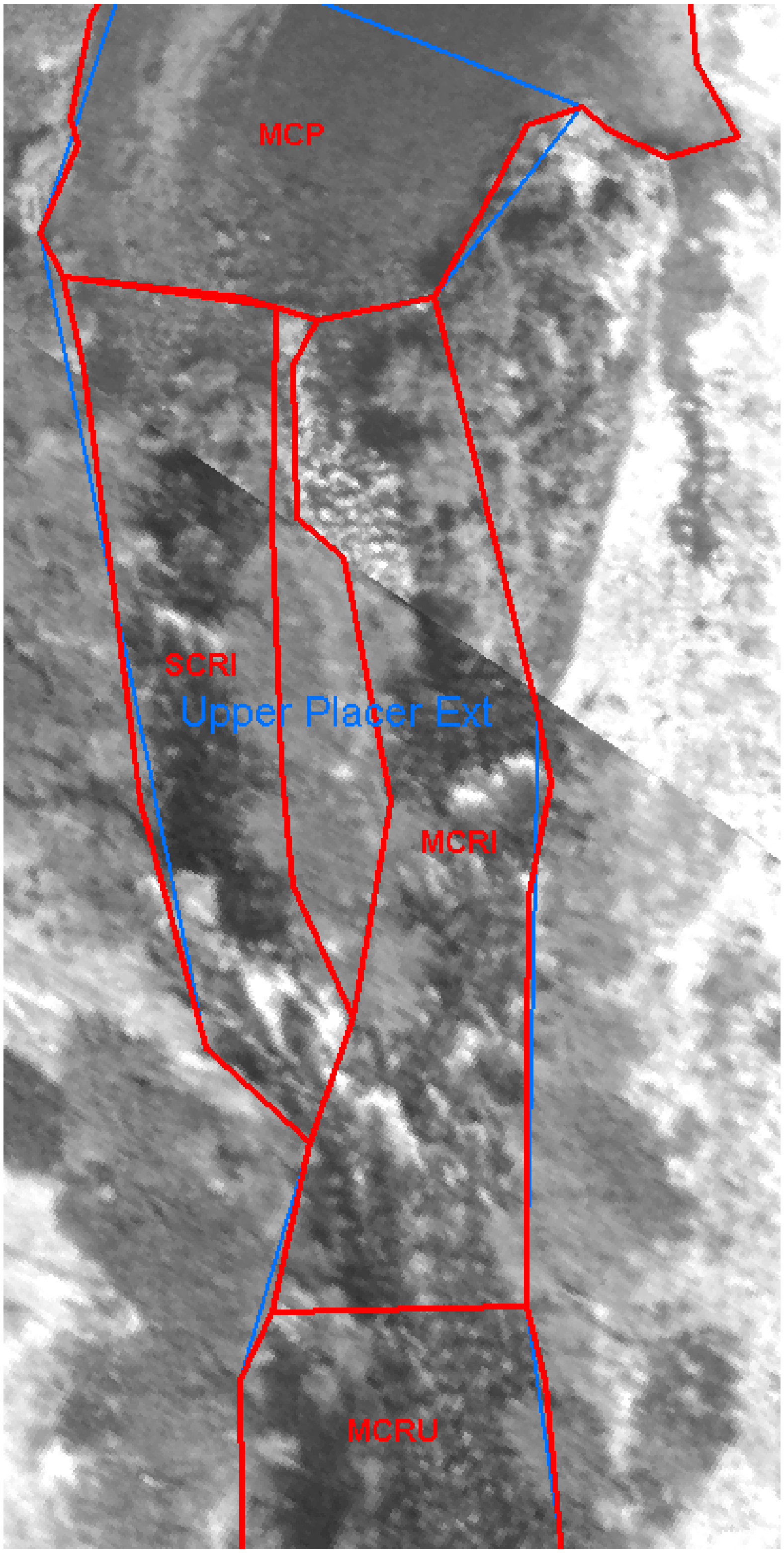
River2D Model Construction

In most cases, the portions of the mesh where there was greater than a 0.1 foot (0.031 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.031 m) vertically of the bed file within 1.0 foot (0.31 m) horizontally of the bed file location. Given that we had a 1-foot (0.31 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file.

River2D Model Calibration

In general, the simulated WSELs at the calibration flow for Narrows, Kanaka and Above Igo sites differed by more than 0.1 foot (0.031 m) in some places along the upstream transect. However, for Kanaka and Above Igo sites, the WSELs next to the locations of the left and right banks within the model were all within the 0.1 foot (0.031 m) criterion value in the final calibration. The PHABSIM simulated WSELs and the measured WSELs used for calibrating the cdg files were based on WSEL measurements taken next to the left and right banks. We decided to accept the calibration results for Kanaka and Above Igo sites at the highest simulation flow because all our WSEL measurements were made next to the left and right banks (Appendix G).

Figure 18. Detail of habitat mapping of a portion of the Upper Placer Extension study site.



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We attribute the maximum difference of 0.27 feet (0.082 m) between the WSEL simulated by River2D and PHABSIM at 900 cfs for the Narrows upstream transect to conditions near the upstream transect that cannot be accurately modeled with a 2-dimensional hydraulic model. Specifically, there were large boulders with flow underneath of them on the left bank near the upstream transect. We represented the topography of these boulders by subtracting the height of the boulders from the elevation of the top of the boulders. We presume that this approximation of the topography at this location forced too much of the flow toward the right bank, elevating the water surface elevation at that location by 0.2 feet (0.061 m), relative to the water surface elevation predicted by PHABSIM. Accordingly, we conclude the calibration for Kanaka and Above Igo sites was acceptable, but that the calibration for Narrows was not acceptable.
We considered the solution to be acceptable for the study site cdg calibration files, which all had a maximum Froude Number greater than 1.0, since the Froude Number only exceeded 1.0 at a few nodes, with the vast majority of the site having Froude Numbers less than 1.0. Furthermore, these nodes were located either at the water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results.

River2D Model Velocity Validation

As noted in the results section, we were unable to validate the velocity predictions for the hydraulic model of the Narrows site. As a result, there is greater uncertainty in the habitat modeling results for this site than for the remaining sites. We were left with two alternatives: 1) to exclude this site and represent main channel pool habitat by the remaining sites in the Canyon Segment; or 2) to include this site. We conclude that it would be more accurate to model rearing habitat in the Canyon Segment not using this site because the remaining sites in the Canyon reach, containing a total of five main channel pools, adequately represent this mesohabitat type.

Differences in magnitude in most cases are likely due to (1) aspects of the bed topography of the site that were not captured in our data collection, (2) operator error during data collection, i.e., the probe was not facing precisely into the direction of current, and (3) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations, and (4) the measured velocities being the component of the velocity in the downstream direction, while the velocities predicted by the 2-D model were the absolute magnitude of velocity[30]. The 2-D model integrates effects from the surrounding elements at each point. Thus, point measurements of velocity can differ from simulated values simply due to the local area integration that takes place. As a result, the area integration effect noted above will produce somewhat smoother lateral velocity profiles than the observations.

[30] For areas with transverse flow, this would result in the 2-D model appearing to over-predict velocities even if it was accurately predicting the velocities.

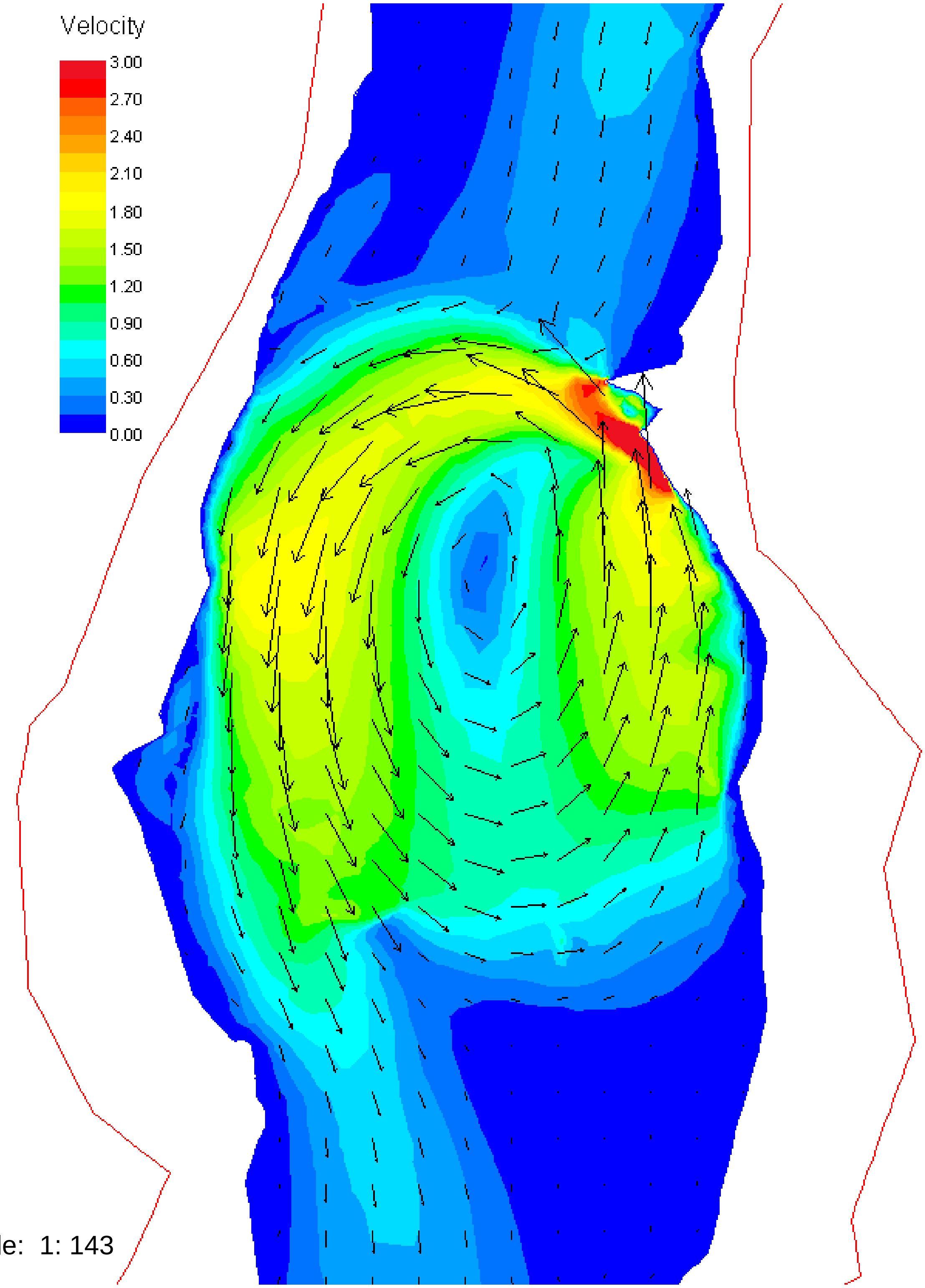
We attribute the overprediction of velocities for the middle portion of the Narrows site to a strong eddy that was produced in the hydraulic model (see Figure 19). The strong simulated upstream velocities on the east side of the channel were countered by the strong downstream velocities on the west side of the channel. Based on the magnitude of the simulated velocities, as compared to the measured velocities, we suspect that there was not an eddy present in this portion of the site, or at least not an eddy of this magnitude. We attribute the presence of the eddy in the model to some aspect of the bed topography which was not captured in our data collection.

The higher simulated velocities on the west side of the channel and the lower simulated velocities in the rest of the channel compared to the measured velocities for Upper Canyon transects 1 and 2 may have been the result of features that were upstream of the study site along the west side of the channel likely acting to reduce the velocities on that side of the channel and increase velocities more toward the rest of the channel. However, we cannot rule out the possibility that deviations in the simulated velocities may have also resulted from errors in the construction of the bed topography within the bed files used for building the RIVER2D file. This explanation also applies to the other study sites where simulated velocities deviated from the velocities measured on the transects, such as the upstream transects for Above Igo and Upper Placer Extension. For Above Igo transect 1, the over-predicted velocities for the majority of the cross-section can be attributed to errors in the velocity measurements on the transect (being too low) or the gaged discharge was in error. For example, in this situation, the gaged discharge was 290 cfs. However, the measured discharge on transect 1 was 260 cfs.

River2D Model Simulation Flow Runs

The simulation flow run cdg files for Upper Canyon, Narrows, Kanaka, Above Igo and Upper Placer Extension where the net Q was greater than 1%, were still considered to have a stable solution since the net Q was not changing and the net Q in all cases was less than 5%. In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is within the same range as the accuracy for USGS gages, and is considered acceptable. Although a majority of the simulation flow files had Max Froude values that exceeded 1.0, we considered these production runs to be acceptable since the Froude Number was only greater than 1.0 at a few nodes, with the vast majority of the area within the site having Froude Numbers less than 1.0. Again, as described in River2D Model Calibration discussion, these nodes were located either at the water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results. In addition, there were limited portions of a few of the sites, such as portions of the upper end of Narrows where water was passing over the top of boulders, where there actually was supercritical flow, where a Max Froude number value of greater than 1.0 would be expected.

Figure 19. Detail of velocity simulation at a flow of 86 cfs for the portion of the Narrows site with a strong eddy generated by River2D. Measured velocities within this portion of the site did not exceed 0.5 m/s. Units of velocity in figure are m/s.



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Habitat Suitability Criteria (HSC) Development

The R^2 values in Tables 17 and 18 in general reflect the large degree of overlap in occupied and unoccupied depths and velocities, as shown in Figures 3 to 6. Low R^2 values are the norm in logistic regression, particularly in comparison with linear regression models (Hosmer and Lemeshow 2000). The R^2 values in this study were significantly lower than those in Knapp and Preisler (1999), Geist et al. (2000) and Guay et al. (2000), which had R^2 values ranging from 0.49 to 0.86. We attribute this difference to the fact that the above studies used a multivariate logistic regression which included all of the independent variables. It would be expected that the proportion of variance (R^2 value) explained by the habitat suitability variables would be apportioned among depth, velocity, adjacent velocity and cover. For example, McHugh and Budy (2004) had much lower R^2 values, in the range of 0.13 to 0.31, for logistic regressions with only one independent variable.

Rubin et al. (1991) present a similar method to logistic regression using fish density instead of presence-absence, and using an exponential polynomial regression, rather than a logistic regression. Rubin et al. (1991) selected an exponential polynomial regression because the distribution of counts of fish resembles a Poisson distribution. We did not select this method for the following reasons: 1) we had low confidence in the accuracy of our estimates of the number of fish in each observation; and 2) while it is reasonable to assume that a school of fish represents higher quality habitat than 1 fish, it is probably unreasonable to assume that, for example, 100 fish represents 100 times better habitat than 1 fish. A more appropriate measure of the effects of the number of fish on habitat quality would probably be to select some measure like log (number of fish + 1), so that 1-2 fish would represent a value of one, 3-30 fish would represent a value of two and 31-315 fish would represent a value of three[31]. We are not aware of any such measure in the literature, nor are we aware of how we could determine what an appropriate measure would be.

It should be noted that the regressions were fit to the raw occupied and unoccupied data, rather than to the frequency histograms shown in Figures 3 through 6. In general, the criteria track the occupied data, but drop off slower than the occupied data due to the frequency of the unoccupied data also dropping over the same range of depths and velocities.

Figures 20 to 23 compare the two to three sets of HSC from this study. Consistent with the scientific literature (Gido and Propst 1999, Sechnick et al. 1986, Baltz and Moyle 1984 and Moyle and Vondracek 1985), our data showed that larger fish select deeper and faster conditions than smaller fish. The criteria also show a consistent preference for composite cover (instream woody plus overhead – cover codes 3.7 and 4.7). Composite cover likely is an important aspect of juvenile salmonid habitat because it reduces the risk of both piscivorous and avian predation. The cover criteria also suggest that cobble cover is more important for Chinook salmon and steelhead/rainbow trout juveniles than for steelhead/rainbow trout fry or Chinook salmon fry.

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[31] The largest number of fish that were in one observation was 42 fish.

Figure 20. Comparison of depth HSC from this study. These criteria indicate that the optimum depths for juvenile fish are greater than those for fry.

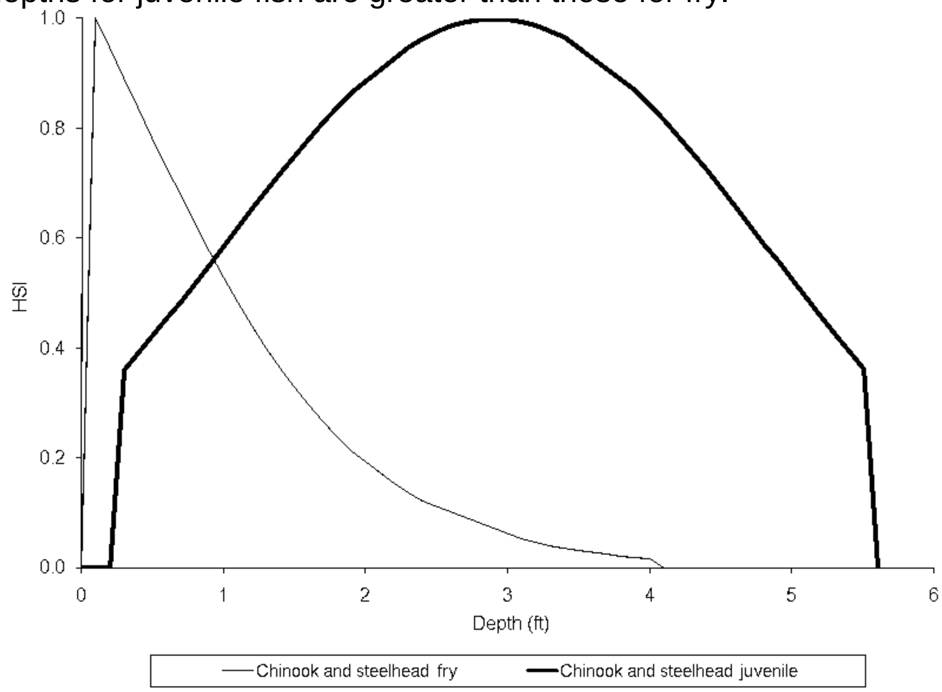


Figure 21. Comparison of velocity HSC from this study. These criteria indicate that there was a slower rate of decline of suitability with increasing velocity for Chinook and steelhead/rainbow trout juveniles than for Chinook salmon and steelhead/ rainbow trout fry.

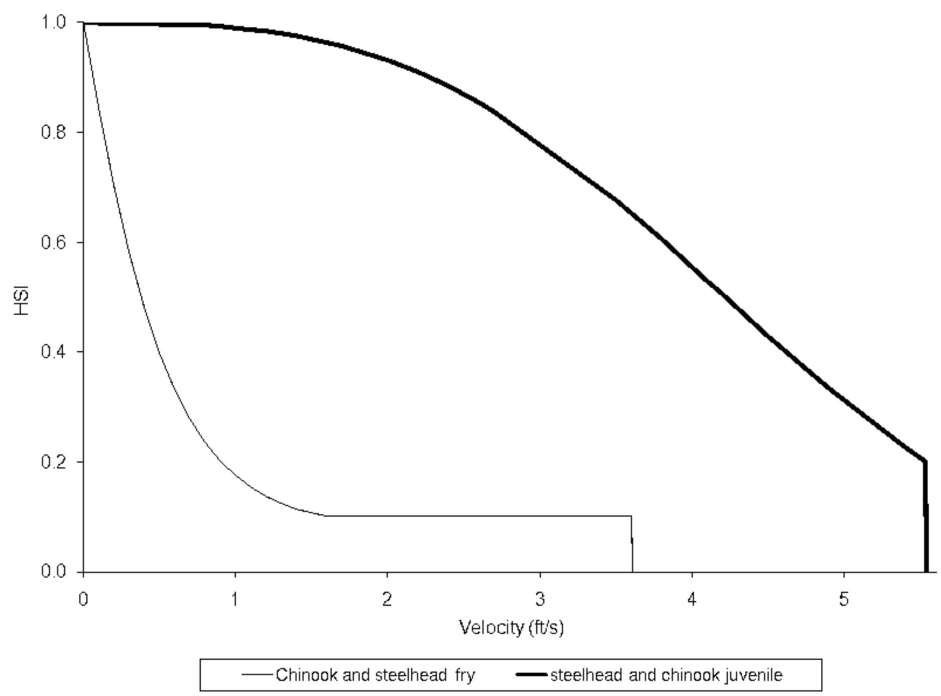


Figure 22. Comparison of cover HSC from this study. These criteria indicate that no cover, cobble and boulder had a lower suitability for fry than juveniles, but that there was a consistent preference for composite cover (instream woody plus overhead).

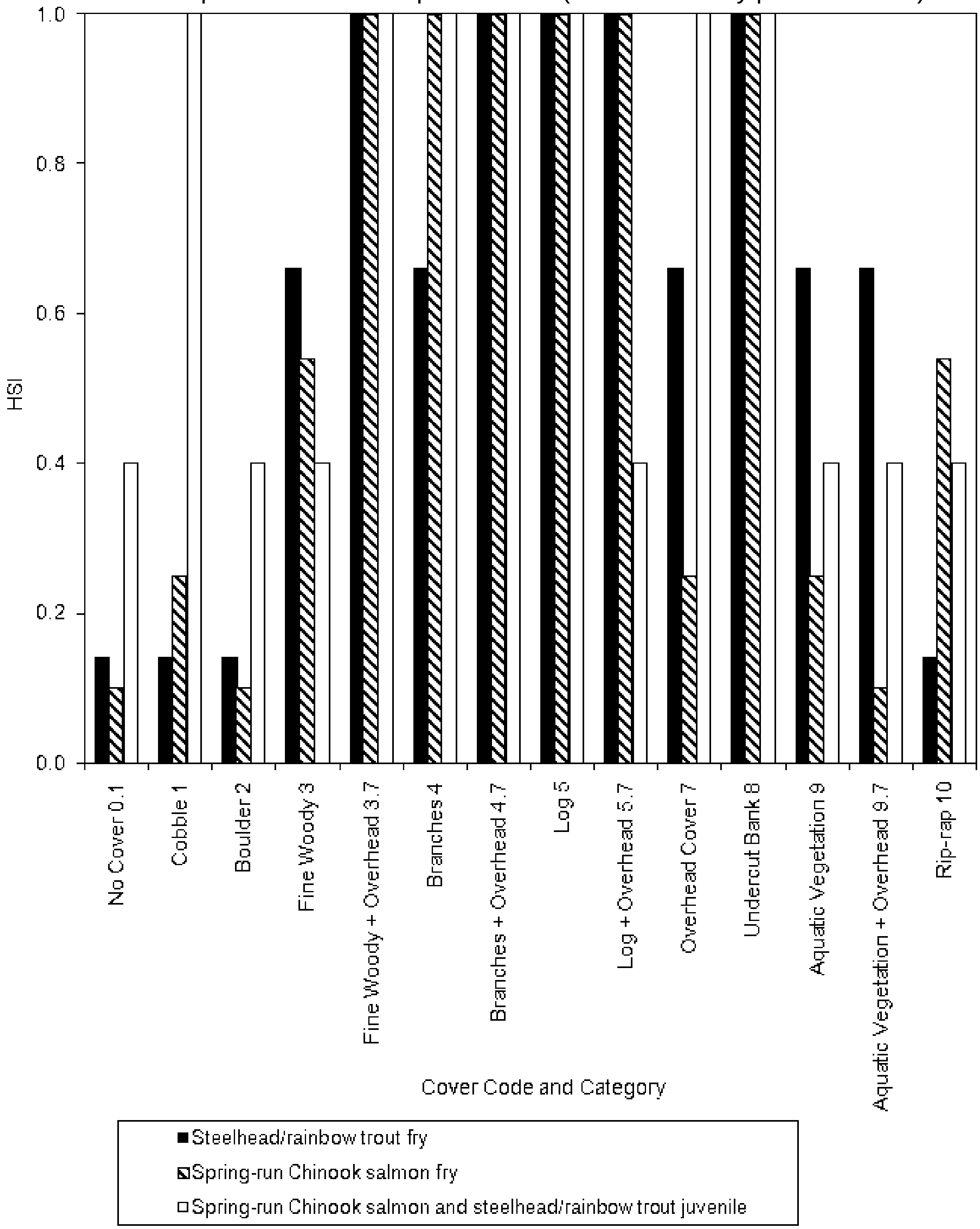
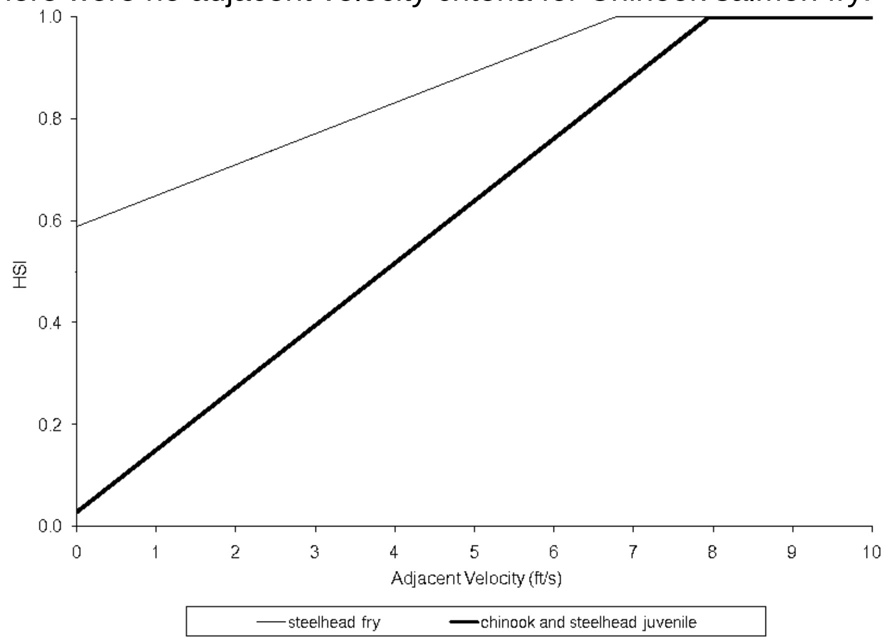


Figure 23. Comparison of adjacent velocity HSC from this study. These criteria indicate that turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas was most important for Chinook salmon and steelhead juveniles. There were no adjacent velocity criteria for Chinook salmon fry.



Figures 24 to 34 compare the criteria from this study with the criteria from other studies. With the exception of Chinook salmon fry, we compared all of the depth and velocity criteria with those from Bovee (1978), since these criteria are commonly used in instream flow studies as reference criteria. A previous instream flow study on Clear Creek (California Department of Water Resources 1985) used the Bovee (1978) criteria to simulate juvenile rearing habitat for fall-run Chinook salmon and steelhead. The previous study did not model habitat for spring-run Chinook salmon. Since Bovee (1978) does not have criteria for Chinook salmon fry, we used another commonly cited reference criteria (Raleigh et al. 1986). For spring-run Chinook salmon rearing, the only two additional criteria we were able to identify were from the Yakima River in Washington (Allen 2000) and Cape Horn and Camas Creeks in Idaho (Rubin et al. 1991). We selected criteria from Allen (2000) and Rubin et al. (1991) to compare to our fry rearing criteria and criteria from Allen (2000) to compare to our juvenile criteria, based on the size of fish reported for these studies[32]. For steelhead/rainbow trout fry and juvenile depth and velocity, the only other HSC developed in California that we were able to identify were from the Feather (California Department of Water Resources 2005) and Trinity (Hampton 1997) rivers.

[32] Allen (2000) includes two sets of criteria where the fish sizes (25 to 76 mm) are most similar to our fry size criteria and one set of criteria where the fish sizes (70 to 110 mm) are most similar to our juvenile size criteria.

Figure 24. Comparison of spring-run Chinook salmon fry depth HSC from this study with other spring-run Chinook salmon fry depth HSC. The criteria from this study show depth suitability shifted to shallower conditions than the other criteria.

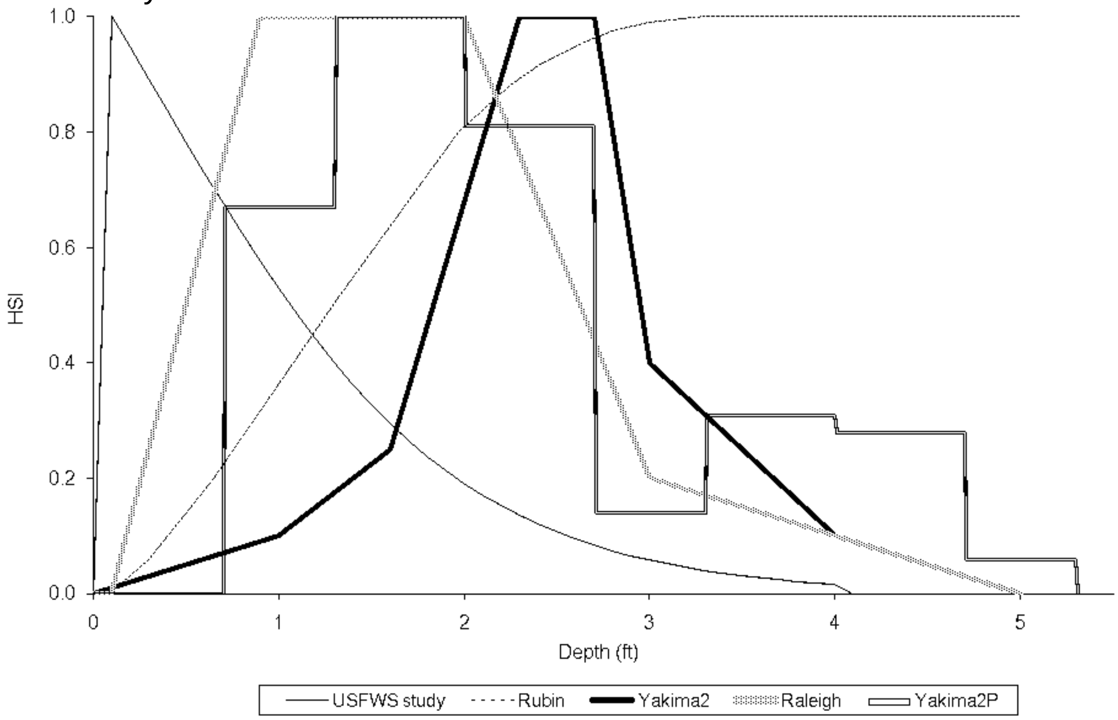


Figure 25. Comparison of spring-run Chinook salmon fry velocity HSC from this study with other spring-run Chinook salmon fry velocity HSC. The criteria from this study show non-zero suitability, albeit at low values, for faster conditions than other criteria.

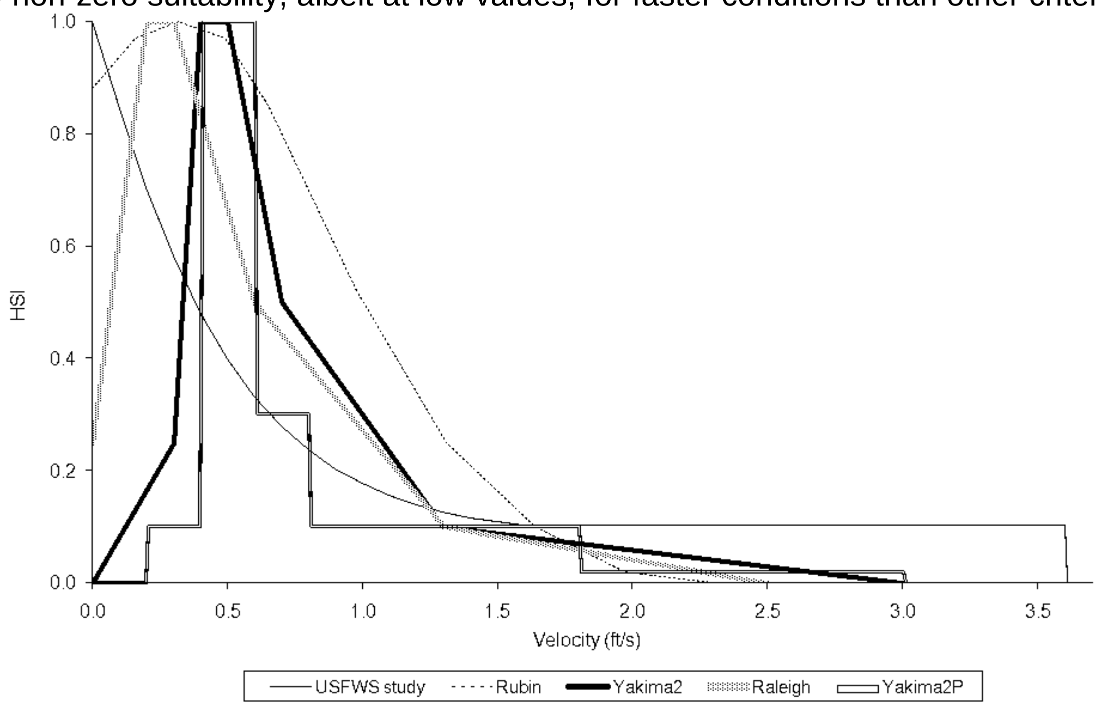


Figure 26. Comparison of spring-run Chinook salmon juvenile depth HSC from this study with other spring-run Chinook salmon juvenile depth HSC. The criteria from this study are similar to the Yakima River criteria, although reaching zero suitability at a shallower depth.

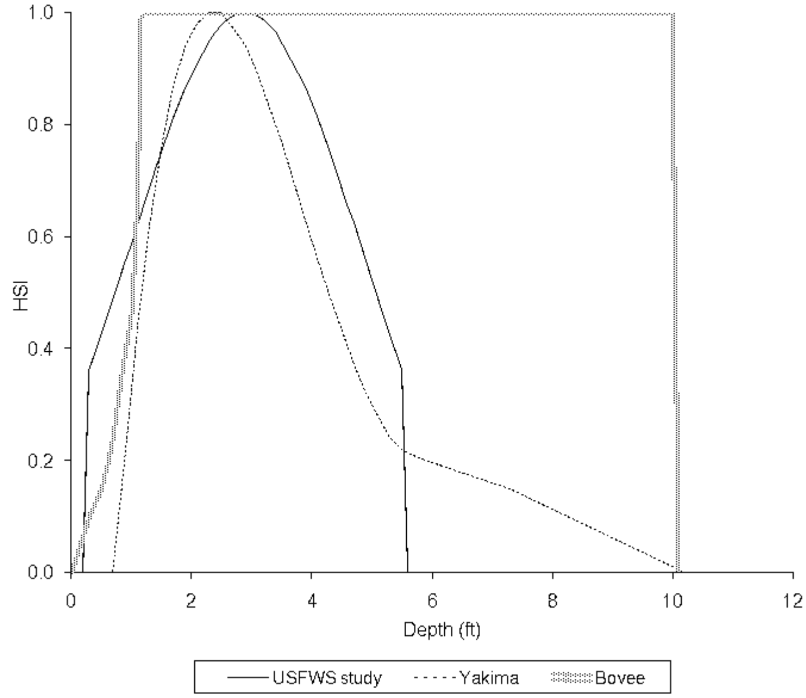


Figure 27. Comparison of spring-run Chinook salmon juvenile velocity HSC from this study with other spring-run Chinook salmon juvenile velocity HSC. The criteria from this study show non-zero suitability for faster conditions than other criteria.

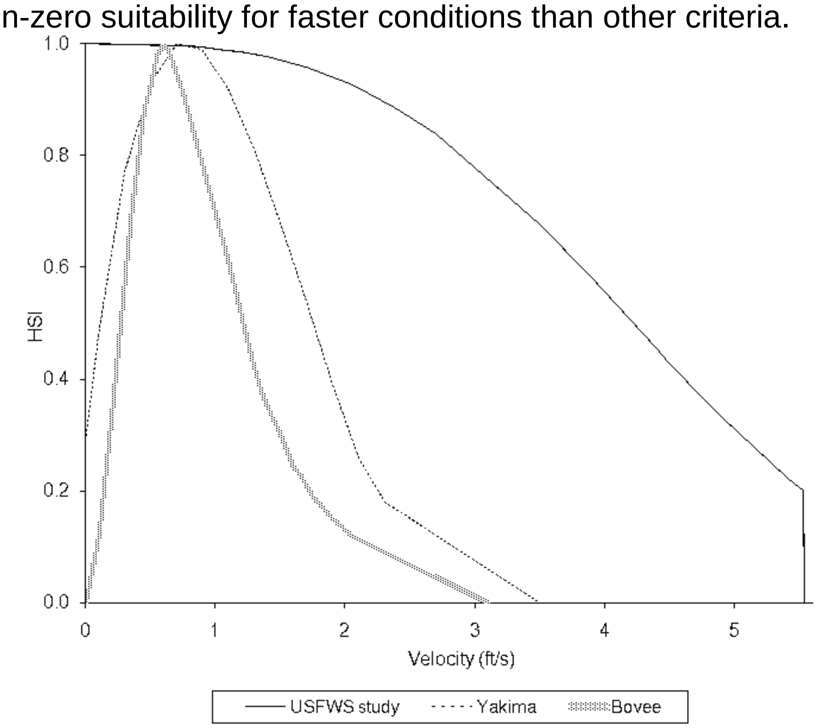


Figure 28. Comparison of steelhead/rainbow trout fry depth HSC from this study with other steelhead fry depth HSC. The criteria from this study show depth suitability shifted to shallower conditions than the other criteria.

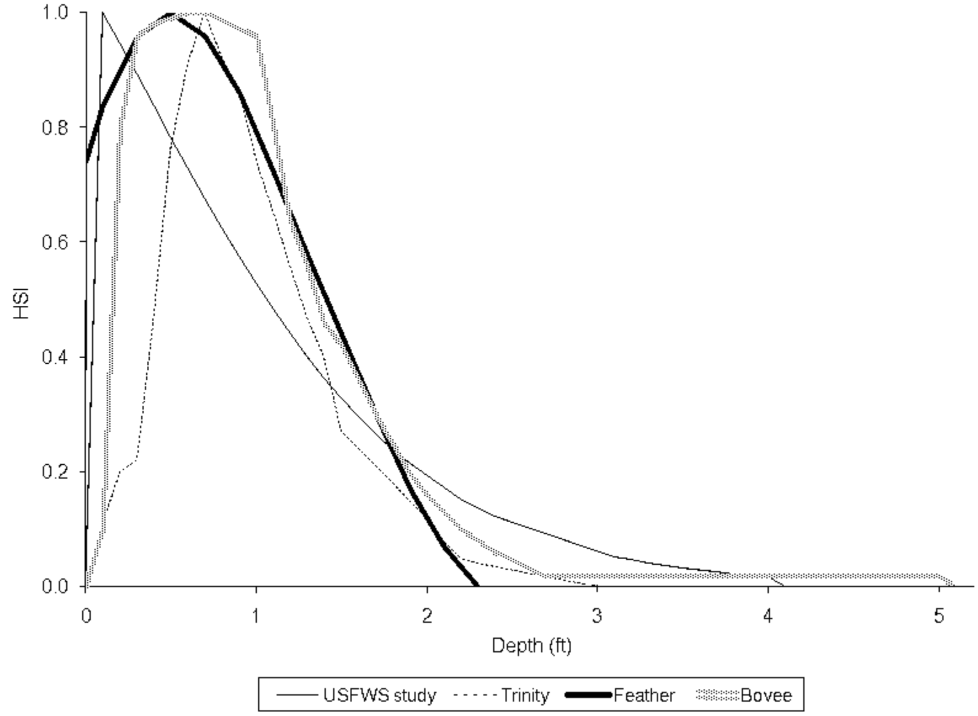


Figure 29. Comparison of steelhead/rainbow trout fry velocity HSC from this study with other steelhead fry velocity HSC. The criteria from this study show non-zero suitability extending to faster conditions than other criteria.

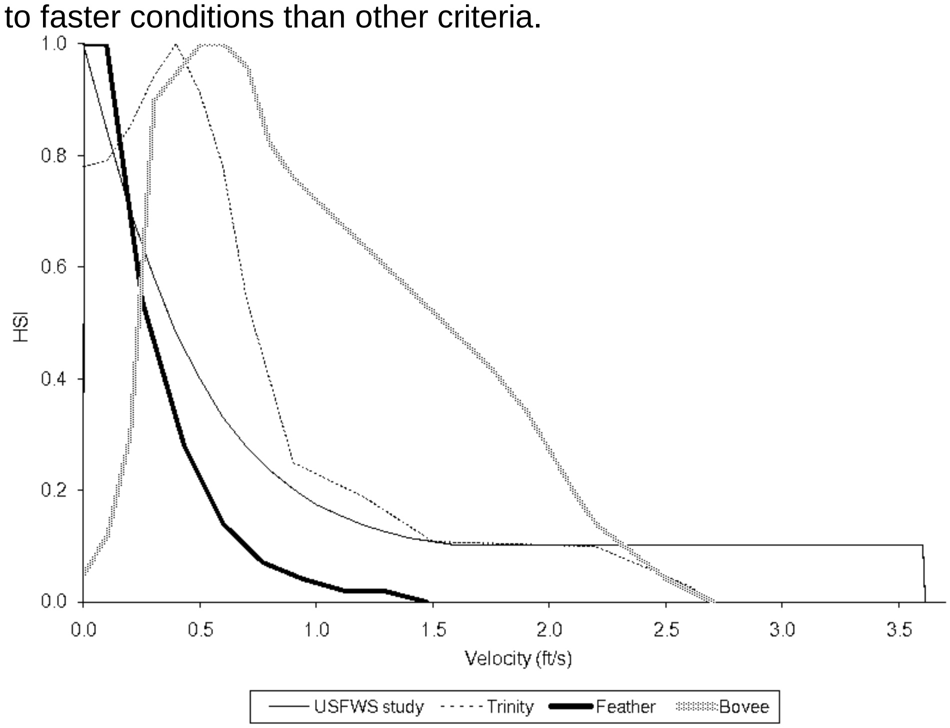


Figure 30. Comparison of steelhead/rainbow trout juvenile depth HSC from this study with other steelhead juvenile depth HSC. The criteria from this study show optimum suitability for deeper conditions than the other criteria.

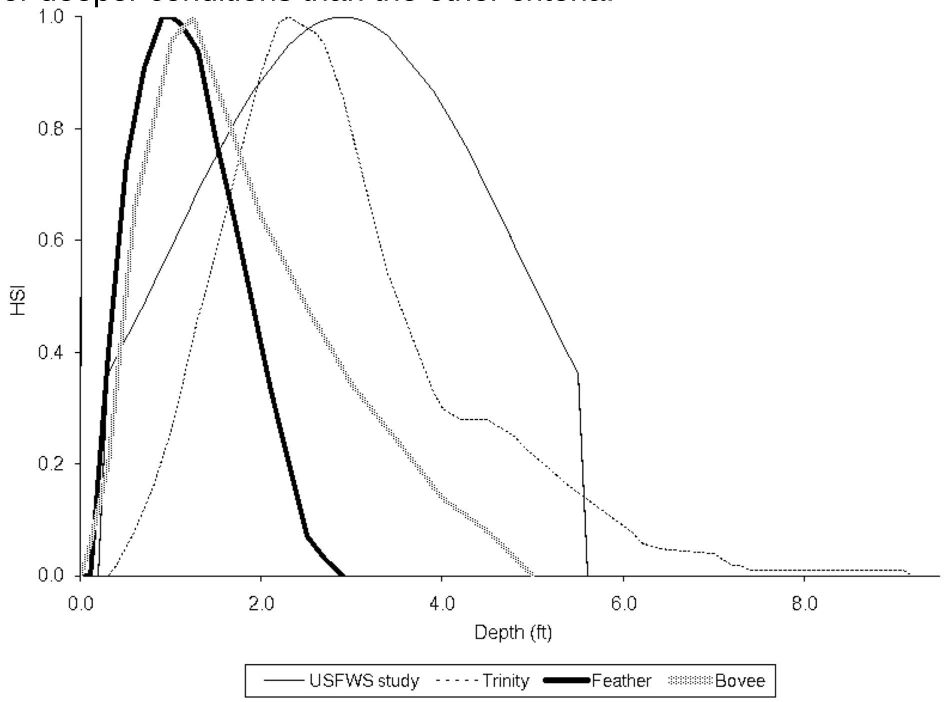


Figure 31. Comparison of steelhead/rainbow trout juvenile velocity HSC from this study with other steelhead juvenile velocity HSC. The criteria from this study show non-zero suitability extending to faster conditions than other criteria.

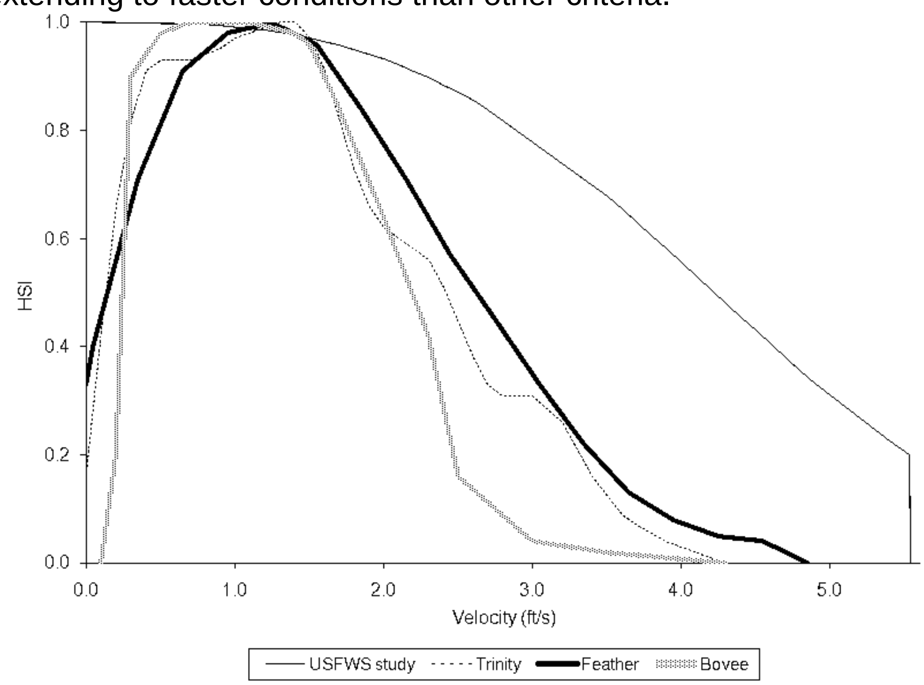
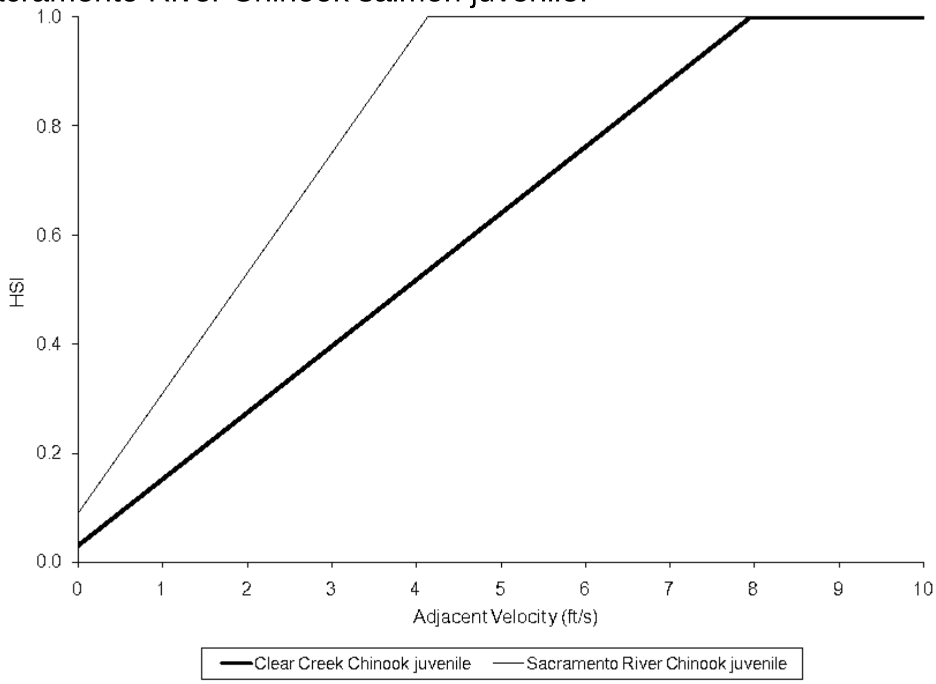


Figure 32. Comparison of spring-run Chinook salmon juvenile adjacent velocity HSC from this study with other Chinook salmon juvenile adjacent velocity HSC. The criteria indicate that turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas was more important for Clear Creek Chinook salmon juvenile than for Sacramento River Chinook salmon juvenile.



For cover, we were limited to comparing the criteria from this study to criteria we had developed on other studies, due to the unique cover coding system we used. We compared the spring-run Chinook salmon fry and juvenile criteria from this study to those we had developed for fall-run Chinook salmon on the Sacramento River (Gard 2006). We have not previously developed criteria for steelhead/rainbow trout fry or juvenile rearing. For adjacent velocity, the only other HSC we were able to identify for Chinook salmon fry or juvenile rearing were the criteria we developed on the Sacramento River (Gard 2006). We have not previously developed criteria for steelhead/rainbow trout fry or juvenile rearing, nor were we able to identify any other adjacent velocity HSC that had been developed for steelhead/rainbow trout fry or juvenile rearing.

The spring-run Chinook salmon and steelhead/rainbow trout fry depth criteria show suitability shifted to shallower conditions, while the steelhead/rainbow trout juvenile criteria show suitability shifted to deeper conditions, as compared to the other criteria. We attribute this to the use of a logistic regression to address availability, and that the other steelhead/rainbow trout juvenile criteria, developed using use data, underestimate the suitability of deeper conditions (in the range of 2.5 to 5.5 feet [0.76 to 1.68 m]) because they do not take availability into account.

Figure 33. Comparison of spring-run Chinook salmon fry cover HSC from this study with other Chinook salmon fry cover HSC. These criteria indicate a consistent preference for composite cover (instream woody plus overhead).

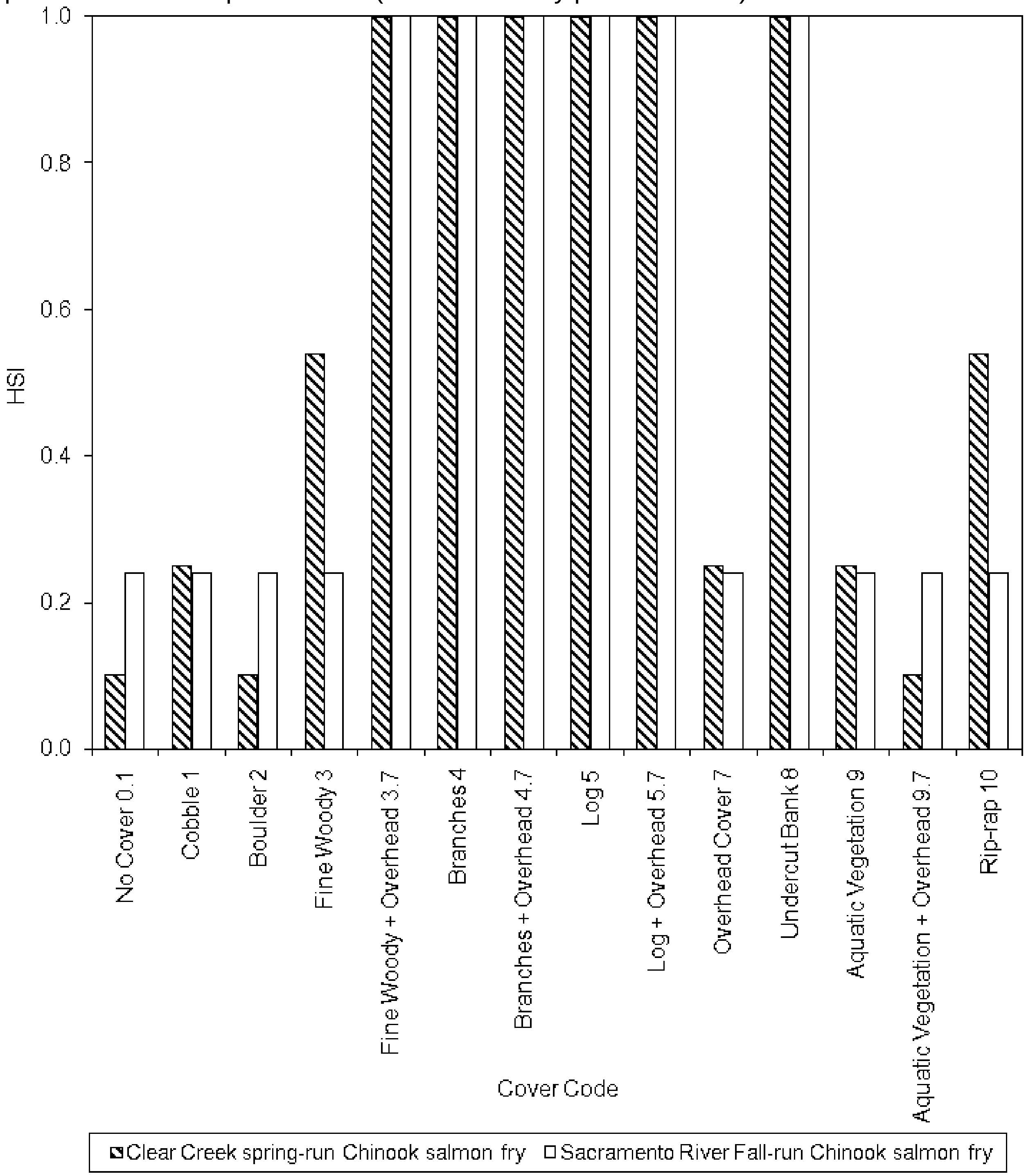
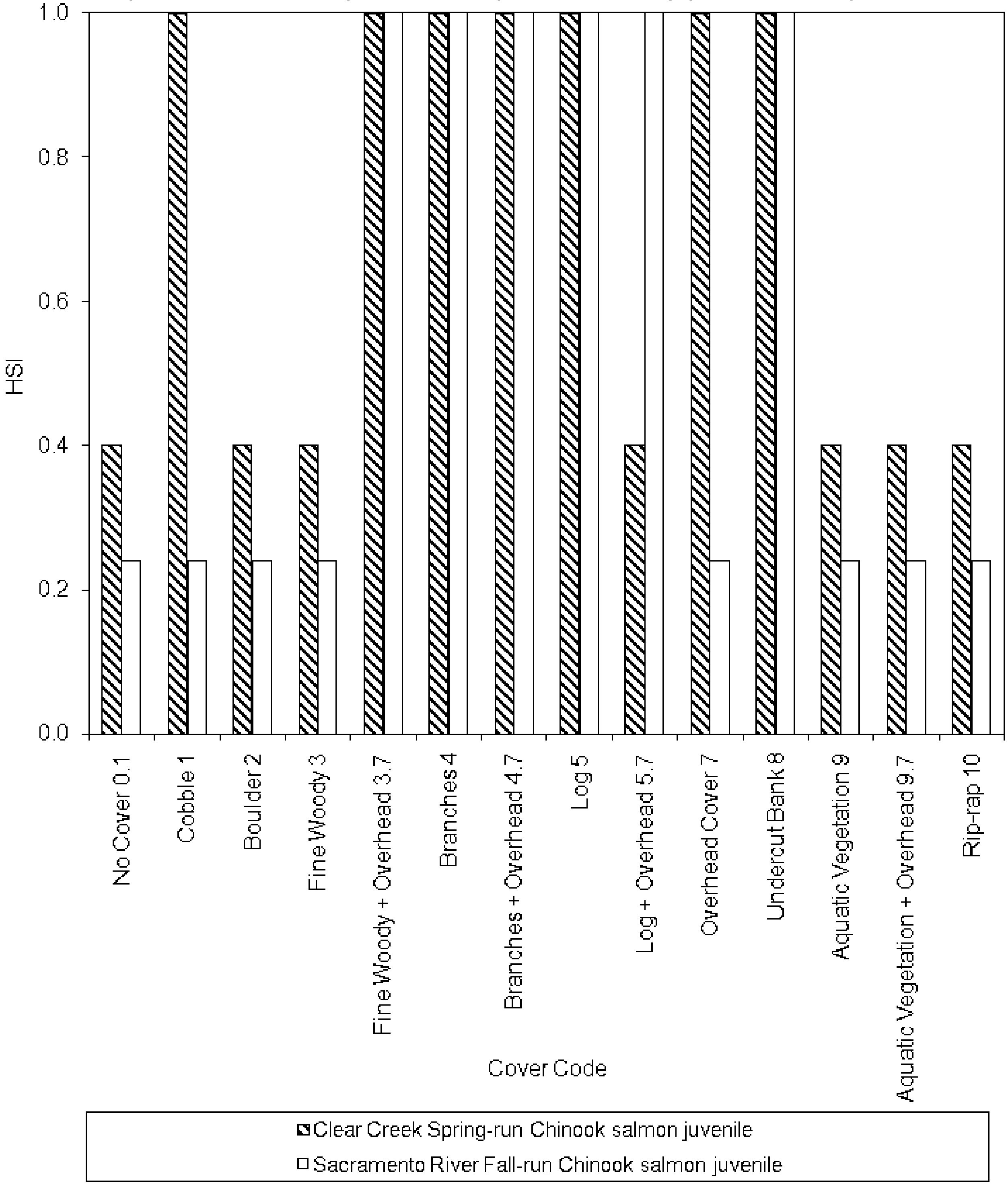


Figure 34. Comparison of spring-run Chinook salmon juvenile cover HSC from this study with other Chinook salmon juvenile cover HSC. These criteria indicate a consistent preference for composite cover (instream woody plus overhead).



The spring-run Chinook salmon and steelhead/rainbow trout fry velocity criteria show non-zero suitability, albeit at low values, for faster conditions than the other criteria. We attribute this to the fact that we observed spring-run Chinook salmon and steelhead/rainbow trout fry at higher velocities than for other criteria; there were observations of spring-run Chinook salmon and steelhead/rainbow trout fry in Clear Creek at velocities as high as 3.6 feet/sec (1.097 m/s), while both the Rubin et al. (1991) and Raleigh et al. (1986) HSC had zero suitability for velocities greater than 2.5 feet/sec (0.76 m/s). Similarly, our spring-run Chinook salmon and steelhead/rainbow trout juvenile velocity criteria show non-zero suitability for faster conditions than other criteria. We attribute this to the fact that we observed spring-run Chinook salmon and steelhead/rainbow trout juveniles at higher velocities than for other criteria. For spring-run Chinook salmon and steelhead/rainbow trout juveniles, there were observations at velocities as high as 5.53 feet/sec (1.685 m/s), while both the Yakima River and Bovee (1978) HSC had zero suitability for velocities greater than 3.5 feet/sec (1.067 m/s). All of our velocity HSC showed an optimal velocity at a lower value than for other criteria. We attribute this to use of a logistic regression to address availability, and that the other criteria, developed primarily using use data, underestimate the suitability of low velocity conditions (in the range of 0 to 0.2 feet/sec [0 to 0.061 m/s]) because they do not take availability into account.

The consistency between the Clear Creek and Sacramento River fry and juvenile Chinook salmon cover criteria, relative to preference for composite cover (instream woody plus overhead), and the Chinook salmon juvenile adjacent velocity criteria supports the importance of these two habitat characteristics for anadromous juvenile salmonid rearing. While cover is frequently used for anadromous juvenile salmonid rearing, the simple cover categories used (typically no cover, object cover, overhead cover and object plus overhead cover) misses the importance of woody composite cover for anadromous juvenile salmonid rearing. The concept of adjacent velocity criteria was included in the original PHABSIM software, through the HABTAV program (Milhous et al. 1989), but has rarely been implemented, and has been envisioned as primarily applying to adult salmonids, where the fish reside in low-velocity areas, but briefly venture into adjacent fast-velocity areas to feed on invertebrate drift. In this study, our Sacramento River study (U.S. Fish and Wildlife Service 2005) and our Yuba River study (U.S. Fish and Wildlife Service 2010), we have developed the adjacent velocity criteria based on an entirely different mechanism, namely turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmonids reside. The use of the adjacent velocity criteria developed for the Sacramento River study was validated on the Merced River (Gard 2006). We conclude that this is an important aspect of anadromous juvenile salmonid rearing habitat that has been overlooked in previous studies.

Habitat Simulation

There was considerable variation from site to site in the flow-habitat relationships shown in Appendix K. For example, the flow with the peak amount of habitat for the five pools in the Canyon Segment varied from 50 to 900 cfs (Figures 35 to 37). However, excluding the Narrows site, the flow with the peak amount of habitat only ranges from 400 to 900 cfs. We attribute the

Figure 35. Comparison of spring-run Chinook salmon fry flow-habitat relationship for the five pools in the Canyon Segment.

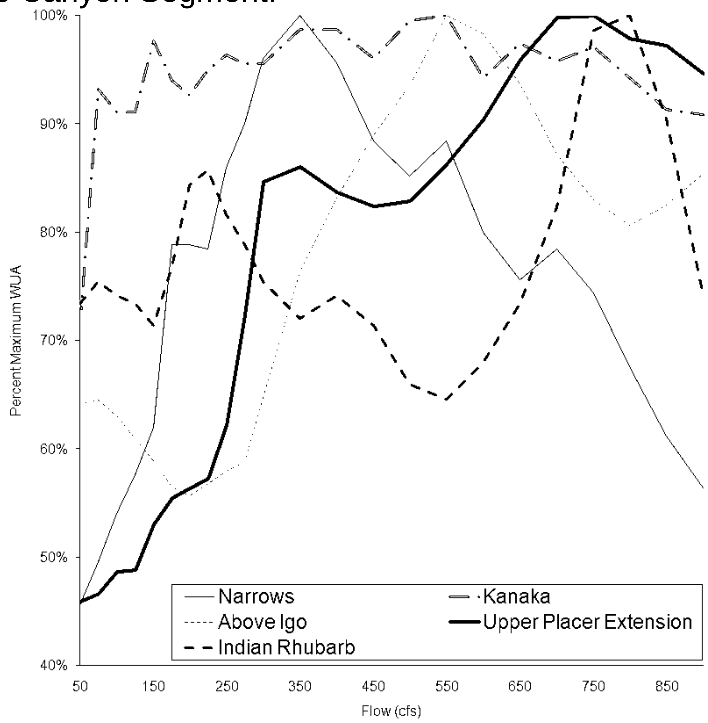


Figure 36. Comparison of steelhead/rainbow trout fry flow-habitat relationship for the five pools in the Canyon Segment.

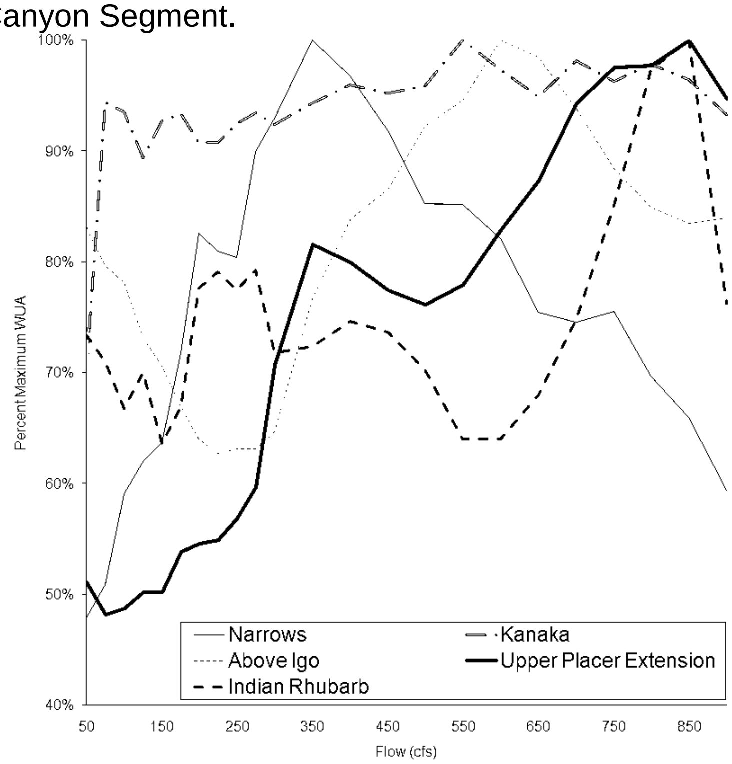
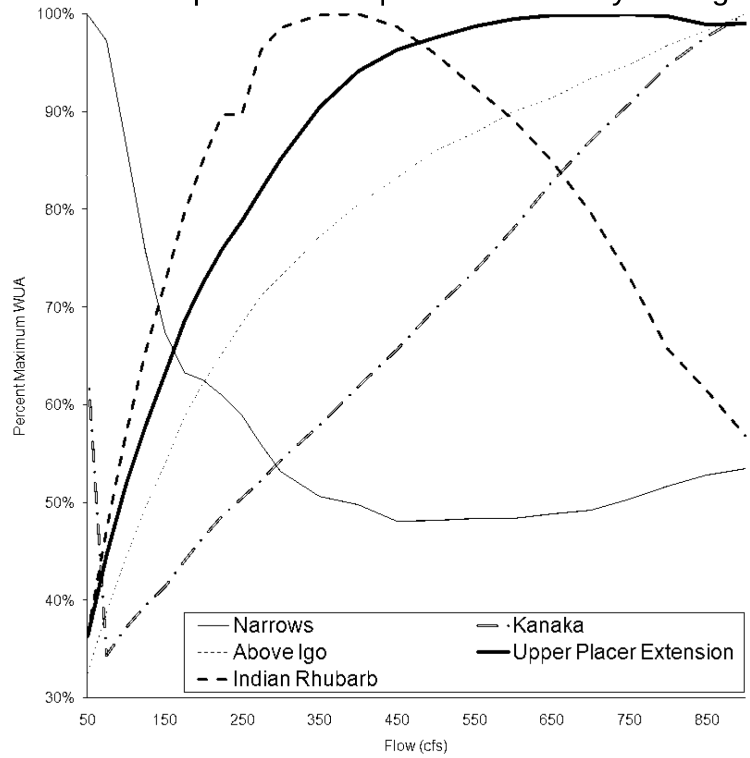


Figure 37. Comparison of steelhead/rainbow trout and spring-run Chinook salmon juvenile flow-habitat relationship for the five pools in the Canyon Segment.



variation from site to site to complex interactions of the combinations of availability and suitability of depth, velocity, adjacent velocity and cover, as they vary with flow. The overall flow-habitat relationships for each segment, as shown in Figures 12 to 17, capture the inter-site variability in flow-habitat relationships by weighting the amount of habitat for each mesohabitat unit in each site by the proportion of each mesohabitat type present within each segment.

An earlier study (California Department of Water Resources 1985) modeled fall-run Chinook salmon juvenile and steelhead fry and juvenile rearing habitat in Clear Creek between Whiskeytown Dam and the confluence with the Sacramento River for flows of 40 to 500 cfs. The previous study did not model spring-run Chinook salmon rearing habitat and did not have any study sites in the Upper Alluvial Segment, although there was one study site in the Canyon Segment (apparently falling within our Upper Placer Extension site). This site was located in a relatively high gradient area, which would tend to result in maximum habitat at lower flows. A representative reach approach was used to place transects, instead of using habitat mapping to extrapolate to the entire segment. PHABSIM was used to model habitat, instead of two-dimensional models. To compare our results to California Department of Water Resources's (1985) results, we added together the amount of habitat in the Upper Alluvial and Canyon Segments. The comparison of the results of the two studies should be taken with a great deal of caution, since we had to compare results for two different races of chinook salmon (fall-run versus spring-run) and for sites in two different sections of stream (sites in both the Upper Alluvial and Canyon Segments in this study versus a site in only the Canyon Segment in the California Department of Water Resources (1985) study).

As shown in Figures 38 to 40, the results from this study predict substantially less habitat at low flows and a peak amount of habitat at higher flows than the California Department of Water Resources (1985) study. However, the difference between studies in the flow with the peak amount of habitat varied by reach. The differences between the results of the two studies can primarily be attributed to the following: 1) the California Department of Water Resources (1985) study used HSC generated only from use data, as opposed to the criteria generated with logistic regression in this study; 2) the California Department of Water Resources (1985) study did not use cover or adjacent velocity criteria; and 3) the use of PHABSIM in the California Department of Water Resources (1985) study, versus 2-D modeling in this study. We conclude that the flow-habitat results in the California Department of Water Resources (1985) study were biased towards lower flows, since the HSC, generated only from use data and without cover or adjacent velocity criteria, were biased towards slower and shallower conditions. We attribute the difference in magnitude of the results from this study versus California Department of Water Resources (1985) primarily to the use of adjacent velocity criteria in this study. A fourth habitat suitability index parameter will tend to result in overall lower amounts of habitat, since the combined suitability index is calculated as the product of the individual suitability indices. The effects of adjacent velocity are most pronounced at low flows, where a large proportion of the channel has low adjacent velocities, and thus low suitability for this parameter.

CONCLUSION

The model developed in this study is predictive for flows ranging from 50 to 900 cfs. The results of this study can be used to evaluate 276 different hydrograph management scenarios (each of the 23 simulation flows in each of the 12 rearing months). For example, increasing flows from 200 cfs to 300 cfs in October would result in an increase of 15.7% of habitat during this month for spring-run Chinook salmon fry rearing in the Upper Alluvial Segment. Based on the conceptual model presented in the introduction, this increase in rearing habitat could increase fry and juvenile growth and survival, increasing rearing success which could result in an increase in spring-run Chinook salmon and steelhead/rainbow trout populations. Evaluation of alternative hydrograph management scenarios will also require the consideration of flow-habitat relationships for Chinook salmon and steelhead/rainbow trout fry and juvenile rearing in the Lower Alluvial Segment, which will be addressed in a future report. We do not feel that there are any significant limitations of the model, within the context of the assumptions given in the introduction and the overall capabilities of models of habitat for aquatic organisms (Gore and Nestler 1998, Hudson et al. 2003, Maughan and Barrett 1991). This study supported and achieved the objective of producing models predicting the availability of physical habitat in the Upper Alluvial and Canyon Segments of Clear Creek for spring-run Chinook salmon and steelhead/rainbow trout rearing over a range of stream flows. The results of this study are intended to support or revise the flow recommendations in the CVPIA AFRP (200 cfs for October through June and 150 cfs or less from July through September). The results of this study suggest that the flow recommendations in the CVPIA AFRP during the spring-run Chinook

Figure 38. Comparison of fall-run juvenile Chinook salmon flow-habitat relationship from California Department of Water Resources (1985) and spring-run juvenile Chinook salmon flow-habitat relationship for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.

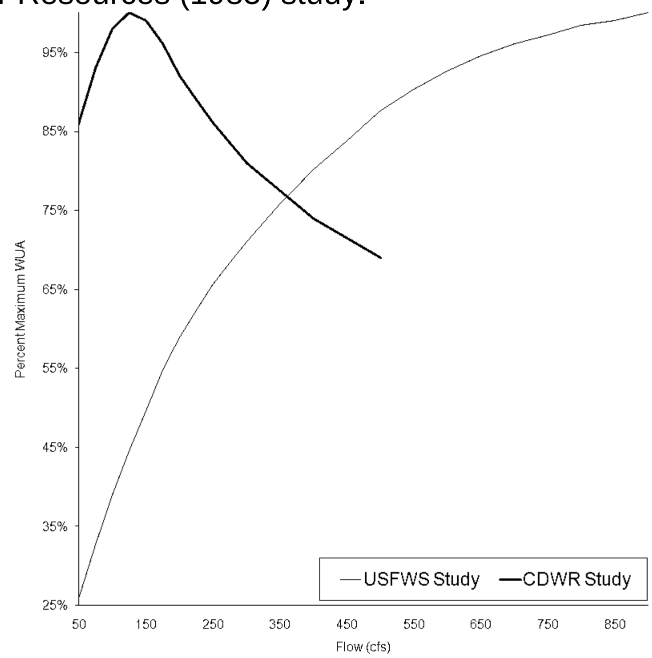


Figure 39. Comparison of steelhead fry flow-habitat relationships from California Department of Water Resources (1985) and for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.

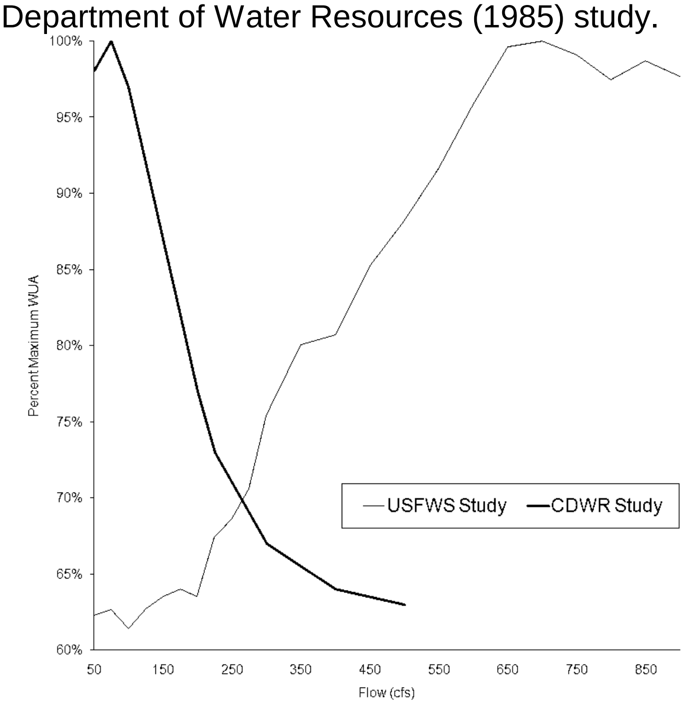
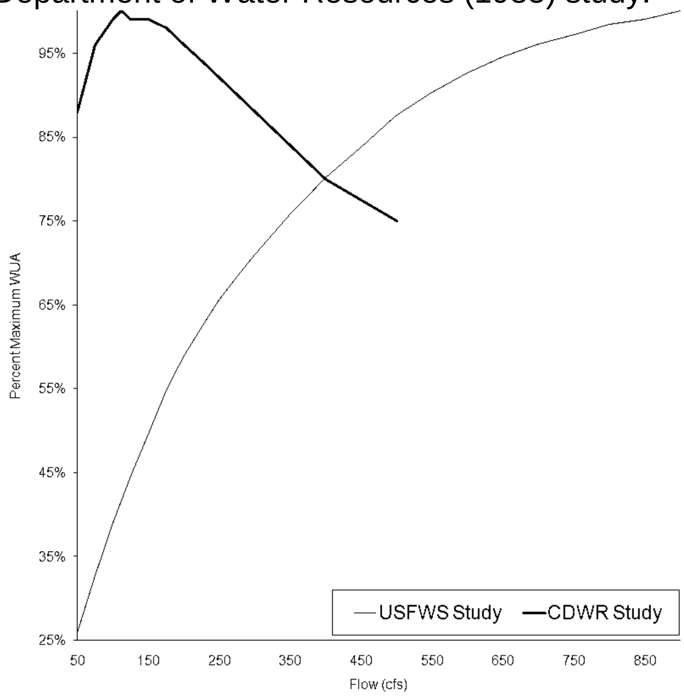


Figure 40. Comparison of steelhead juvenile flow-habitat relationships from California Department of Water Resources (1985) and for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.



salmon and steelhead/rainbow trout rearing period of October-September (150-200 cfs) may not be close to achieving maximum habitat availability and productivity for rearing spring-run Chinook salmon and steelhead/rainbow trout in Clear Creek (50 to 64 % of maximum WUA).

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APPENDIX A
HABITAT MAPPING DATA

Habitat distribution identified in the Clear Creek Upper Alluvial Segment

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
1	Main Channel Pool	3,737
2	Main Channel Run	155
2.1	Side Channel Riffle	182
3	Main Channel Riffle	350
4.1	Side Channel Pool	18
4	Main Channel Pool	1,050
6	Main Channel Riffle	637
7	Main Channel Pool	1,595
8	Main Channel Glide	464
8.1	Side Channel Glide	112
9	Main Channel Riffle	955
9.1	Side Channel Riffle	70
9.2	Side Channel Pool	81
10	Main Channel Run	77
11	Main Channel Riffle	498
12	Main Channel Run	744
14	Main Channel Riffle	458
15	Main Channel Run	281
16	Main Channel Pool	408
17	Main Channel Glide	257
18	Main Channel Pool	1,570
19	Main Channel Riffle	663
19.1	Side Channel Pool	67
19.2	Side Channel Run	49
19.3	Side Channel Riffle	49
20	Main Channel Pool	387
21	Main Channel Riffle	162
21.1	Side Channel Riffle	160
22	Main Channel Run	911
23	Main Channel Riffle	437
24	Main Channel Run	629
25	Main Channel Riffle	425
25.1	Side Channel Run	73
26	Main Channel Pool	809
27	Main Channel Riffle	1,616
27.1	Side Channel Run	81
27.2	Side Channel Riffle	56
28	Main Channel Run	954

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
29	Main Channel Riffle	141
30	Main Channel Run	2,231
33	Main Channel Riffle	181
34	Main Channel Run	527
35	Main Channel Pool	1,515
36	Main Channel Run	1,479
36.1	Side Channel Run	136
37	Main Channel Pool	518
38	Main Channel Run	304
39	Main Channel Riffle	75
40	Main Channel Run	418
41	Main Channel Pool	314
42.1	Side Channel Riffle	41
42	Main Channel Pool	249
43	Main Channel Riffle	386
43.1	Side Channel Run	123
44	Main Channel Pool	1,115
45	Main Channel Riffle	287
46	Main Channel Run	1,410
47	Main Channel Riffle	1,913
48	Main Channel Run	2,185
51	Main Channel Riffle	330
52	Main Channel Run	731
53	Main Channel Riffle	510
54	Main Channel Pool	3,207
55	Main Channel Riffle	1,337
55A	Main Channel Run	1,737
55B	Main Channel Riffle	466
56.1	Side Channel Glide	329
56	Main Channel Run	1,285
57	Main Channel Pool	2,146
58	Main Channel Riffle	1,331
58.1	Side Channel Riffle	133
58.2	Side Channel Run	198
58.3	Side Channel Riffle	103

Habitat distribution identified in the Clear Creek Canyon Segment

Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
2	1	Main Channel Run	759
2	2	Main Channel Riffle	791
2	3	Main Channel Run	248
2	4	Main Channel Riffle	289
2	5	Main Channel Run	643
2	6	Main Channel Pool	585
2	7	Main Channel Riffle	173
2	8	Main Channel Cascade	183
2	9	Main Channel Pool	1,419
2	10	Main Channel Cascade	632
2	11	Main Channel Run	584
2	12	Main Channel Pool	635
2	13	Main Channel Cascade	1,109
2	14	Main Channel Run	781
2	15	Main Channel Riffle	93
2	16	Main Channel Pool	392
2	17	Main Channel Riffle	237
2	18	Main Channel Pool	647
2	19	Main Channel Riffle	559
2	20	Main Channel Run	166
2	21	Main Channel Riffle	170
2	22	Main Channel Pool	2,034
2	23	Main Channel Cascade	27
2	24	Main Channel Pool	85
2	25	Main Channel Pool	1,183
2	26	Main Channel Pool	632
2	27	Main Channel Riffle	204
2	28	Main Channel Cascade	158
2	29	Main Channel Pool	878
2	30	Main Channel Pool	471
2	31	Main Channel Pool	474
2	32	Main Channel Pool	440
2	33	Main Channel Pool	482
2	34	Main Channel Pool	617
2	35	Main Channel Pool	970
2	36	Main Channel Riffle	295

Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
2	37	Main Channel Pool	1,119
2	38	Main Channel Pool	1,117
2	39	Main Channel Riffle	92
2	40	Main Channel Pool	936
2	41	Main Channel Pool	680
2	42	Main Channel Run	225
2	43	Main Channel Pool	1,308
2	44	Main Channel Riffle	221
2	45	Main Channel Run	637
2	46	Main Channel Riffle	129
2	47	Main Channel Pool	1,906
2	48	Main Channel Riffle	327
2	49	Main Channel Run	124
2	50	Main Channel Riffle	72
2	51	Main Channel Pool	354
2	52	Main Channel Run	504
2	53	Main Channel Pool	351
2	54	Main Channel Riffle	90
2	55	Main Channel Pool	126
2	56	Main Channel Pool	890
2	57	Main Channel Run	130
2	58	Main Channel Pool	840
2	59	Main Channel Riffle	302
2	60	Main Channel Cascade	96
2	61	Main Channel Pool	359
2	62	Main Channel Cascade	313
2	63	Main Channel Pool	1,541
2	63.1	Side Channel Run	120
2	65	Main Channel Pool	632
2	64	Main Channel Riffle	346
2	66	Main Channel Riffle	744
2	67	Main Channel Cascade	484
2	68	Main Channel Pool	402
2	69	Main Channel Run	756
2	70	Main Channel Pool	421
2	71	Main Channel Riffle	509
2	72	Main Channel Cascade	317
2	73	Main Channel Pool	1,234

Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
2	74	Main Channel Riffle	144
2	75	Main Channel Cascade	635
2	76	Main Channel Pool	2,172
3	1	Main Channel Riffle	533
3	2	Main Channel Run	378
3	3	Main Channel Pool	1,382
3	4	Main Channel Cascade	268
3	5	Main Channel Riffle	396
3	6	Main Channel Run	277
3	7	Main Channel Pool	463
3	8	Main Channel Glide	203
3	9	Main Channel Run	256
3	10	Main Channel Riffle	161
3	11	Main Channel Pool	206
3	12	Main Channel Run	166
3	13	Main Channel Pool	856
3	14	Main Channel Riffle	358
3	15	Main Channel Run	170
3	17	Main Channel Run	150
3	16	Main Channel Riffle	235
3	18	Main Channel Pool	978
3	19	Main Channel Run	187
3	20	Main Channel Riffle	145
3	21	Main Channel Run	214
3	22	Main Channel Riffle	231
3	23	Main Channel Pool	1,941
3	24	Main Channel Run	801
3	25	Main Channel Glide	531
3	26	Main Channel Riffle	418
3	27	Main Channel Run	339
3	28	Main Channel Riffle	429
3	29	Main Channel Pool	520
3	30	Main Channel Run	321
3	31	Main Channel Pool	1,858
3	32	Main Channel Glide	244
3	33	Main Channel Cascade	700
3	34	Main Channel Run	431
3	35	Main Channel Glide	508

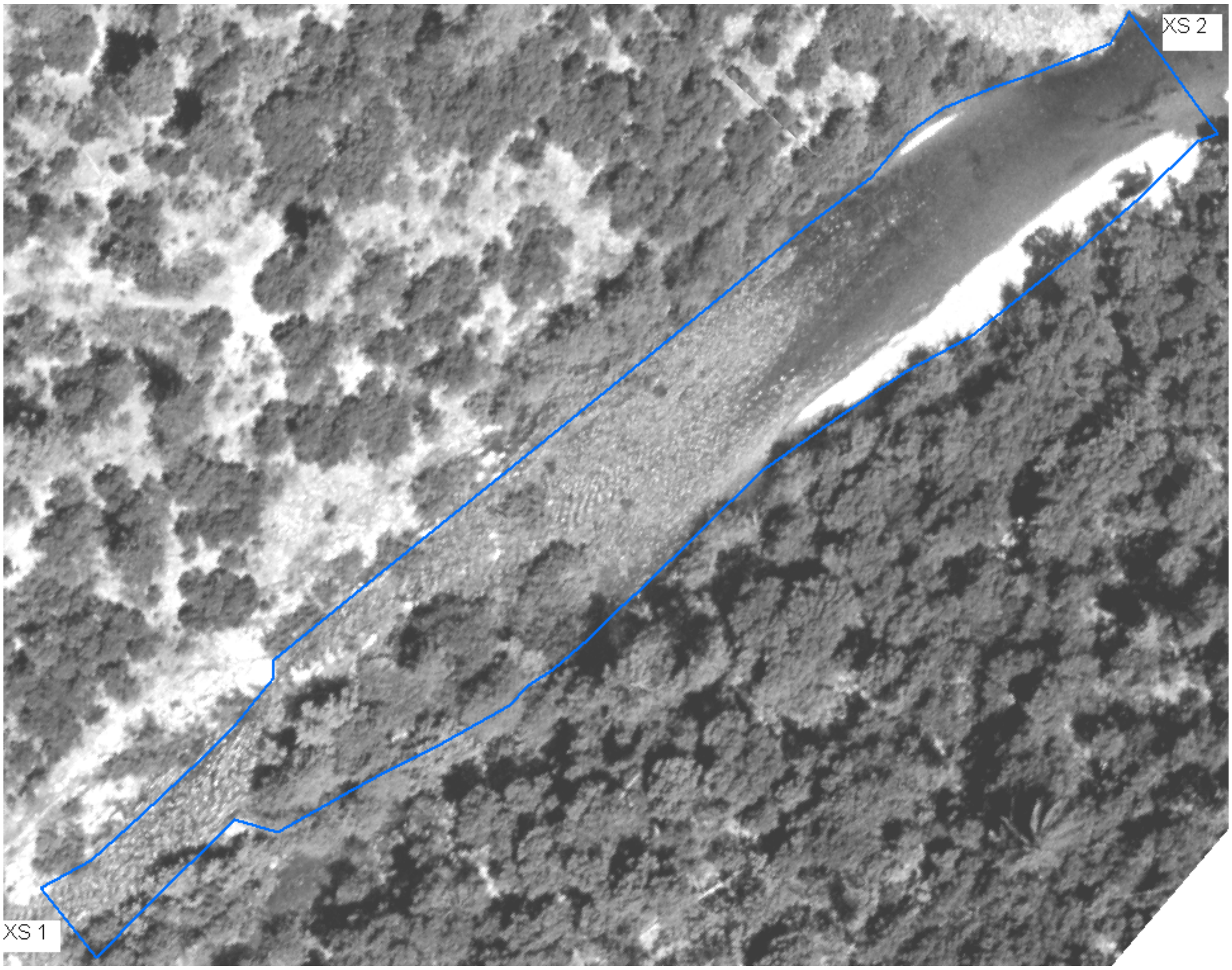
Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
3	36	Main Channel Riffle	876
3	37	Main Channel Run	208
3	38	Main Channel Riffle	246
3	39	Main Channel Pool	578
3	40	Main Channel Riffle	286
3	41	Main Channel Run	454
3	42	Main Channel Cascade	918
3	43	Main Channel Pool	199
3	44	Main Channel Cascade	93
3	45	Main Channel Pool	158
3	46	Main Channel Cascade	133
3	47	Main Channel Pool	1,111
3	48	Main Channel Cascade	446
3	49	Main Channel Pool	697
3	50	Main Channel Cascade	403
3	51	Main Channel Pool	499
3	52	Main Channel Cascade	241
3	53	Main Channel Pool	273
3	54	Main Channel Cascade	120
3	55	Main Channel Pool	182
3	56	Main Channel Run	358
3	57	Main Channel Cascade	556
3	58	Main Channel Run	204
3	59	Main Channel Riffle	340
3	60	Main Channel Run	267
3	61	Main Channel Cascade	259
3	62	Main Channel Pool	311
3	63	Main Channel Cascade	98
3	64	Main Channel Pool	1,418
3	65	Main Channel Run	218
3	66	Main Channel Cascade	171
3	68	Main Channel Pool	2,308
3	67	Main Channel Run	429
3	69	Main Channel Cascade	383
3	70	Main Channel Run	300
3	71	Main Channel Pool	6,528
3	72	Main Channel Run	1,003
4	1	Main Channel Pool	1,093

Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
4	2.1	Side Channel Riffle	320
4	2	Main Channel Riffle	452
4	3	Main Channel Run	975
4	4	Main Channel Riffle	491
4	5	Main Channel Pool	888
4	6	Main Channel Riffle	380
4	7	Main Channel Pool	271
4	8	Main Channel Riffle	588
4	9	Main Channel Pool	822
4	10	Main Channel Cascade	76
4	11	Main Channel Pool	1,258
4	12	Main Channel Riffle	316
4	13	Main Channel Pool	667
4	14	Main Channel Pool	607
4	15	Main Channel Riffle	226
4	16	Main Channel Run	632
4	17	Main Channel Pool	304
4	18	Main Channel Run	1,256
4	19	Main Channel Riffle	925
4	20	Main Channel Run	321
4	21	Main Channel Riffle	60
4	22	Main Channel Pool	1,564
4	23	Main Channel Pool	2,858
4	24	Main Channel Riffle	1,229
4	25	Main Channel Run	311
4	26	Main Channel Pool	637
4	27	Main Channel Cascade	1,746
4	28	Main Channel Pool	1,529
4	29	Main Channel Cascade	1,394
4	30	Main Channel Pool	855
4	31	Main Channel Cascade	563
4	32	Main Channel Pool	1,767
4	33	Main Channel Riffle	377
4	33.1	Side Channel Riffle	72
4	34	Main Channel Pool	879
4	35	Main Channel Cascade	185
4	36	Main Channel Pool	1,503
4	37	Main Channel Pool	2,352

Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
4	38	Main Channel Cascade	433
4	39	Main Channel Pool	654
4	40	Main Channel Run	318
4	41	Main Channel Pool	1,270
4	42	Main Channel Cascade	448
4	43	Main Channel Pool	3,636
4	44	Main Channel Riffle	767
4	45	Main Channel Run	2,914
4	46	Main Channel Riffle	905
4	47	Main Channel Run	338
4	48	Main Channel Riffle	263
4	49	Main Channel Pool	1,745
4	50	Main Channel Run	487
4	51	Main Channel Pool	5,261

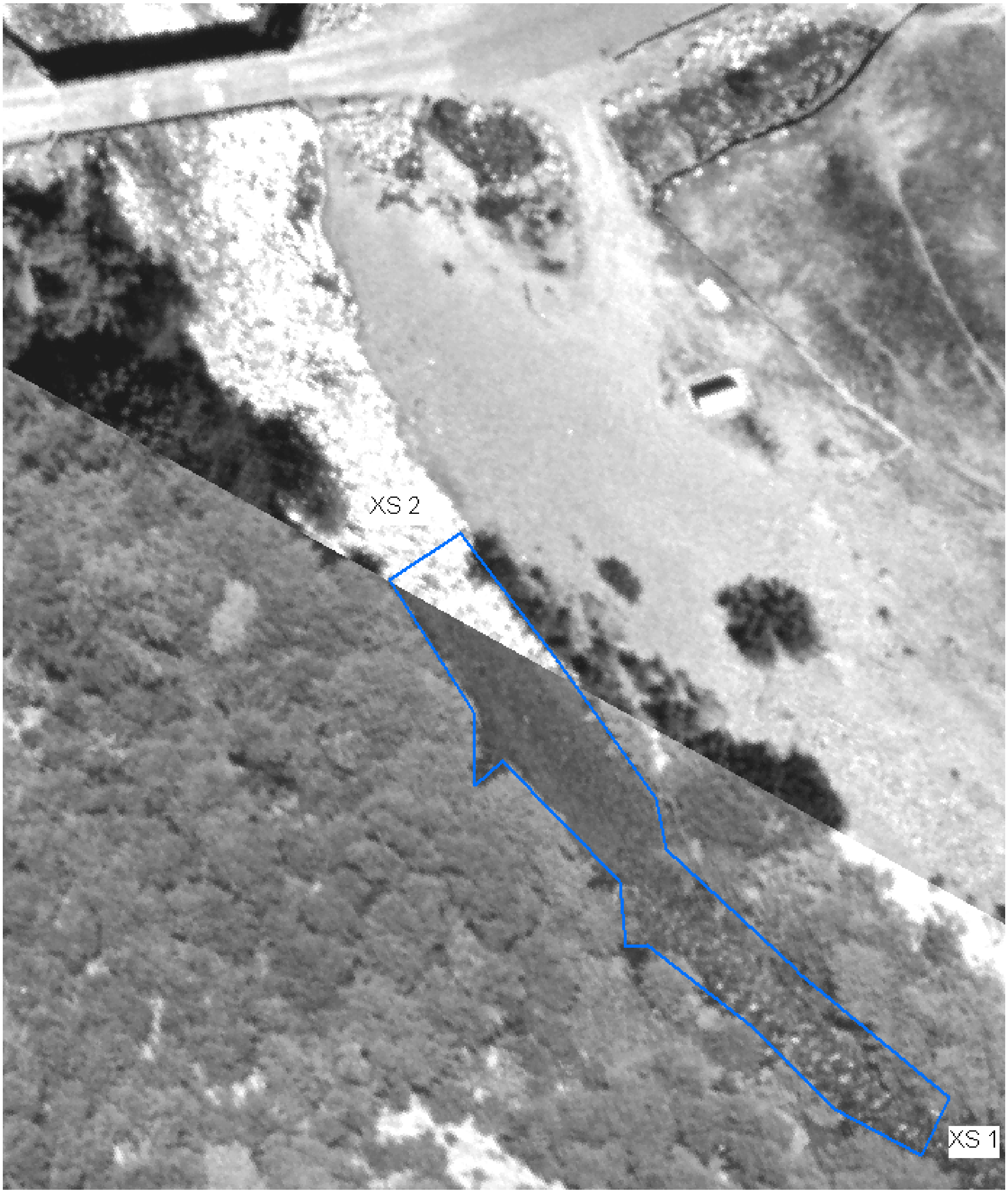
APPENDIX B
STUDY SITE AND TRANSECT LOCATIONS

DOG GULCH STUDY SITE



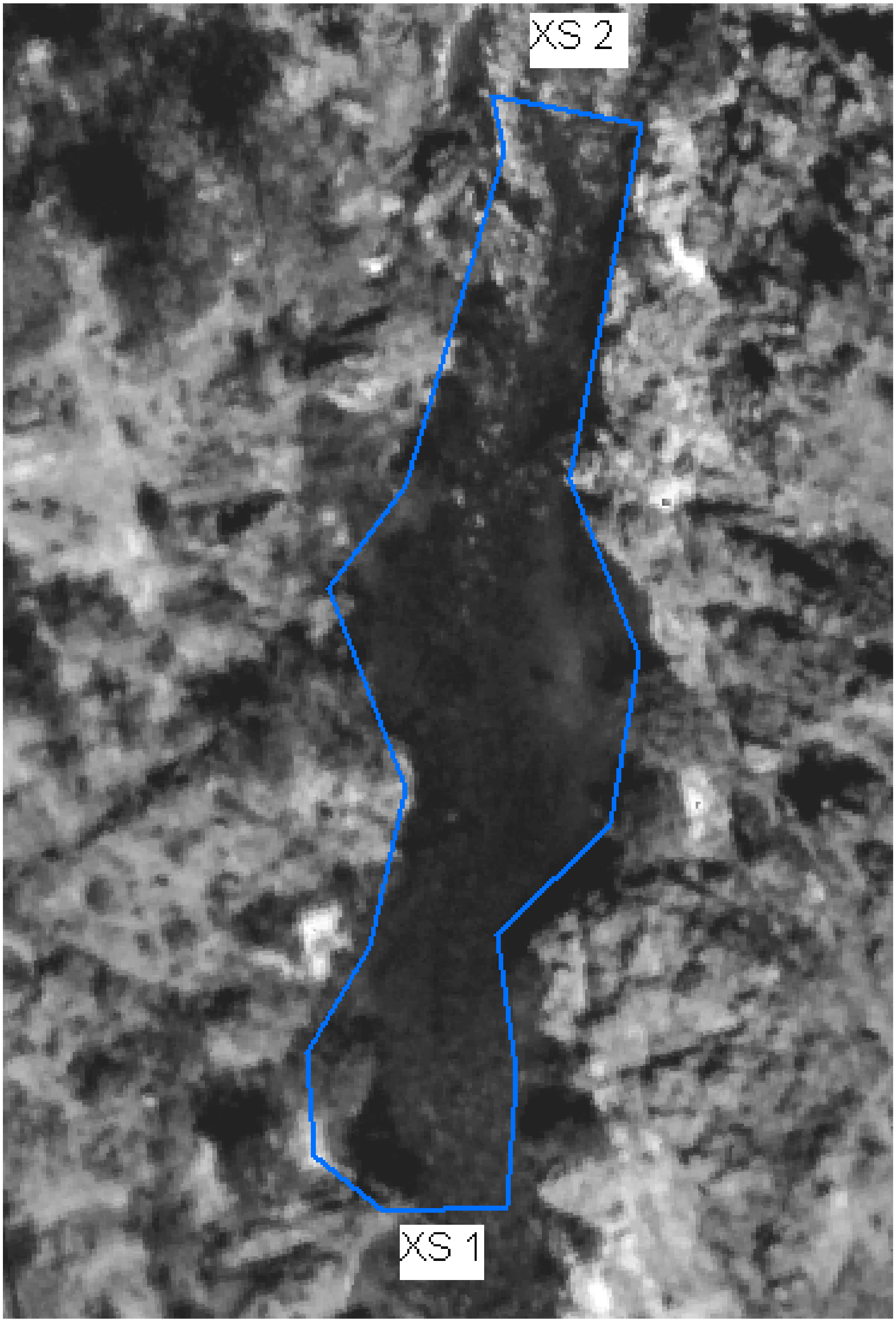
Scale: 1: 1,294

UPPER CANYON STUDY SITE



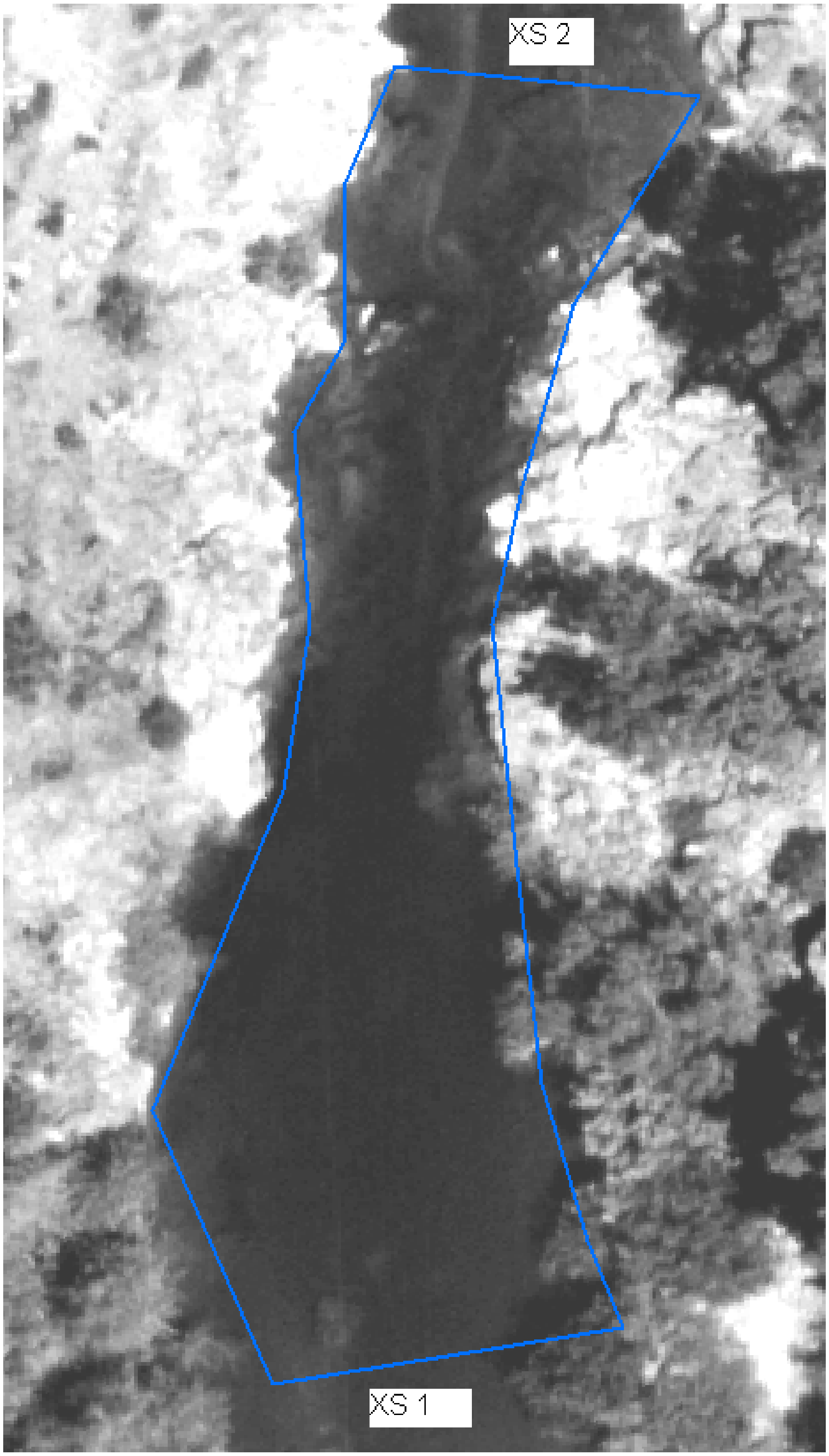
Scale: 1: 450

NARROWS STUDY SITE



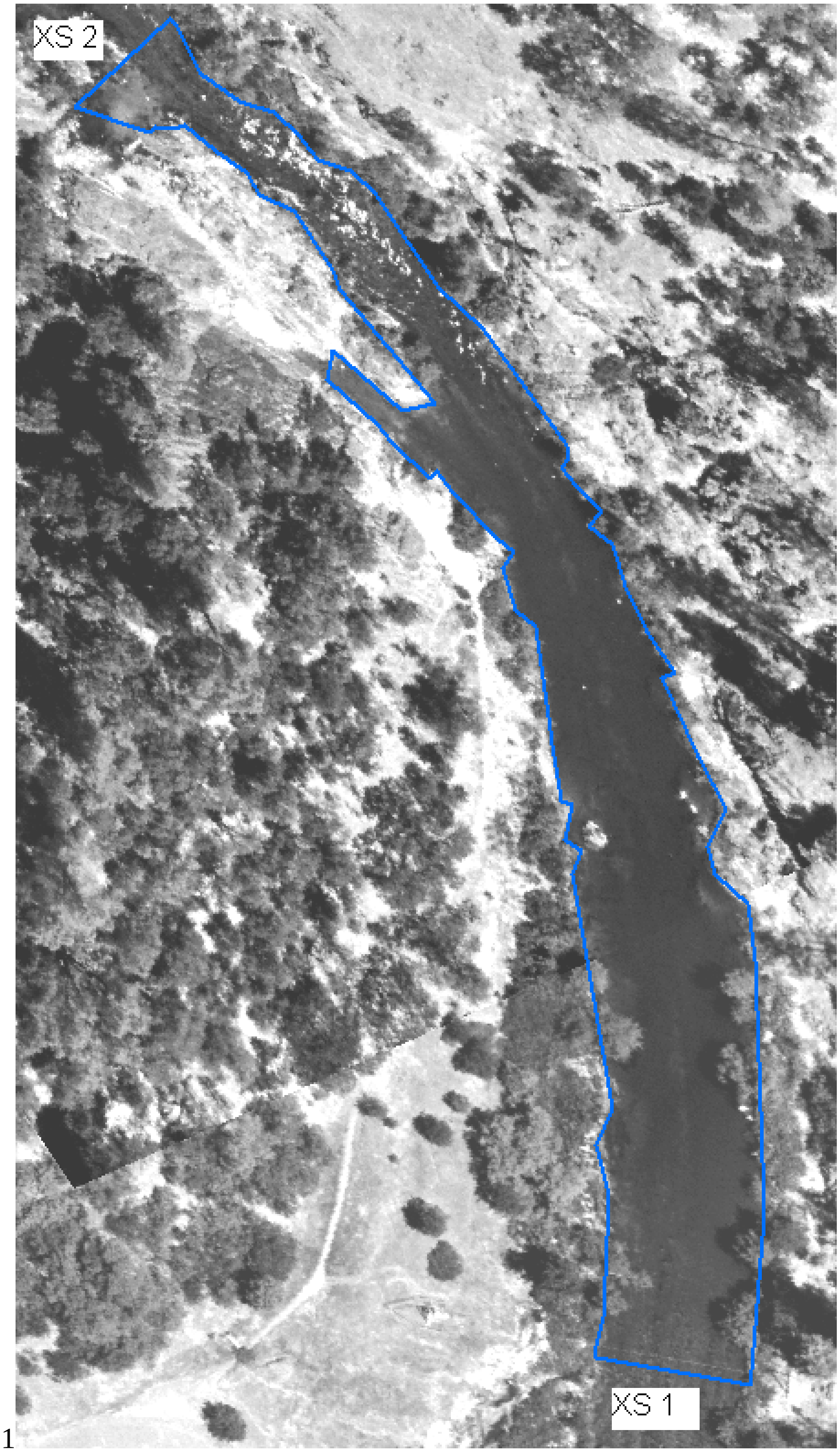
Scale: 1: 313

KANAKA STUDY SITE



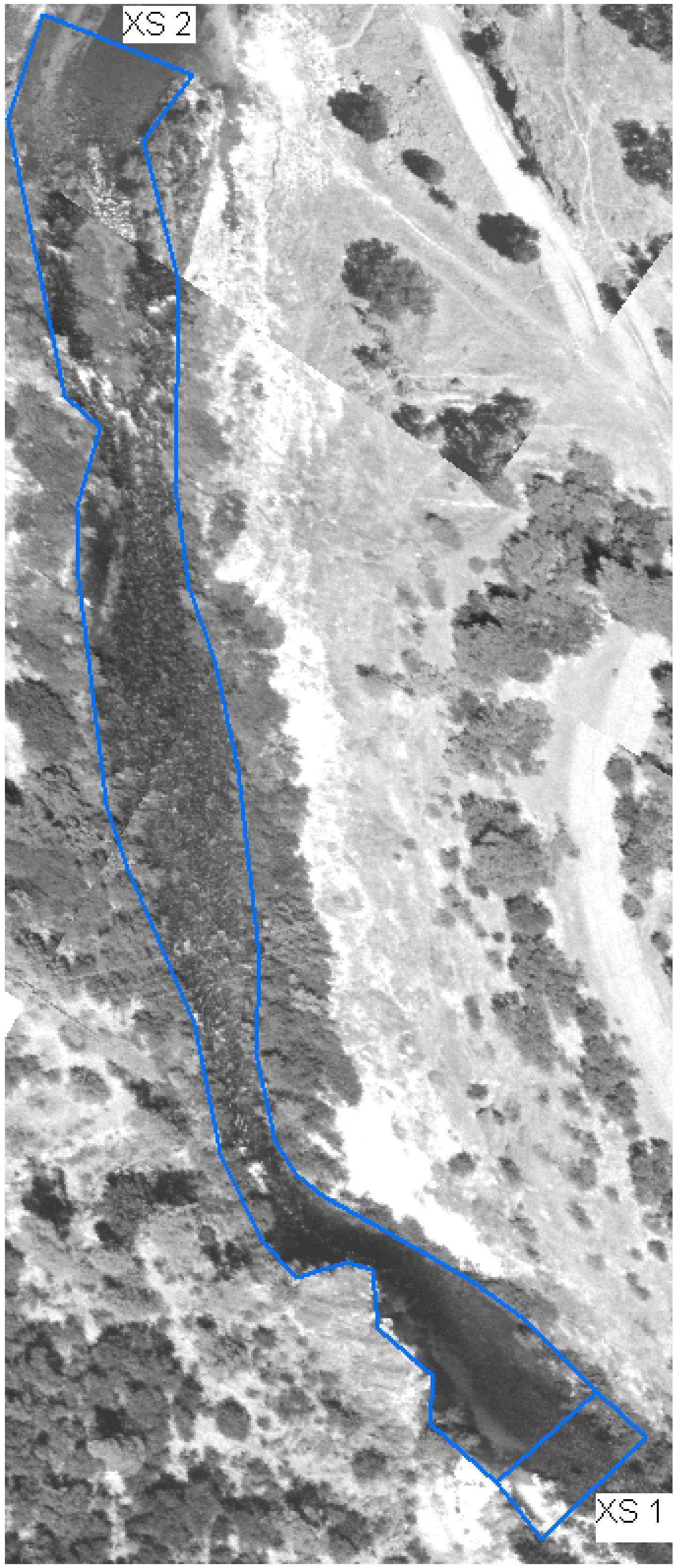
Scale: 1: 1,027

ABOVE IGO STUDY SITE



Scale: 1: 901

UPPER PLACER EXTENSION STUDY SITE



Scale: 1: 717

APPENDIX C
PHABSIM WSEL CALIBRATION[33]

[33] Units of flows are cfs. Units of Difference (measured vs. pred WSELs) are feet.

Stage of Zero Flow Values

Study Site	XS # 1 SZF (ft)	XS # 2 SZF (ft)
Dog Gulch	93.9	99.5
Upper Canyon	93.1	94.09
Narrows	93.4	93.4
Kanaka	87.7	87.7
Above Igo	95.2	95.2
Upper Placer Extension	N/A	101.8

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range (cfs)	Calibration Flows (cfs)	Method	Parameters
Dog Gulch	1,2	50-900	120, 150, 200, 431, 779	IFG4	- - -
Upper Canyon	1	50-900	122, 202, 227, 433, 781	IFG4	- - -
Upper Canyon	2	50-900	122, 202, 227, 438, 781	IFG4	- - -
Narrows	1	50-150	86, 122, 162	IFG4	- - -
Narrows	1	175-900	162, 432, 779	IFG4	- - -
Narrows	2	50-150	86, 122, 162	IFG4	- - -
Narrows	2	175-900	162, 437, 784	IFG4	- - -
Kanaka	1,2	50-150	79, 86, 122, 162	IFG4	- - -
Kanaka	1,2	175-900	162, 432, 784	IFG4	- - -
Above Igo	1	50-275	91, 127, 207, 290	IFG4	- - -
Above Igo	1	300-900	290, 441, 793	IFG4	- - -
Above Igo	2	50-275	91, 127, 155, 207	IFG4	- - -
Above Igo	2	300-900	207, 441, 793	IFG4	- - -
Upper Place Extension	2	50-200	91, 127, 155, 214	IFG4	- - -
Upper Placer Extension	2	225-900	214, 441, 793	IFG4	

Dog Gulch Study Site

	BETA	%MEAN	Calculated vs Given[34] Discharge (%)					Difference[35] (measured vs. pred. WSELs)				
XS	COEFF.	ERROR	120	150	200	431	779	120	150	200	431	779
1	2.50	4.3	1.6	4.4	4.0	7.0	4.5	0.01	0.03	0.03	0.07	0.06
2	3.00	5.2	9.3	12.1	0.5	2.2	1.3	0.05	0.08	0.00	0.02	0.01

Upper Canyon Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)					Difference (measured vs. pred. WSELs)				
XS	COEFF.	ERROR	122	202	227	433	781	122	202	227	433	781
1	3.13	3.0	2.8	5.0	2.8	2.6	1.9	0.02	0.05	0.03	0.03	0.03

	BETA	%MEAN	Calculated vs Given Discharge (%)					Difference (measured vs. pred. WSELs)				
XS	COEFF.	ERROR	122	202	227	438	781	122	202	227	438	781
2	2.98	3.7	5.1	3.9	0.8	4.8	4.0	0.05	0.05	0.01	0.07	0.08

34 Given refers to flows from gage readings.
35 Units of Difference are feet.

Narrows Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	86	122	162	86	122	162
1	2.01	2.4	2.4	4.6	2.0	0.03	0.07	0.04

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	162	432	779	162	432	779
1	3.16	1.7	0.9	2.5	1.6	0.01	0.04	0.03

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	86	122	162	86	122	162
2	2.01	2.2	1.8	3.4	1.6	0.02	0.06	0.03

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	162	437	784	162	437	784
2	2.8	0.8	0.4	1.1	0.7	0.01	0.02	0.02

Kanaka Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	79	86	122	162	79	86	122	162
1	2.30	1.7	1.0	0.7	3.4	1.7	0.01	0.01	0.04	0.03
2	2.34	2.2	2.6	1.3	3.2	1.7	0.03	0.01	0.04	0.02

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	162	432	784	162	432	784
1	3.19	1.4	2.2	1.3	0.9	0.01	0.03	0.02
2	3.11	0.1	0.2	0.1	0.1	0.00	0.00	0.00

Above Igo Study Site

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 91	127	207	290	Difference (measured vs. pred. WSELs) 91	127	207	290
1	3.48	2.2	1.2	3.3	2.4	2.0	0.01	0.01	0.03	0.02

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 91	127	155	207	Difference (measured vs. pred. WSELs) 91	127	155	207
2	3.45	1.9	1.7	4.0	1.6	0.6	0.00	0.01	0.03	0.01

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 290	441	793	Difference (measured vs. pred. WSELs) 290	441	793
1	3.22	0.1	0.9	0.2	0.1	0.00	0.00	0.00

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 207	441	793	Difference (measured vs. pred. WSELs) 207	441	793
2	2.90	0.2	0.1	0.3	0.2	0.00	0.00	0.02

Upper Placer Extension Study Site

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 91	127	155	214	Difference (measured vs. pred. WSELs) 91	127	155	214
2	3.33	1.0	1.8	0.3	0.9	1.1	0.01	0.01	0.00	0.01

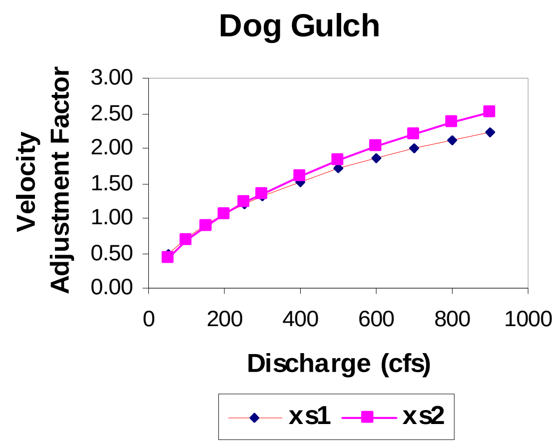
XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 214	441	793	Difference (measured vs. pred. WSELs) 214	441	793
2	2.55	2.1	1.3	3.2	1.9	0.01	0.04	0.03

APPENDIX D
VELOCITY ADJUSTMENT FACTORS[36]

[36] Units of discharge are cfs.

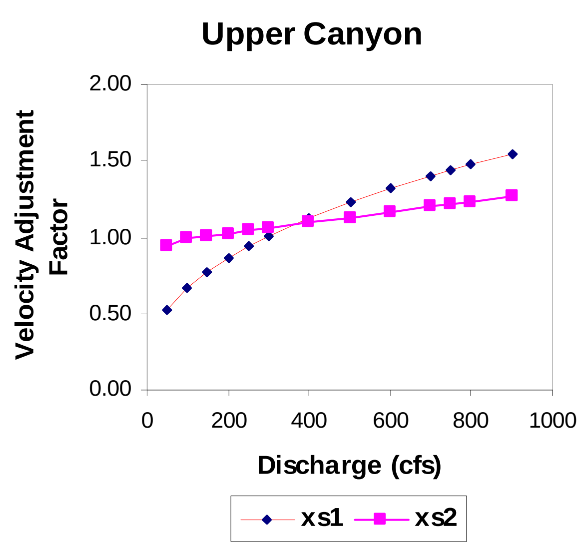
Dog Gulch

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
50	0.48	0.43
100	0.73	0.69
150	0.91	0.89
200	1.07	1.06
250	1.20	1.22
300	1.32	1.36
400	1.53	1.60
500	1.70	1.82
600	1.86	2.02
700	1.99	2.20
800	2.12	2.37
900	2.23	2.52



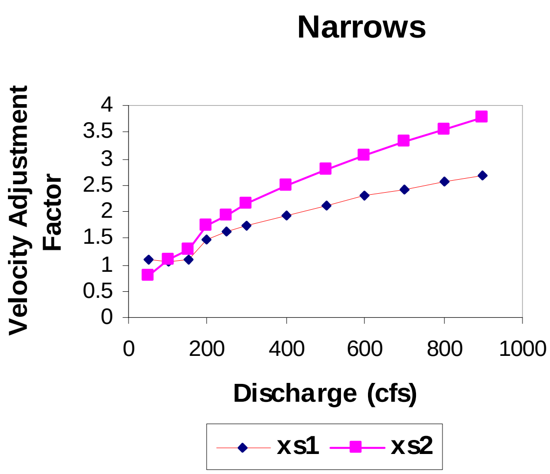
Upper Canyon

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
50	0.52	0.94
100	0.67	1.00
150	0.77	1.01
200	0.86	1.03
250	0.94	1.04
300	1.00	1.06
400	1.12	1.09
500	1.22	1.13
600	1.31	1.16
700	1.40	1.20
750	1.44	1.21
800	1.47	1.23
900	1.55	1.26



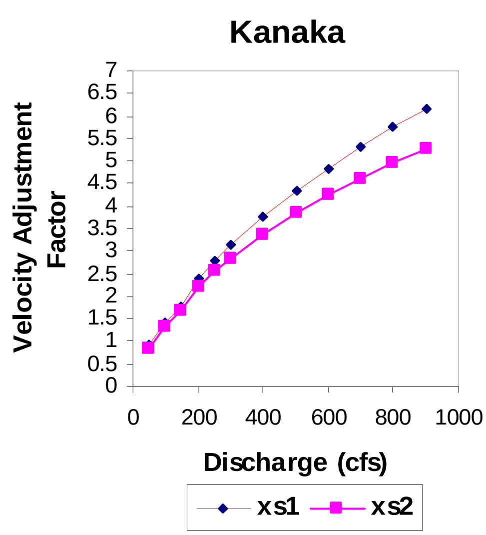
Narrows

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	1.08	0.79
100	1.06	1.08
150	1.08	1.28
200	0.90	0.42
250	0.98	0.47
300	1.05	0.52
400	1.18	0.60
500	1.29	0.67
600	1.39	0.73
700	1.47	0.79
800	1.55	0.83
900	1.63	0.88



Kanaka

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.93	0.84
100	1.42	1.32
150	1.77	1.66
200	2.41	2.22
250	2.79	2.55
300	3.14	2.85
400	3.76	3.38
500	4.32	3.83
600	4.84	4.24
700	5.31	4.61
800	5.75	4.96
900	6.17	5.28



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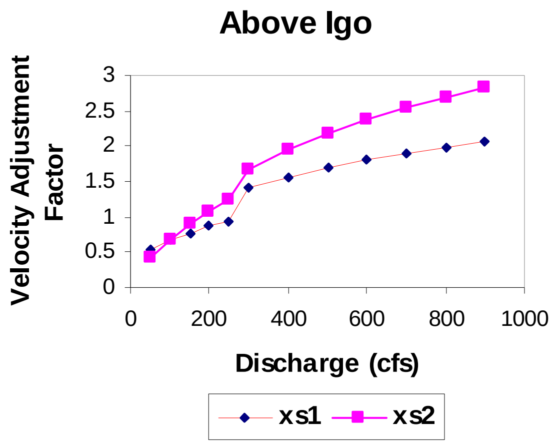
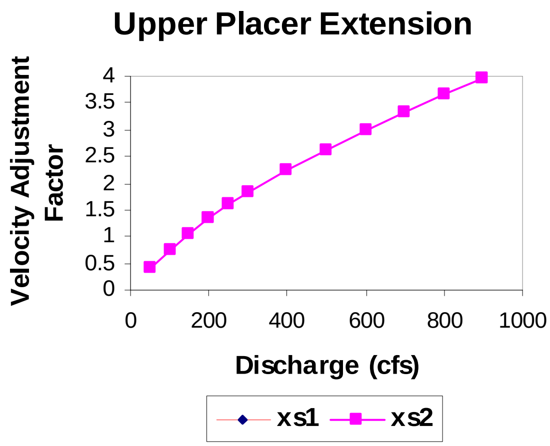
Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
50	0.53	0.43
100	0.67	0.69
150	0.78	0.90
200	0.87	1.08
250	0.94	1.25
300	1.41	1.66
400	1.56	1.94
500	1.69	2.18
600	1.80	2.37
700	1.90	2.54
800	1.99	2.70
900	2.07	2.83

Above Igo



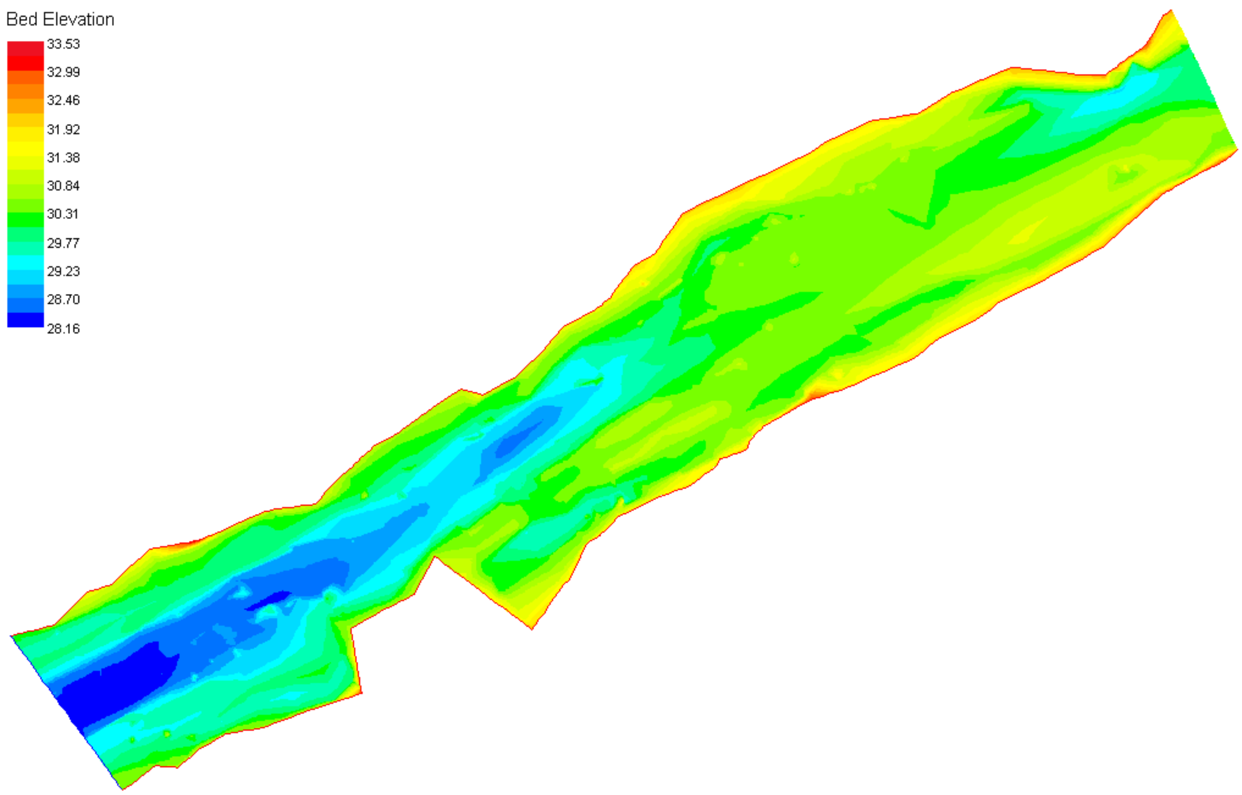
Upper Placer Extension

Discharge	Velocity Adjustment Factors Xsec 2
50	0.42
100	0.76
150	1.06
200	1.34
250	1.59
300	1.82
400	2.24
500	2.63
600	2.99
700	3.32
800	3.64
900	3.95



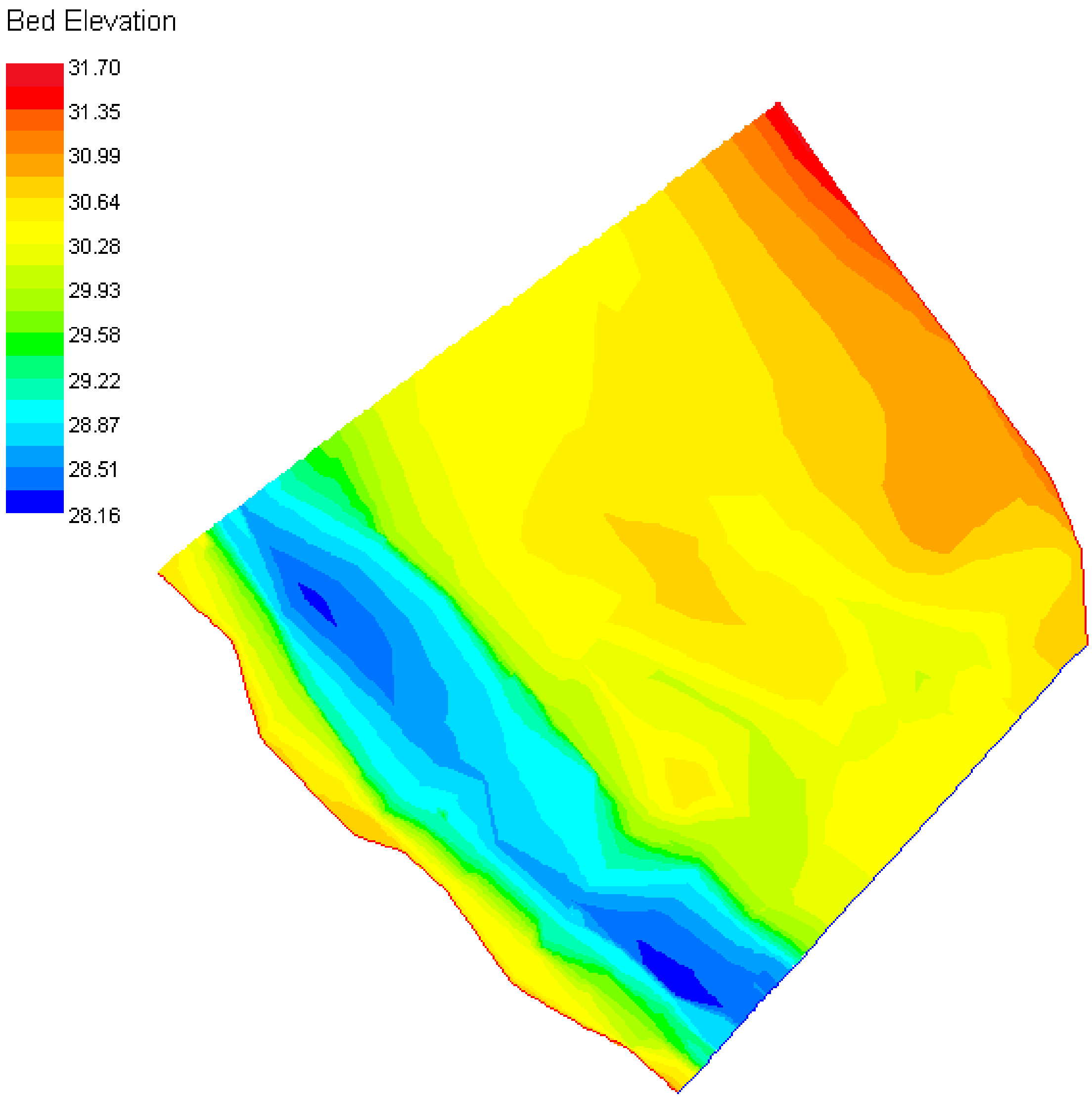
APPENDIX E
BED TOPOGRAPHY OF STUDY SITES

Dog Gulch Study Site



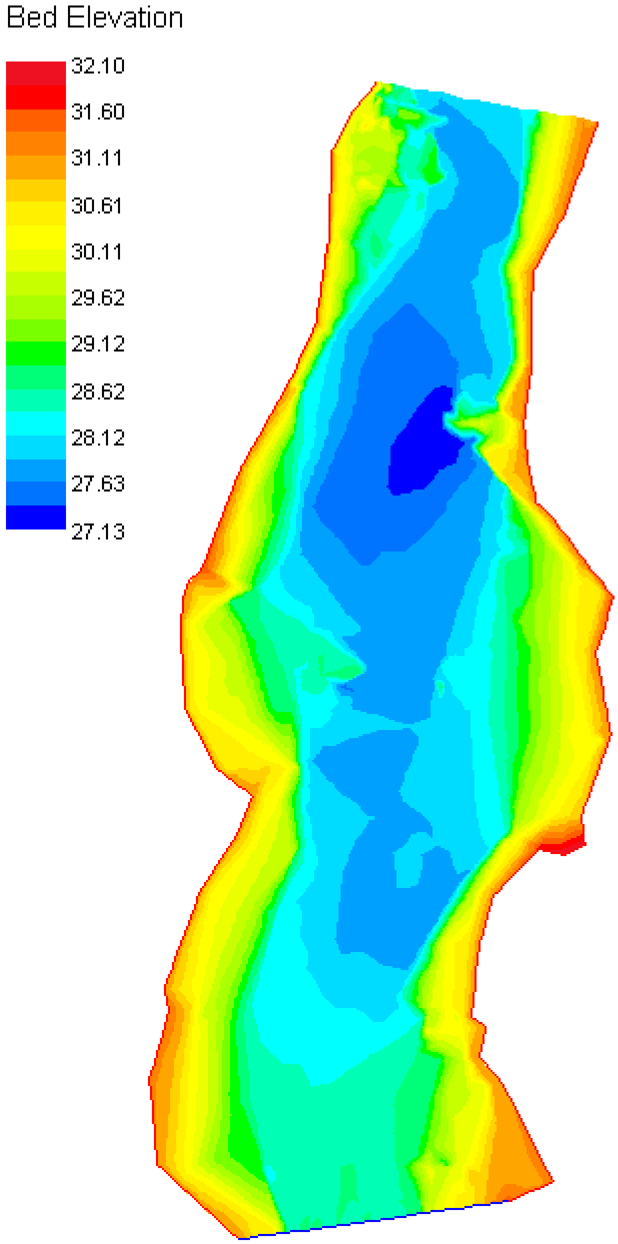
Scale: 1: 1,405
Units of Bed Elevation are meters.

Upper Canyon Study Site



Scale: 1: 655
Units of Bed Elevation are meters.

Narrows Study Site



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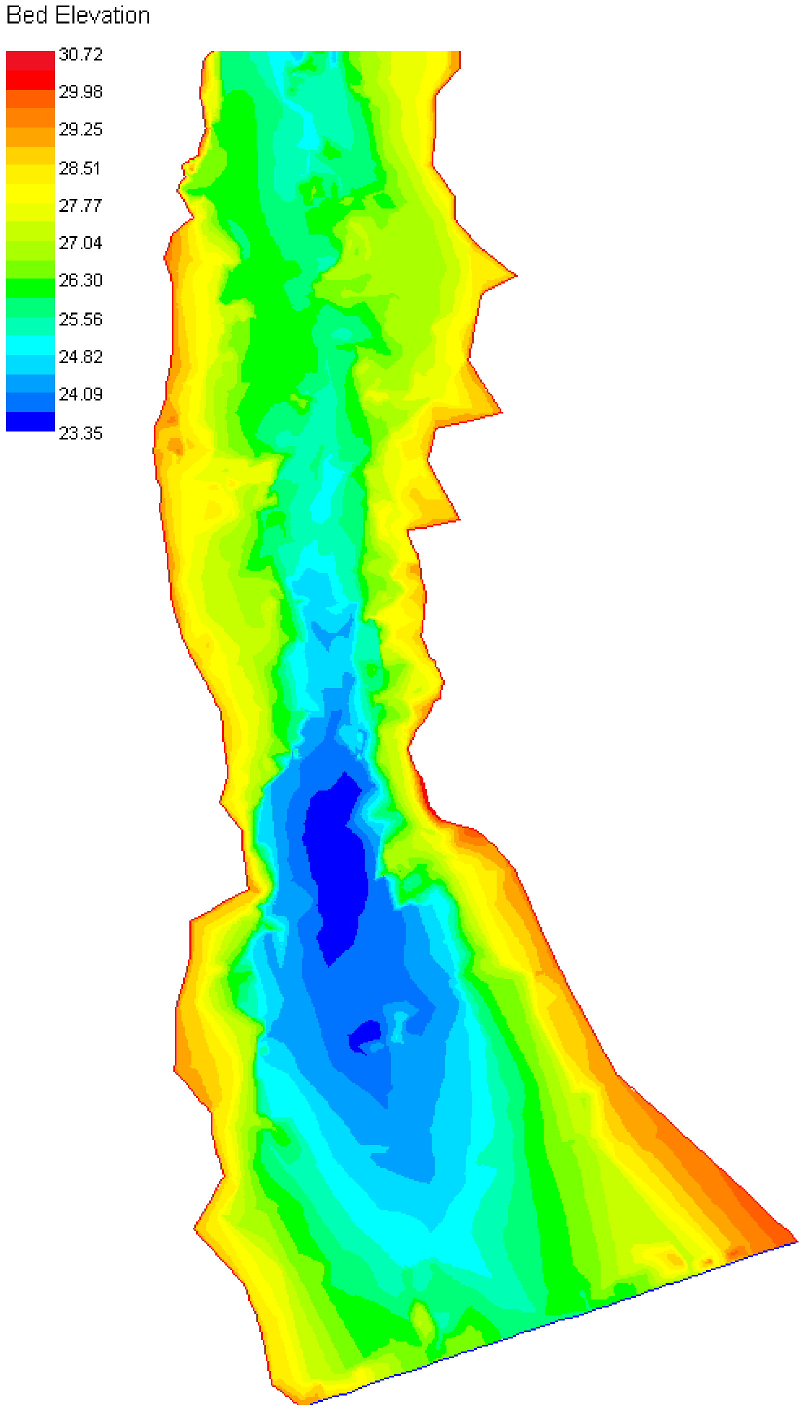
Units of Bed Elevation are meters.

Kanaka Study Site



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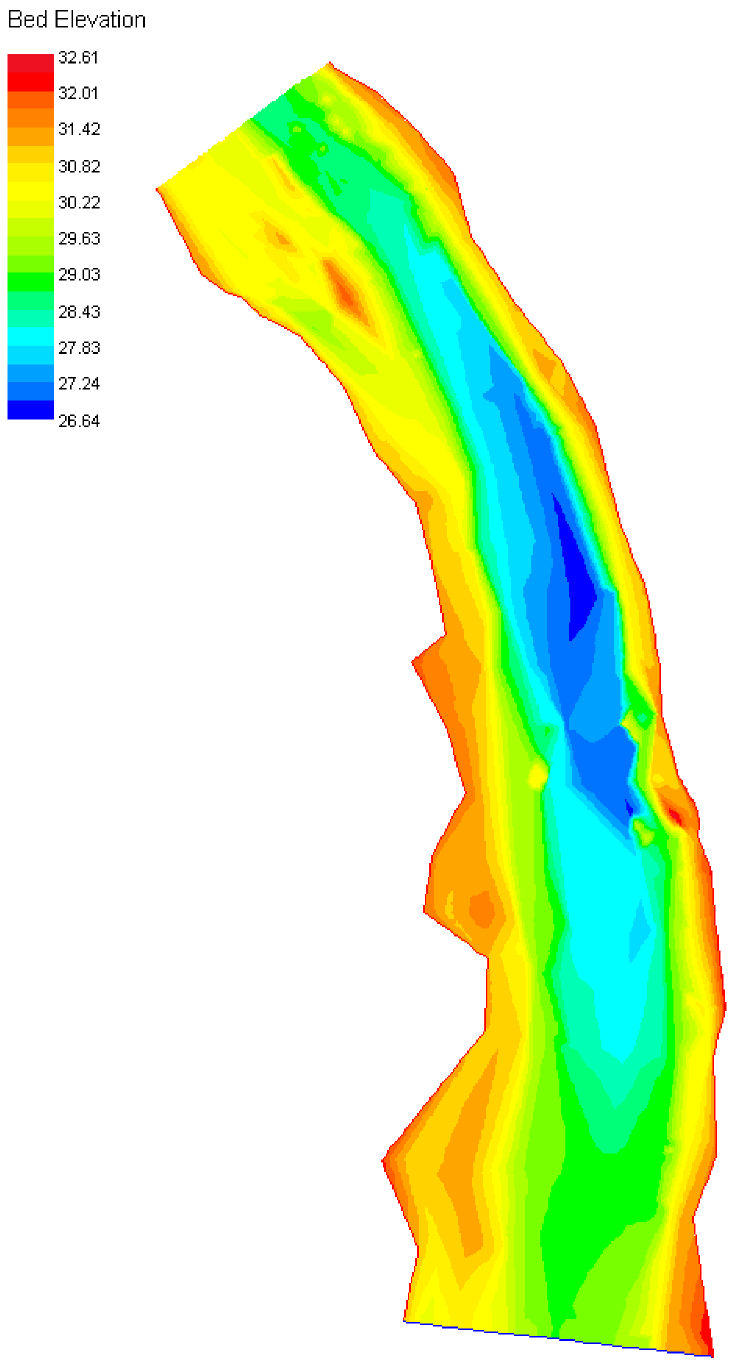
Units of Bed Elevation are meters.

Above Igo Study Site



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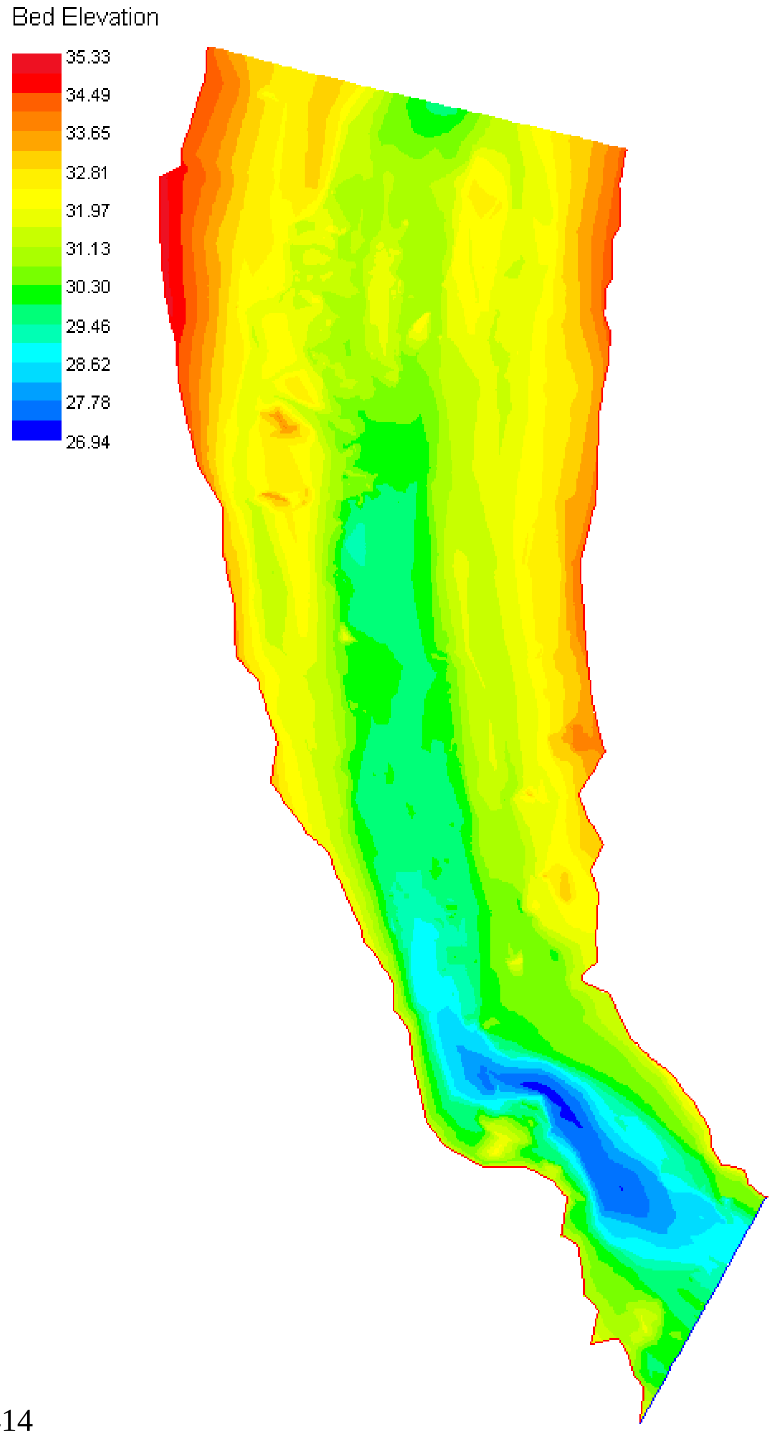
Units of Bed Elevation are meters.

Upper Placer Extension Study Site



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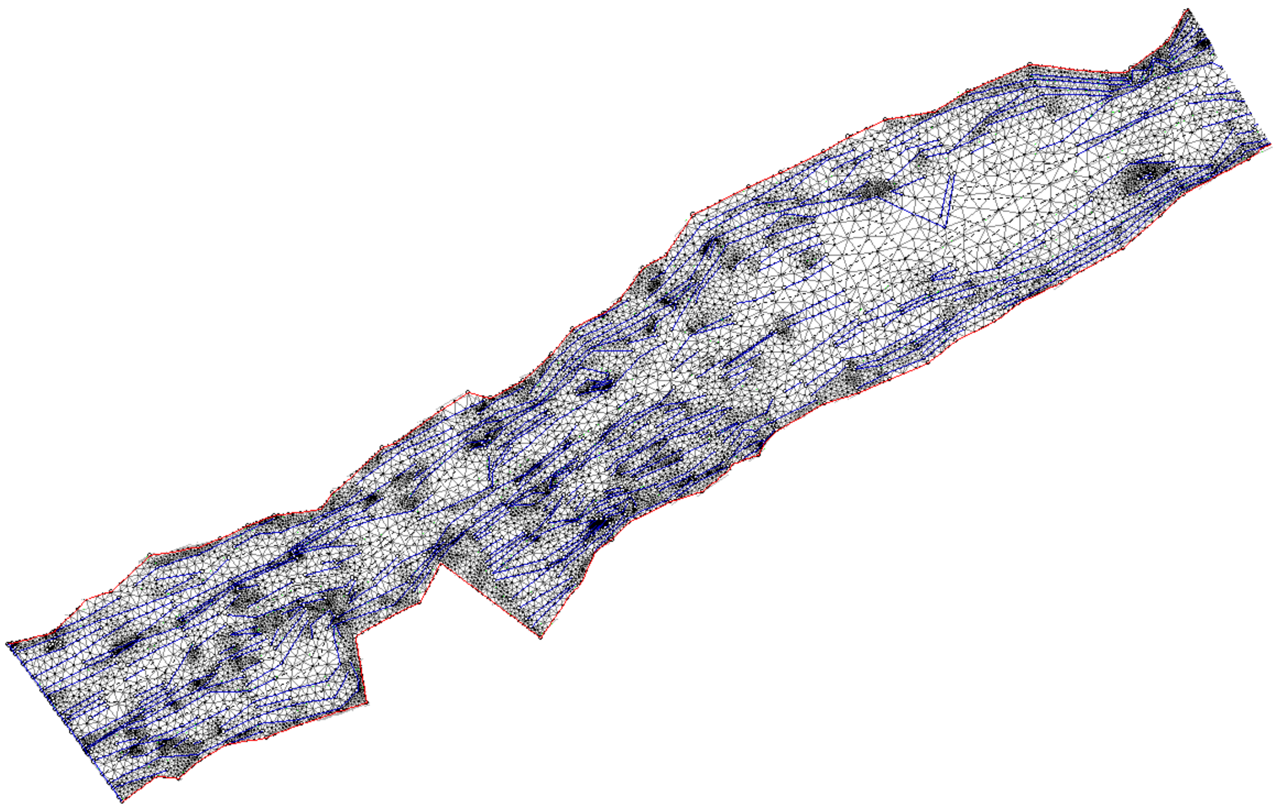
Units of Bed Elevation are meters.

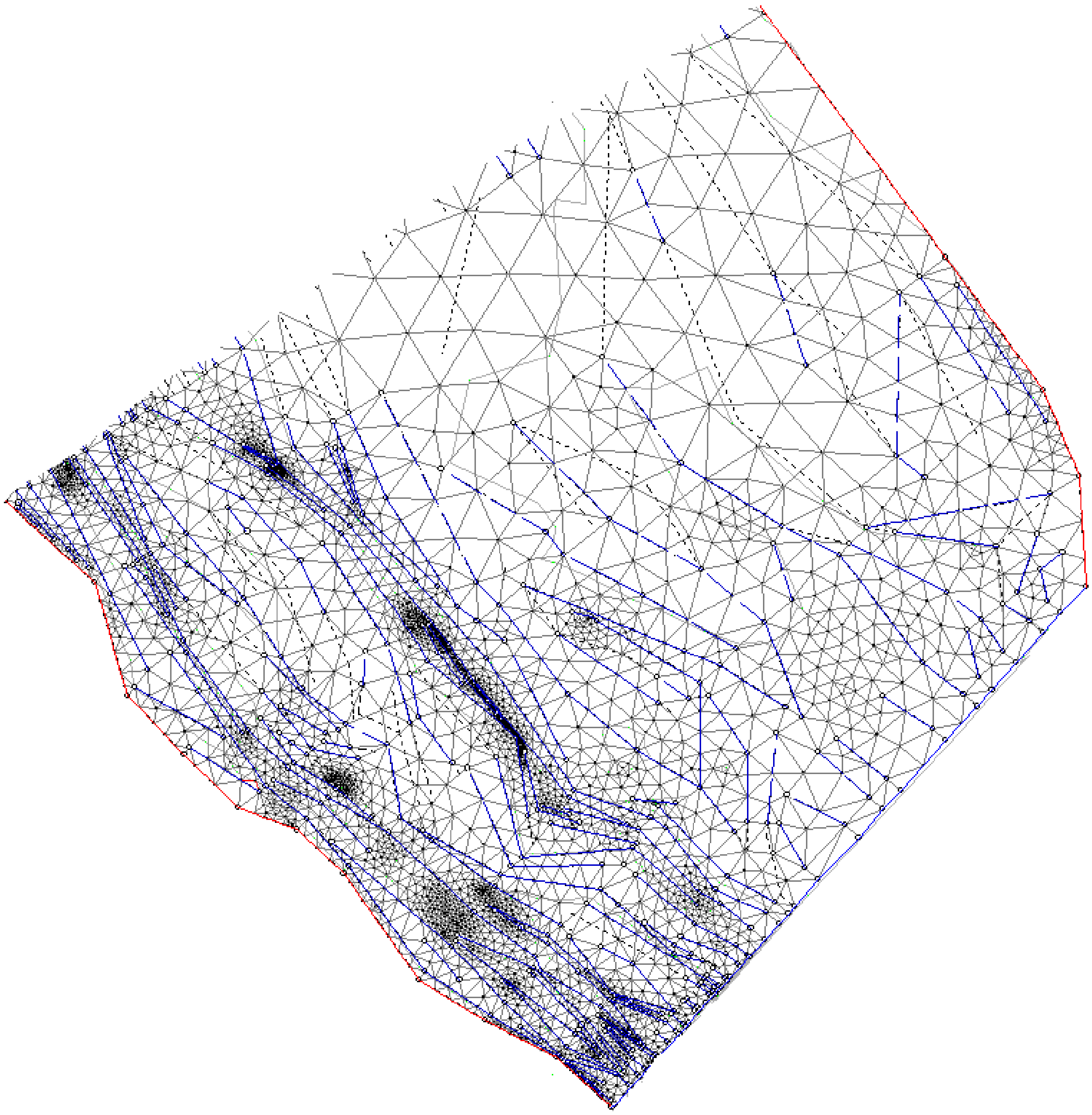
APPENDIX F
COMPUTATIONAL MESHES OF STUDY SITES

Dog Gulch Study Site



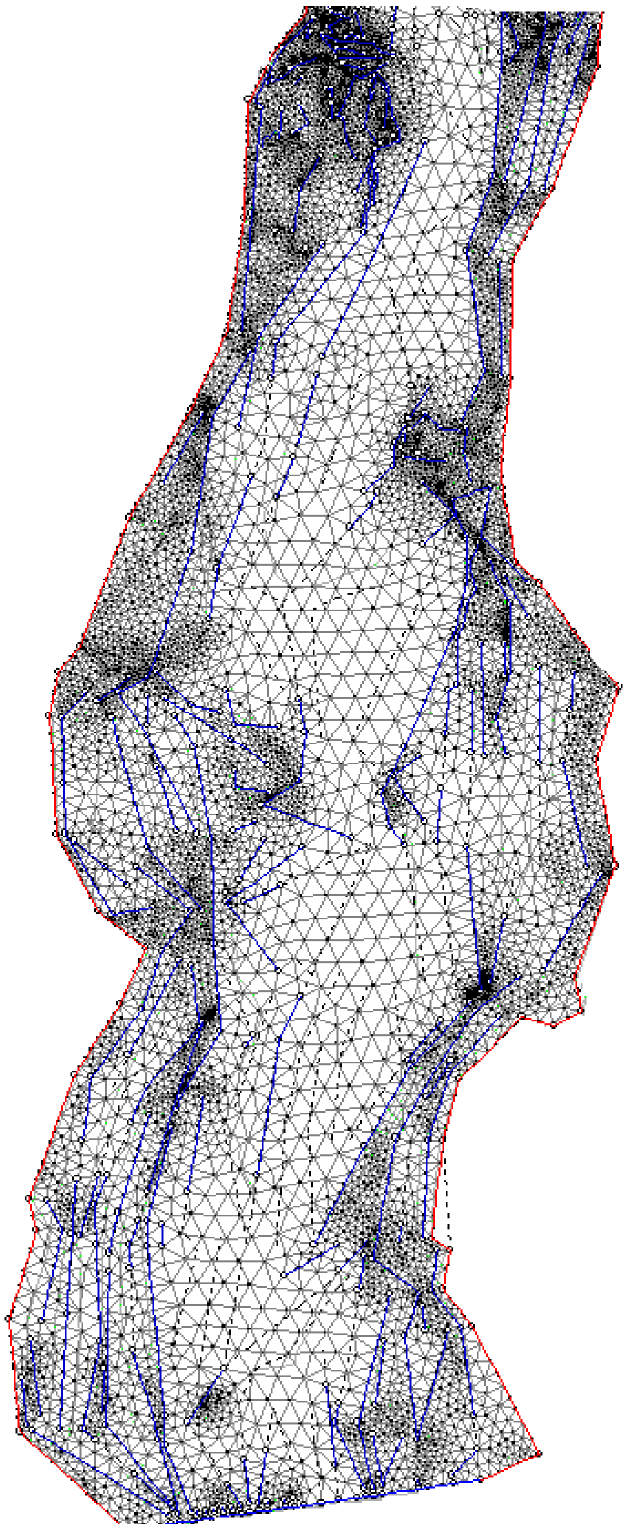
Scale: 1: 1,373

Upper Canyon Study Site



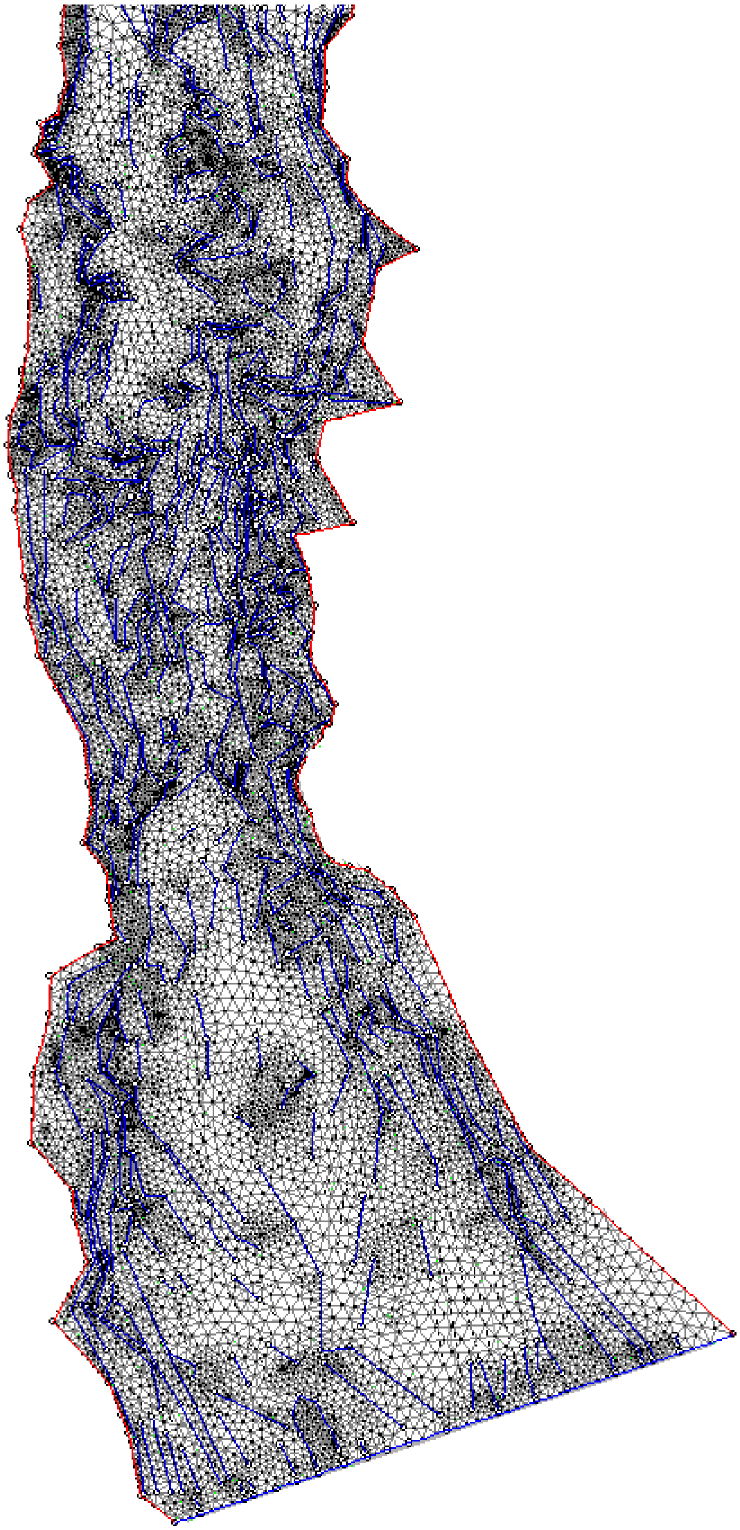
Scale: 1: 554

Narrows Study Site



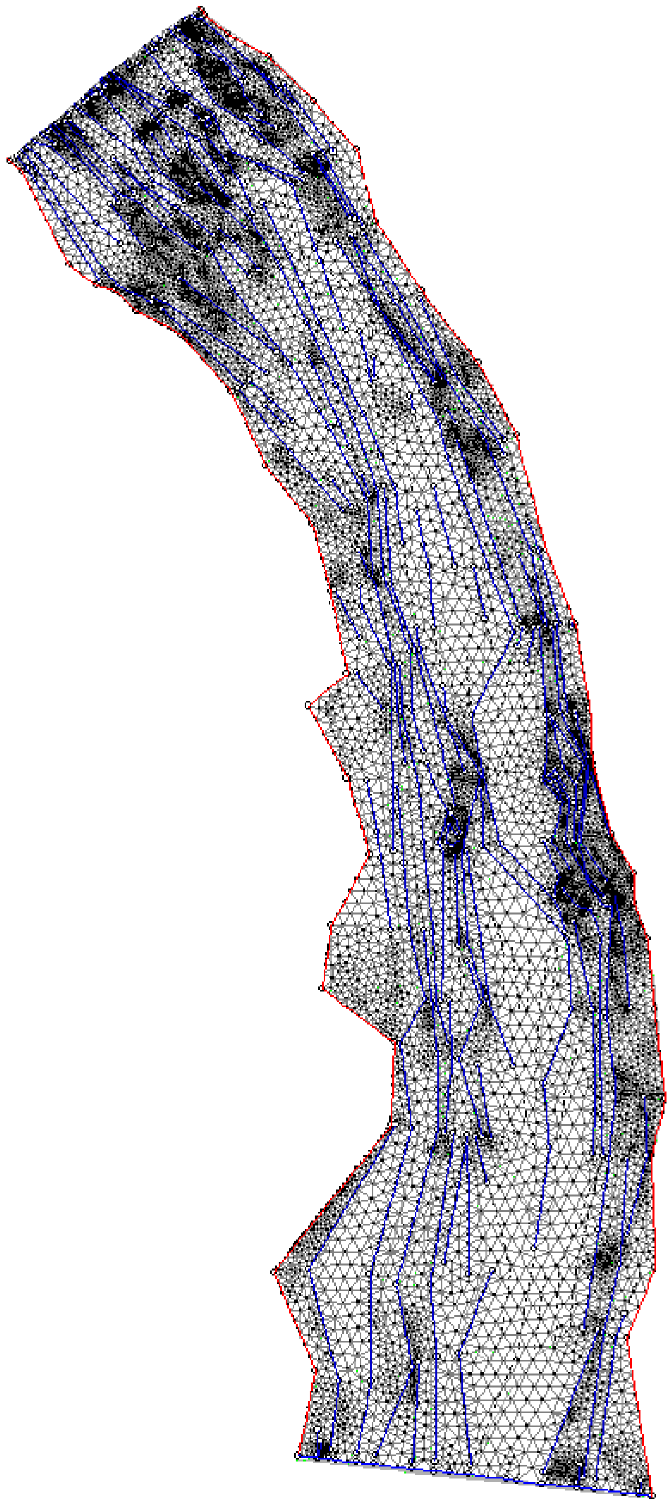
Scale: 1: 277

Kanaka Study Site



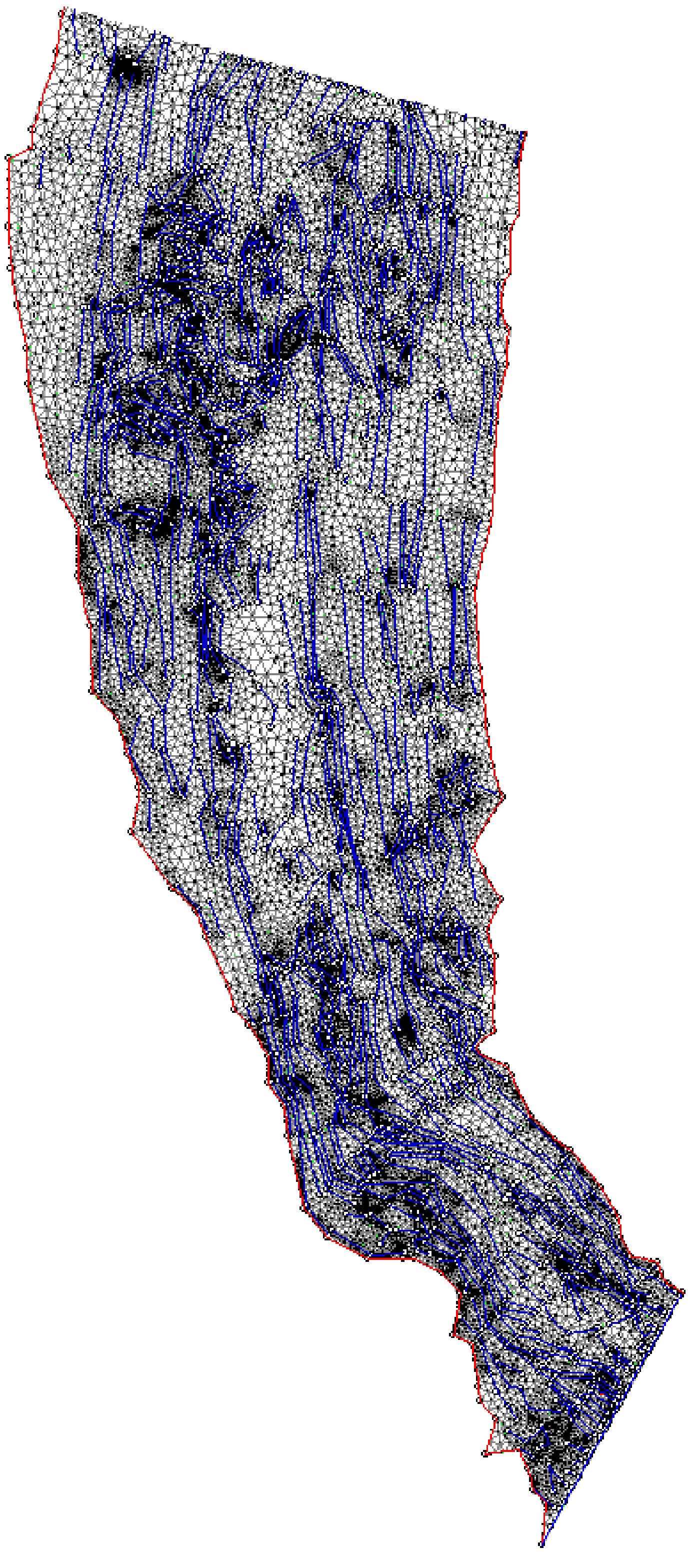
Scale: 1: 970

Above Igo Study Site



Scale: 1: 984

Upper Placer Extension Study Site



Scale: 1: 1,250

APPENDIX G
2-D WSEL CALIBRATION

Calibration Statistics

Site Name	Cal Q (cfs)	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Dog Gulch	900	87%	11,844	0.30	0.008%	<.000001	7.16
Upper Canyon	900	94%	4,936	0.30	0.16%	.000002	2.07
Narrows	900	81%	13,673	0.34	0.20%	<.000001	1.32
Kanaka	900	80%	16,666	0.30	0.12%	<.000001	3.22
Above Igo	900	83%	12,533	0.30	0.06%	.000009	1.10
Up. Placer Ext.	900	82%	23,590	0.30	0.07%	<.000001	6.09

Dog Gulch Site

		Difference (measured vs. pred. WSELs, feet)		
XSEC	Br Multiplier	Average	Standard Deviation	Maximum
2	1.0	0.03	0.03	0.08

Upper Canyon Site

		Difference (measured vs. pred. WSELs, feet)		
XSEC	Br Multiplier	Average	Standard Deviation	Maximum
2	1.3	0.04	0.02	0.06

Narrows Site

		Difference (measured vs. pred. WSELs, feet)		
XSEC	Br Multiplier	Average	Standard Deviation	Maximum
2	0.3	0.22	0.06	0.27
2 LB	0.3	0.01	0	0.01
2 RB	0.3	0.18	0.02	0.20

Kanaka

		Difference (measured vs. pred. WSELs, feet)		
XSEC	Br Multiplier	Average	Standard Deviation	Maximum
2	0.3	0.10	0.03	0.13
2 LB	0.3	0.10	0	0.10
2 RB	0.3	0.08	0.02	0.10

Above Igo Site

XSEC	Br Multiplier	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2	1.6	0.03	0.03	0.11
2 LB	1.6	0.03	0.02	0.09
2 RB	1.6	0.08	0.02	0.09

Upper Placer Extension Site

XSEC	Br Multiplier	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2	1.0	0.03	0.02	0.06

APPENDIX H
VELOCITY VALIDATION STATISTICS

Site Name	Number of Observations	Correlation Between Measured and Simulated Velocities
Dog Gulch	93	0.73
Upper Canyon	92	0.71
Narrows	92	0.03
Kanaka	92	0.63
Above Igo	99	0.85
Upper Placer Extension	94	0.72

Measured Velocities less than 3 ft/s

Difference (measured vs. pred. velocities, ft/s)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Dog Gulch	77	0.50	0.54	3.81
Upper Canyon	47	0.88	0.83	2.98
Narrows	92	0.90	1.33	5.40
Kanaka	92	0.15	0.12	0.56
Above Igo	99	0.27	0.23	1.08
Upper Placer Extension	79	0.60	0.61	2.27

All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

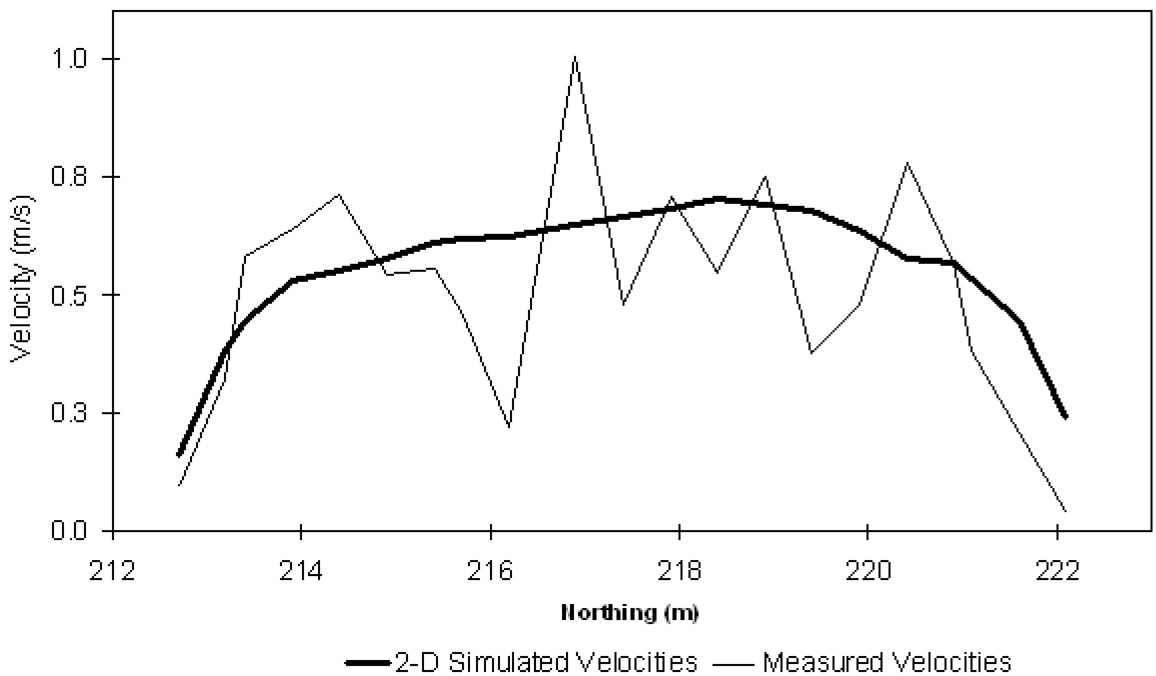
Measured Velocities greater than 3 ft/s

Percent difference (measured vs. pred. velocities)

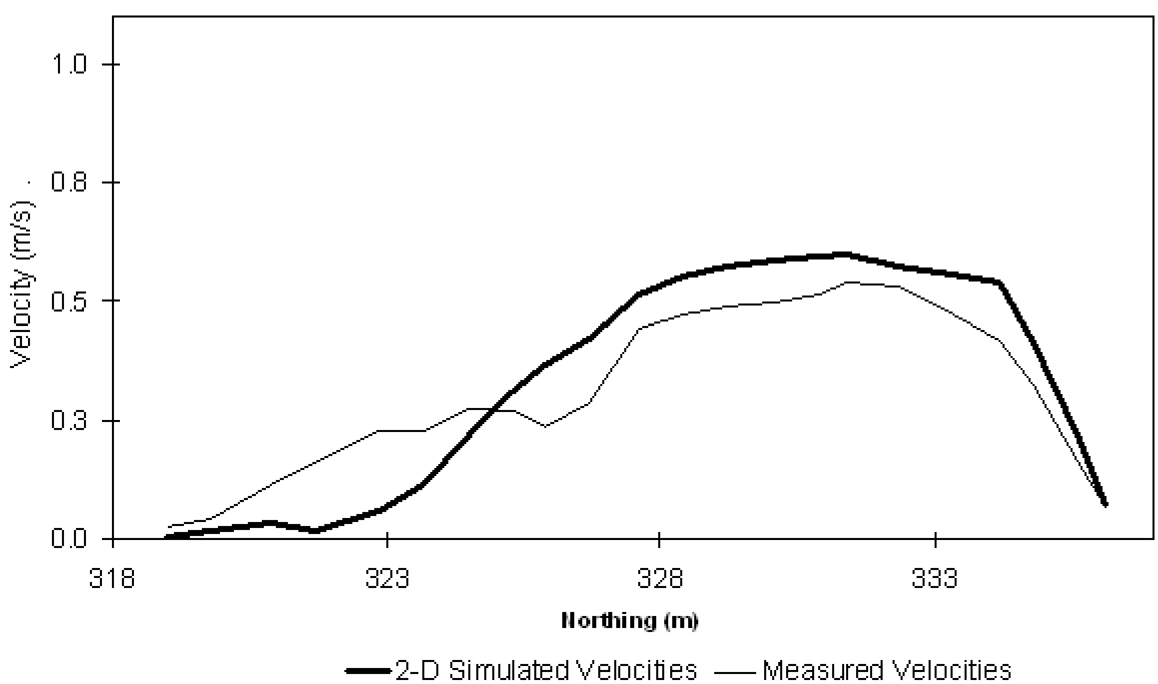
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Dog Gulch	16	36%	33%	100%
Upper Canyon	45	23%	12%	44%
Narrows	N/A	N/A	N/A	N/A
Kanaka	N/A	N/A	N/A	N/A
Above Igo	N/A	N/A	N/A	N/A
Upper Placer Extension	15	23%	19%	72%

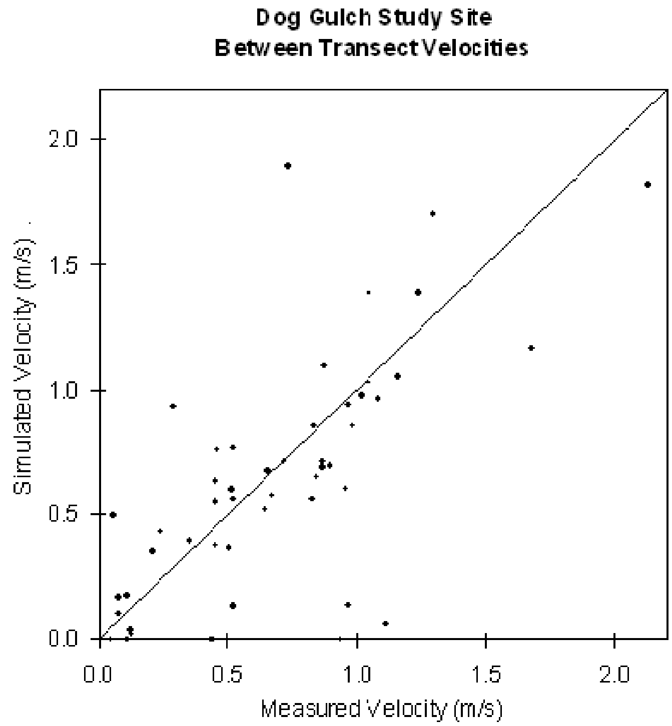
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

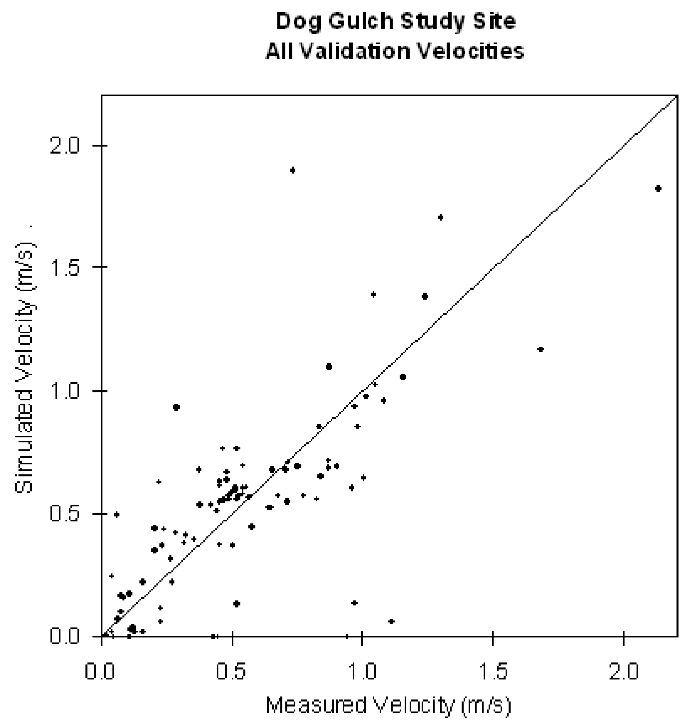
Dog Gulch Site XS1, Q = 200 cfs



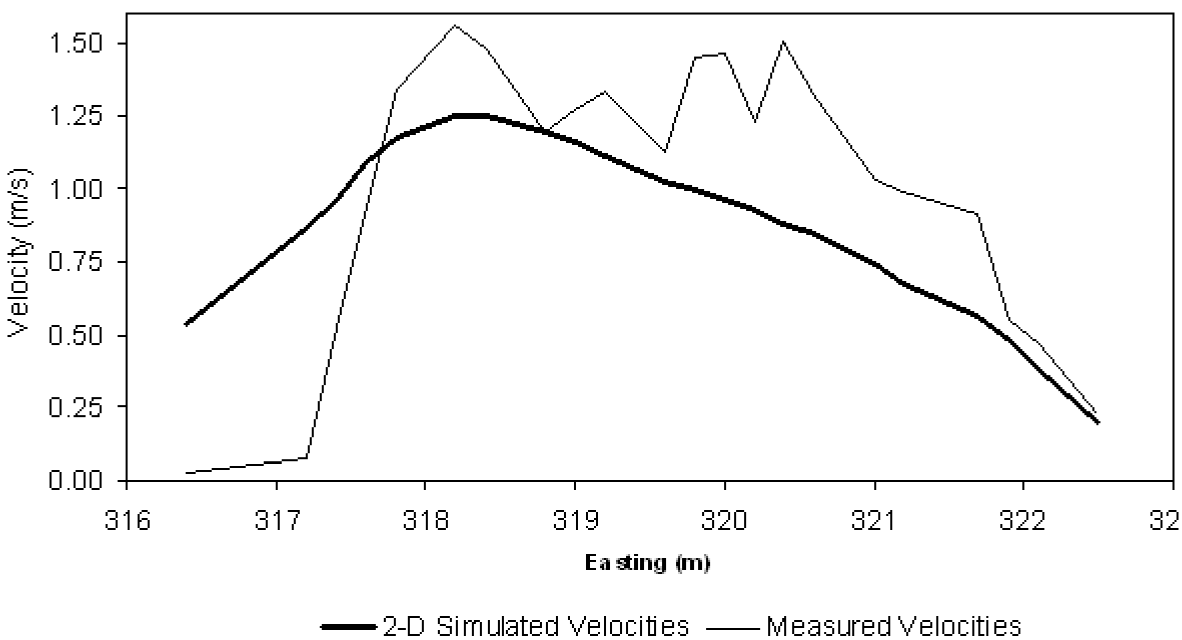
Dog Gulch Site XS2, Q = 200 cfs




Dog Gulch Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5
2.0

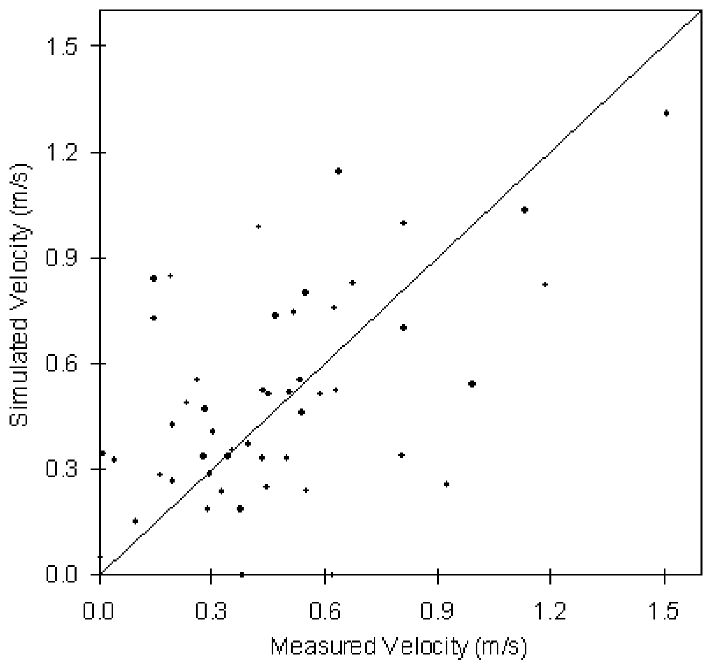

Dog Gulch Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5
2.0

Upper Canyon Site XS1, Q= 227 cfs

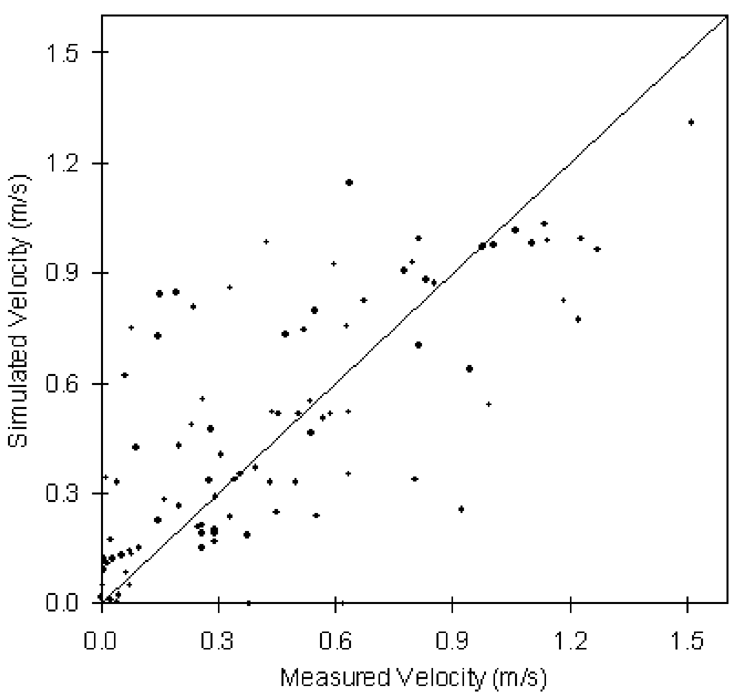


Upper Canyon Site XS2, Q= 227 cfs

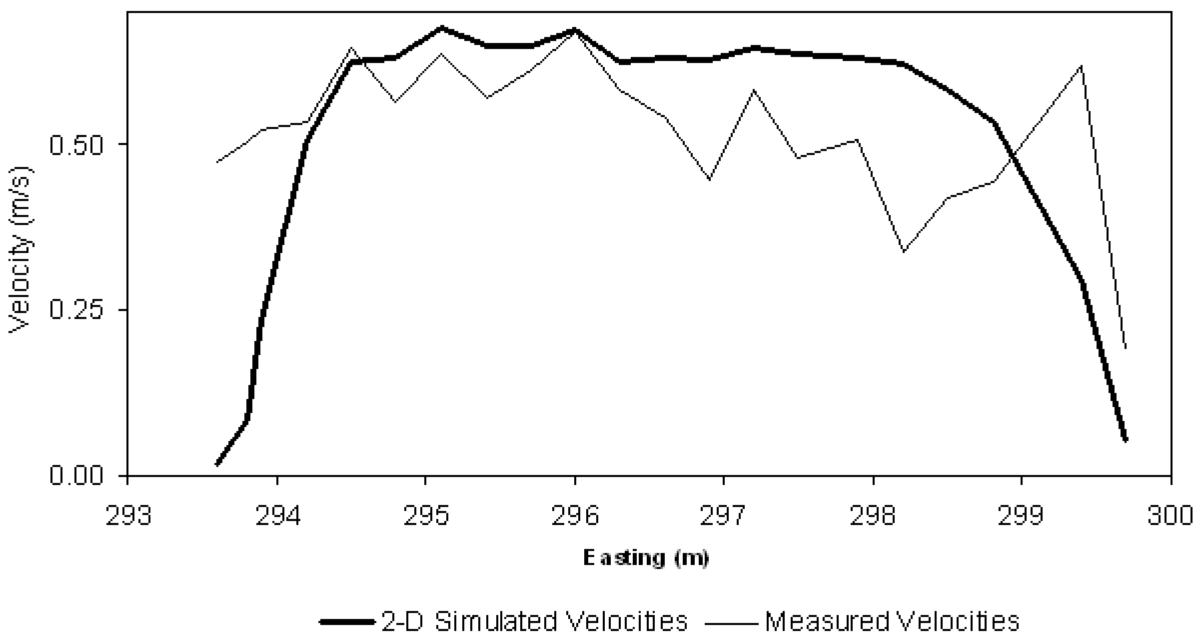
Upper Placer Extension Study Site
Between Transect Velocities



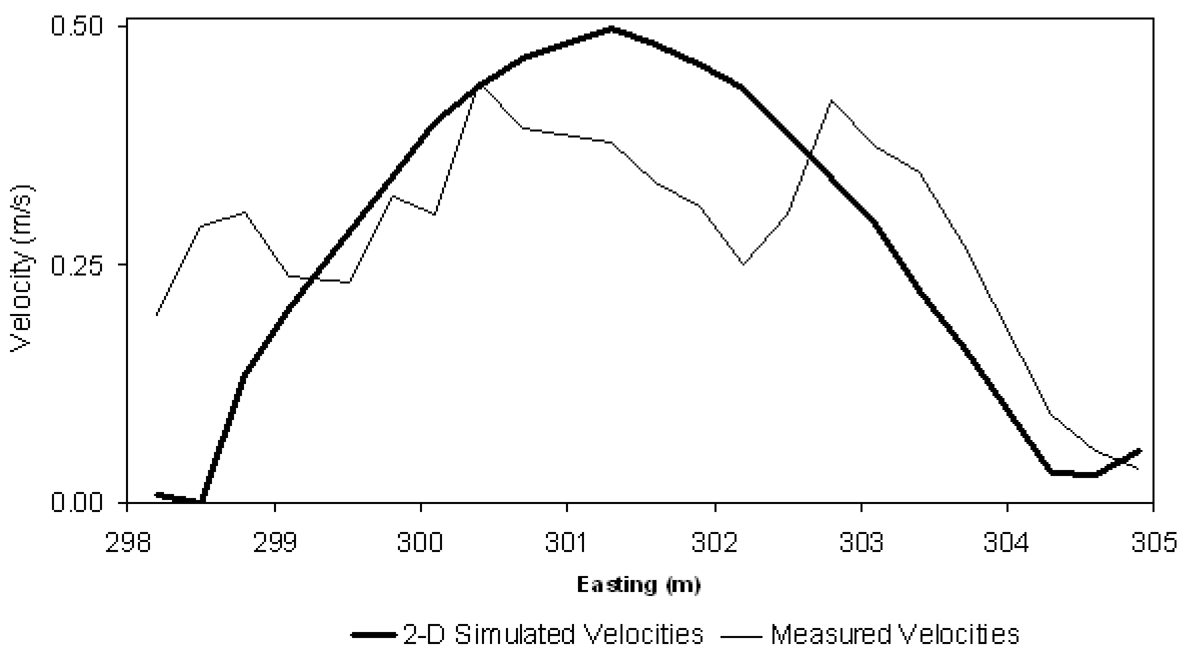
Upper Placer Extension Study Site
All Validation Velocities



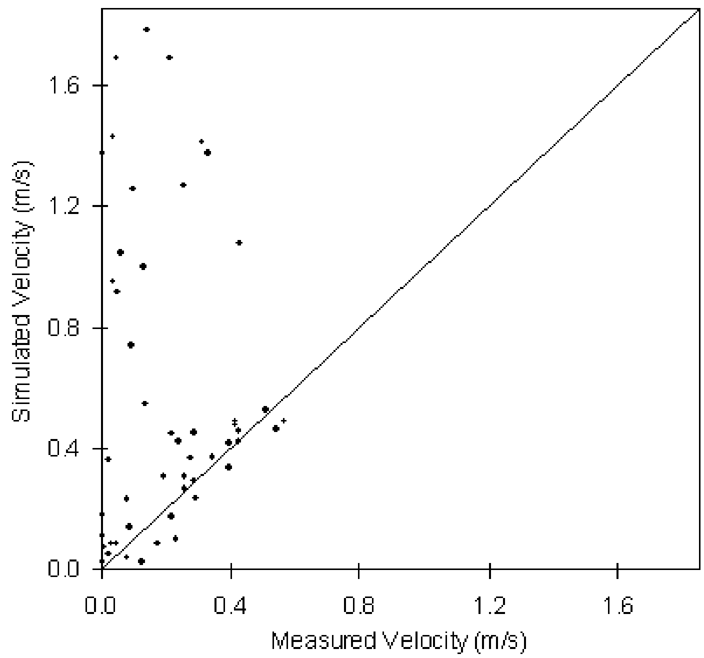
Narrows Site XS1, Q = 86 cfs



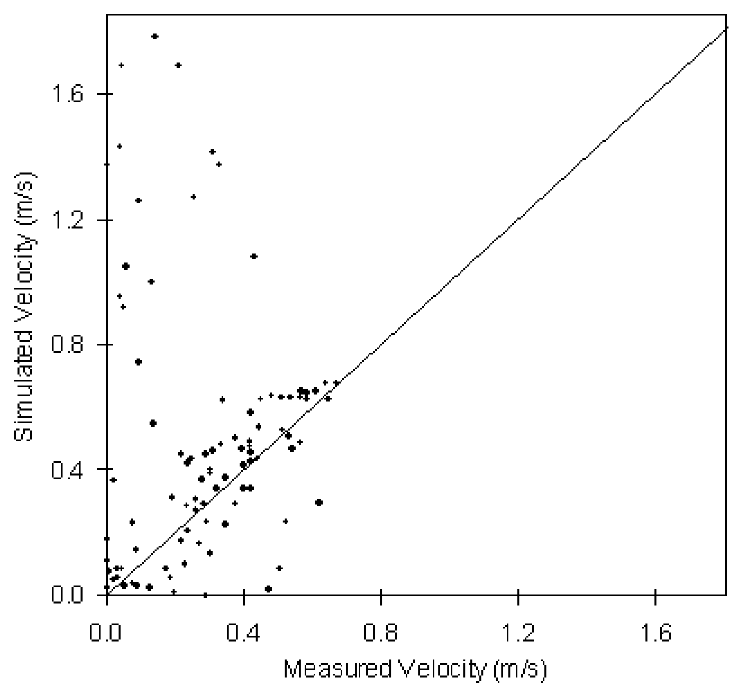
Narrows Site XS2, Q = 86 cfs

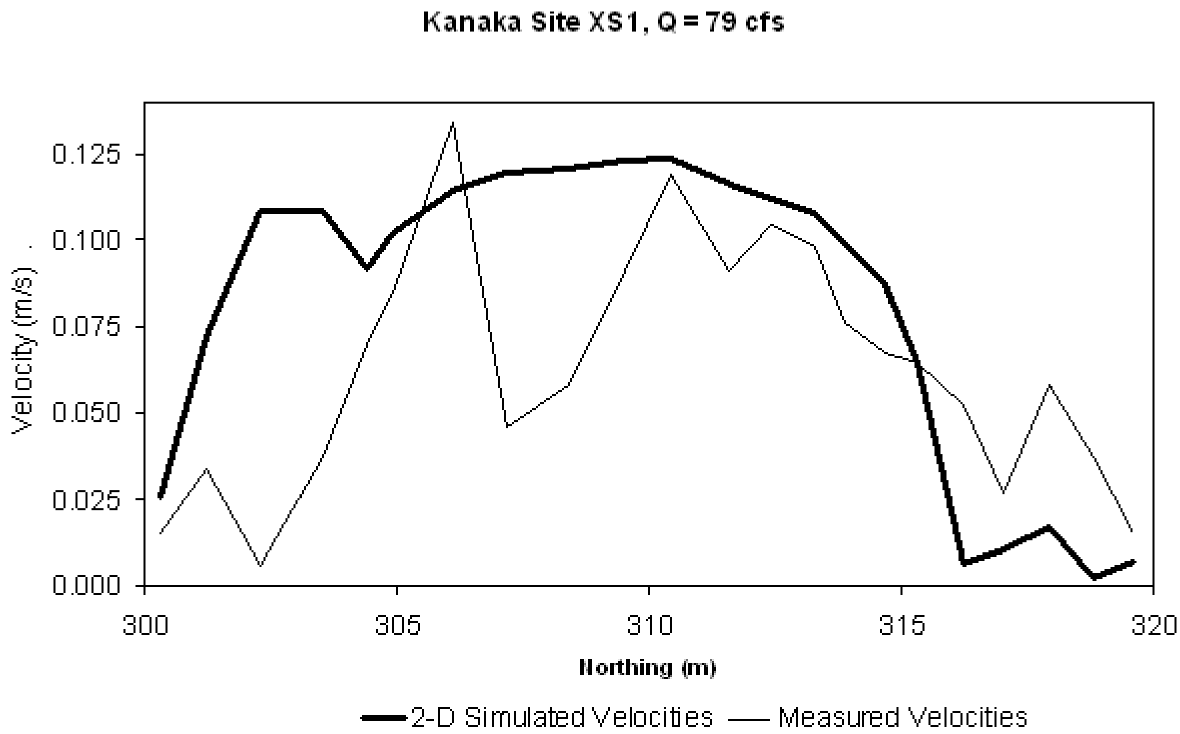


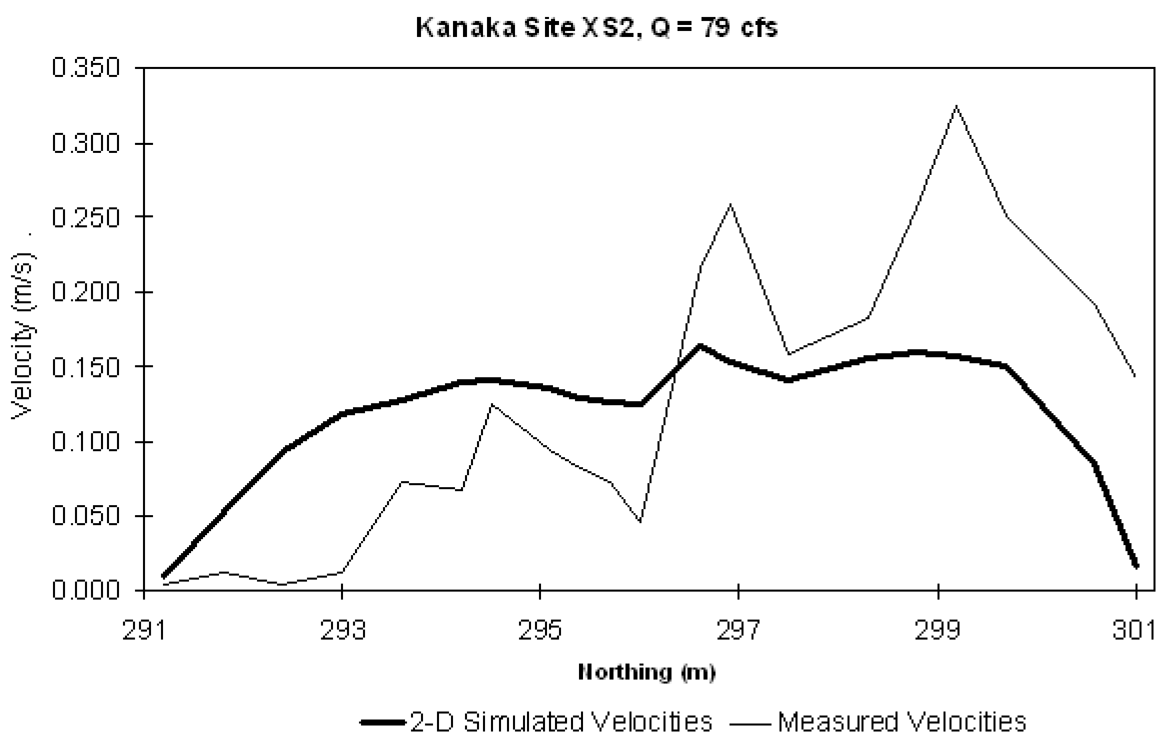
Narrows Study Site
Between Transect Velocities



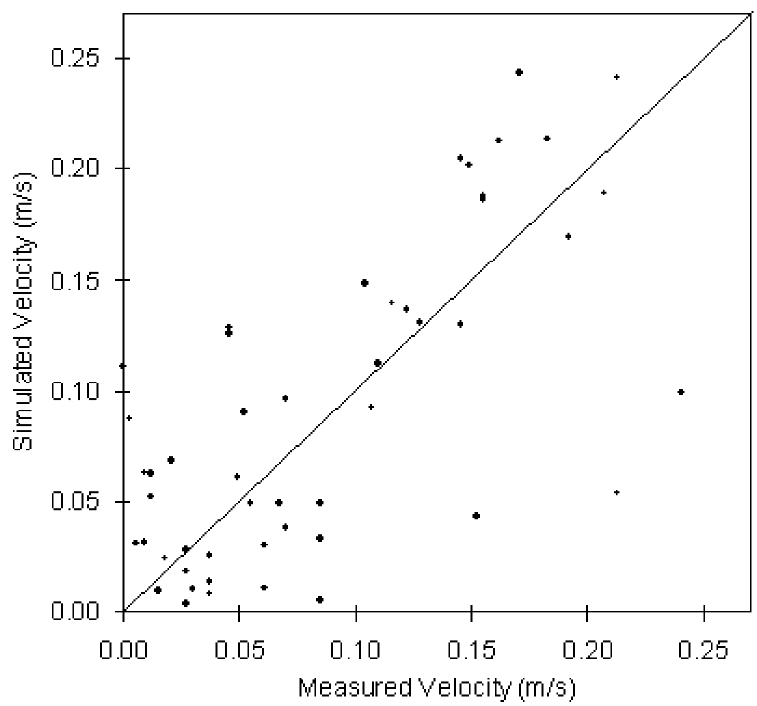
Narrows Study Site
All Validation Velocities



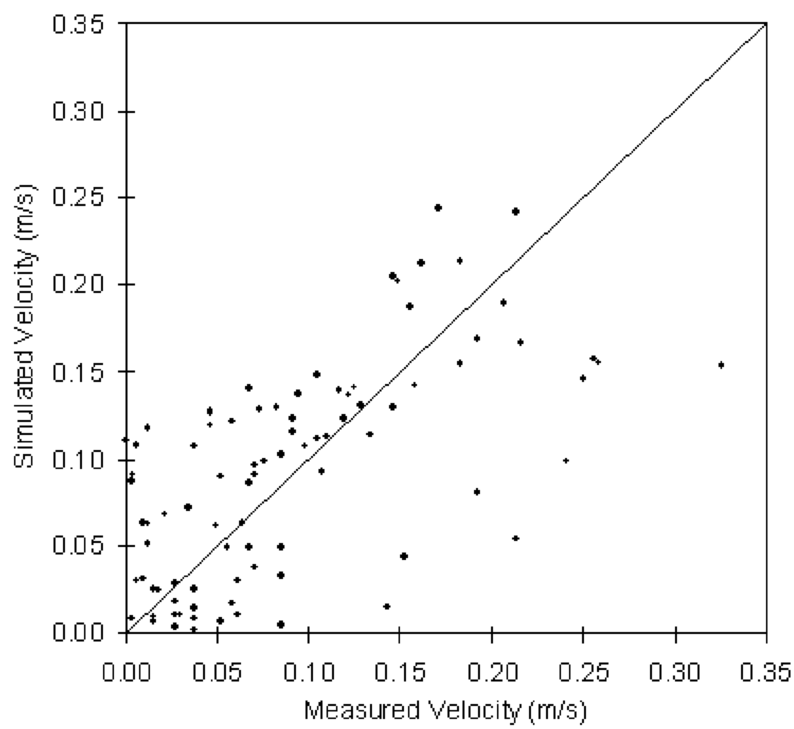

Kanaka Site XS1, Q = 79 cfs
Velocity (m/s)
0.125
0.100
0.075
0.050
0.025
0.000
300
305
310
315
320
Northing (m)
2-D Simulated Velocities
Measured Velocities

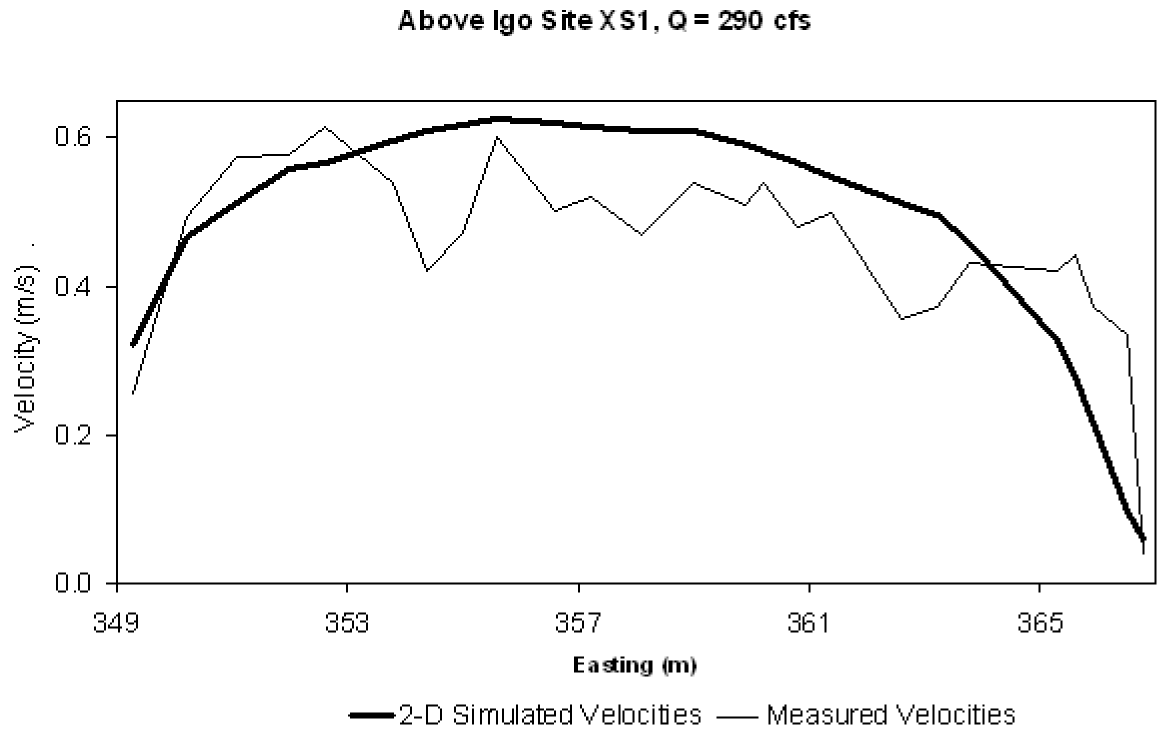

Kanaka Site XS2, Q = 79 cfs
Velocity (m/s)
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
291
293
295
297
299
301
Northing (m)
2-D Simulated Velocities
Measured Velocities

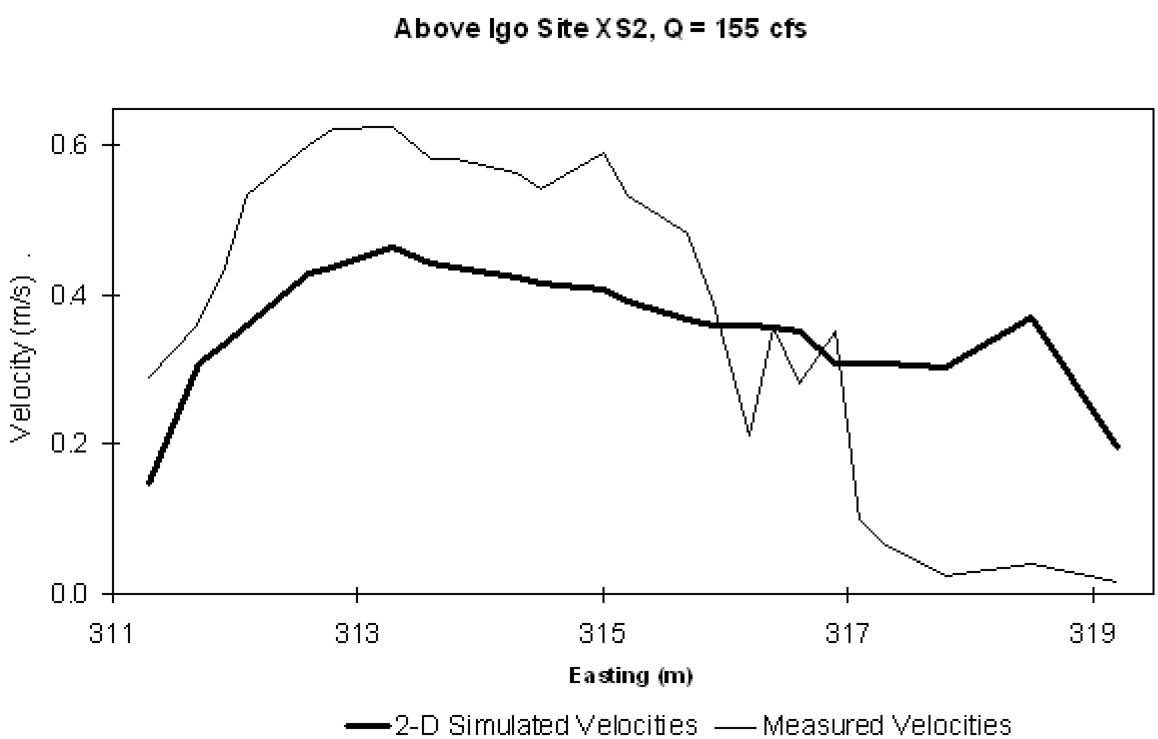
Kanaka Study Site
Between Transect Velocities

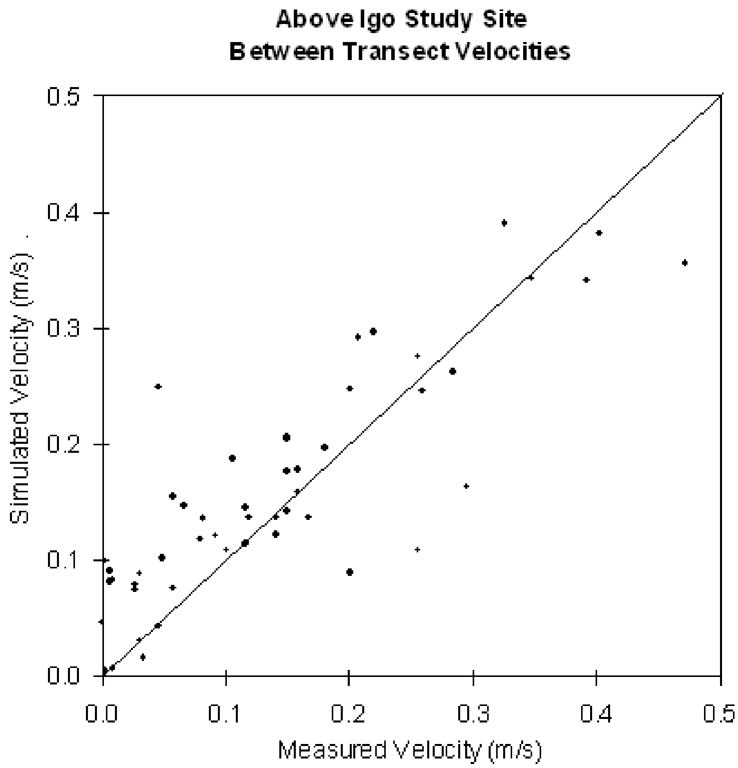


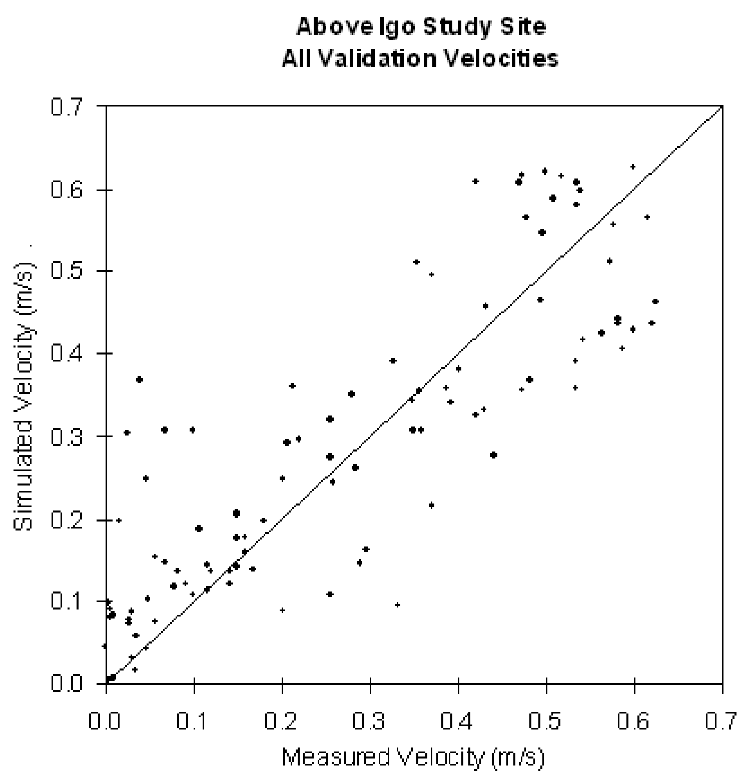
Kanaka Study Site
All Validation Velocities




Above Igo Site XS1, Q = 290 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
349
353
357
361
365
Easting (m)
2-D Simulated Velocities
Measured Velocities

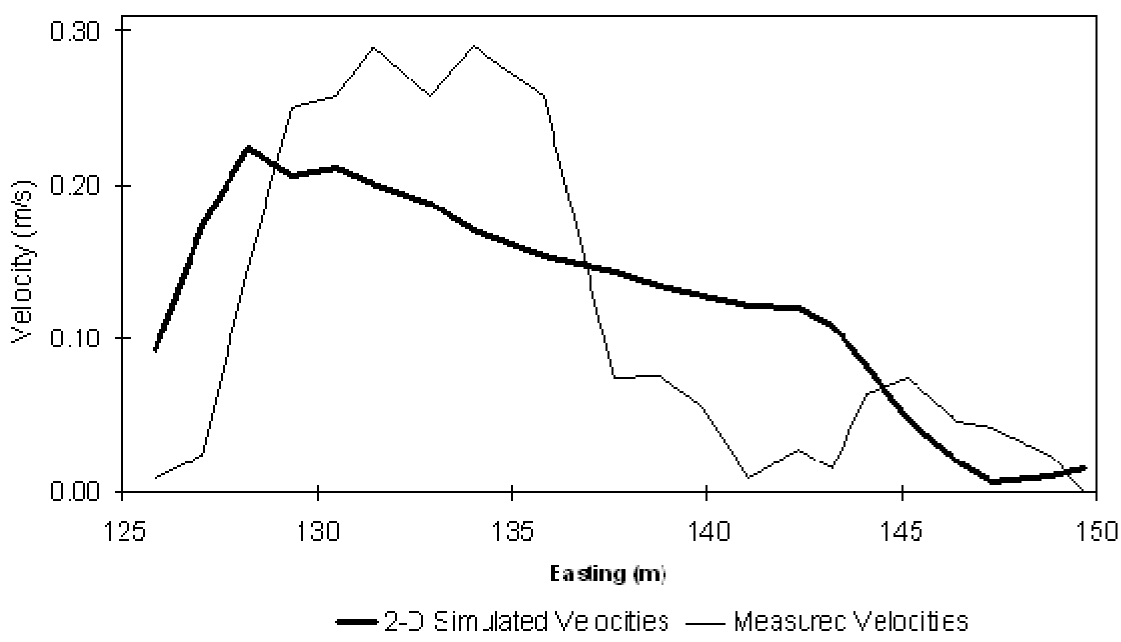

Above Igo Site XS2, Q = 155 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
311
313
315
317
319
Easting (m)
2-D Simulated Velocities
Measured Velocities

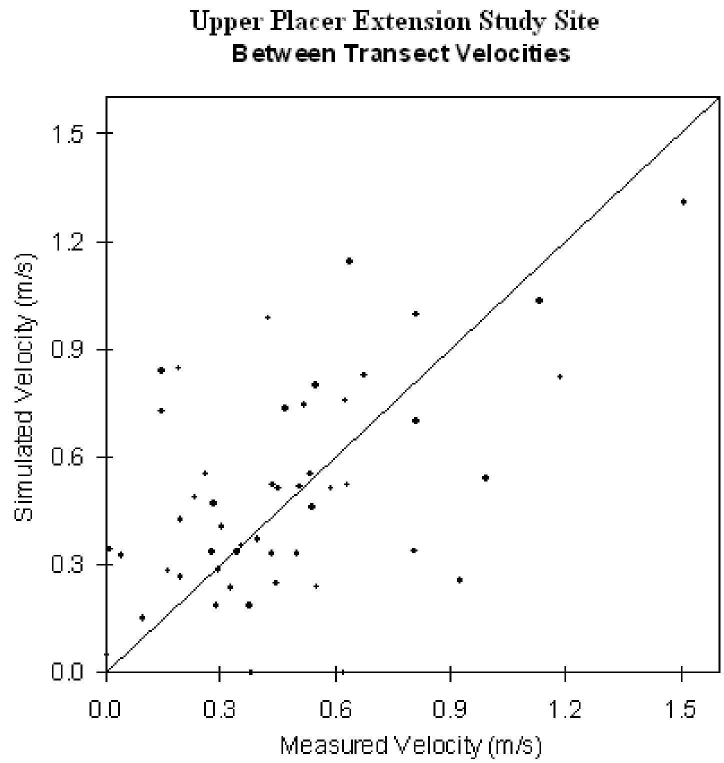

Above Igo Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.1
0.2
0.3
0.4
0.5

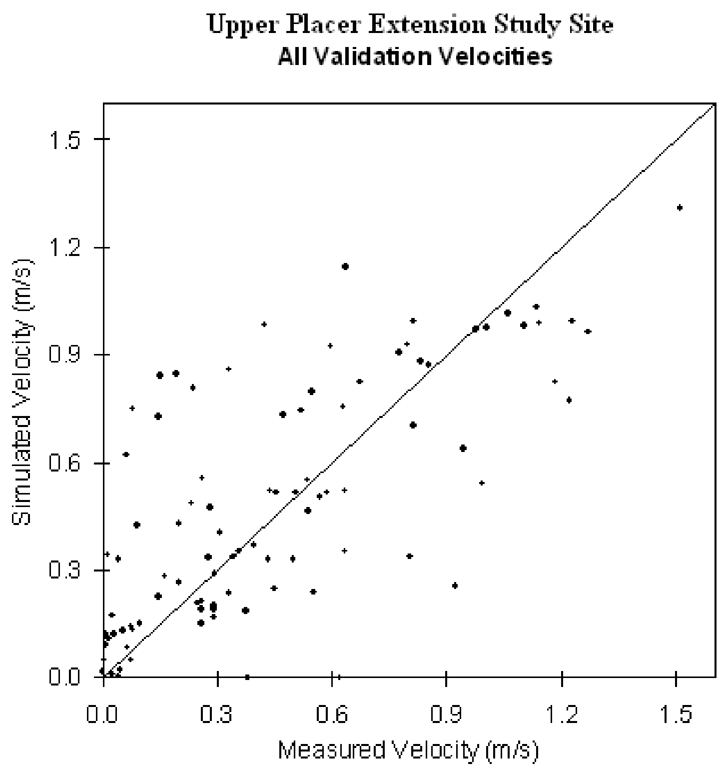

Above Igo Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Upper Placer Extension Site XS 1, Q = 251 cfs

Upper Placer Extension Study Site XS 2, Q = 155 cfs




Upper Placer Extension Study Site
Between Transect Velocities
1.5
1.2
0.9
0.6
0.3
0.0
Simulated Velocity (m/s)
0.0
0.3
0.6
0.9
1.2
1.5
Measured Velocity (m/s)


Upper Placer Extension Study Site
All Validation Velocities
1.5
1.2
0.9
0.6
0.3
0.0
Simulated Velocity (m/s)
0.0
0.3
0.6
0.9
1.2
1.5
Measured Velocity (m/s)

APPENDIX I
SIMULATION STATISTICS

Dog Gulch

Flow (cfs)	Net Q	Sol	Max F
50	0.14%	< .000001	1.22
75	0.10%	.000001	1.36
100	0.04%	< .000001	1.32
125	0.09%	.000003	2.74
150	0.02%	.000005	2.35
175	0.04%	< .000001	1.71
200	0.70%	< .000001	1.47
225	0.14%	< .000001	4.12
250	0.06%	< .000001	2.85
275	0.05%	< .000001	2.25
300	0.04%	< .000001	8.92
350	0.04%	< .000001	2.55
400	0.01%	< .000001	3.79
450	0.00%	< .000001	2.72
500	0.01%	< .000001	4.15
550	0.00%	< .000001	4.60
600	0.02%	.000002	7.17
650	0.02%	< .000001	8.74
700	0.01%	< .000001	5.03
750	0.02%	.000007	4.78
800	0.01%	< .000001	4.09
850	0.02%	< .000001	7.68
900	0.04%	< .000001	7.16

Upper Canyon

Flow (cfs)	Net Q	Sol	Max F
50	1.43%	< .000001	0.90
75	0.95%	.000008	1.19
100	0.71%	.000005	1.03
125	0.57%	.000004	1.00
150	0.48%	.000005	0.97
175	0.40%	.000006	1.02
200	0.53%	.000003	1.03
225	0.47%	.000004	1.13
250	0.42%	.000007	0.98
275	0.26%	.000002	1.10
300	0.24%	.000007	1.27
350	0.20%	.000001	1.32
400	0.18%	.000006	1.75
450	0.16%	.000002	2.05
500	0.14%	.000008	1.43
550	0.13%	.000002	1.46
600	0.12%	.000002	1.72
650	0.11%	.000004	1.48
700	0.15%	< .000001	1.53
750	0.14%	.000002	2.13
800	0.13%	.000002	2.14
850	0.12%	< .000001	2.11
900	0.16%	.000002	2.07

Narrows

Flow (cfs)	Net Q	Sol	Max F
50	1.43%	< .000001	8.32
75	0.95%	< .000001	8.28
100	1.07%	.000002	10.61
125	1.14%	.000002	14.81
150	1.19%	< .000001	32.74
175	0.80%	< .000001	13.40
200	0.88%	< .000001	26.76
225	0.16%	< .000001	10.01
250	0.00%	< .000001	4.99
275	0.00%	< .000001	2.97
300	0.24%	< .000001	1.57
350	0.40%	< .000001	1.62
400	0.35%	< .000001	1.95
450	0.47%	< .000001	1.93
500	0.14%	< .000001	1.29
550	0.00%	< .000001	1.11
600	0.12%	< .000001	1.07
650	0.22%	< .000001	1.61
700	0.30%	< .000001	2.39
750	0.38%	< .000001	1.86
800	0.04%	< .000001	2.91
850	0.08%	< .000001	1.47
900	0.20%	< .000001	1.32

Kanaka

Flow (cfs)	Net Q	Sol	Max F
50	5.00%	.000001	6.39
75	0.19%	< .000001	0.57
100	0.11%	< .000001	0.41
125	0.14%	< .000001	0.57
150	0.10%	< .000001	0.53
175	0.10%	< .000001	0.90
200	0.09%	< .000001	2.49
225	0.08%	< .000001	1.07
250	0.07%	< .000001	2.19
275	0.05%	< .000001	2.49
300	0.05%	< .000001	1.09
350	0.06%	< .000001	0.86
400	0.09%	< .000001	0.95
450	0.08%	< .000001	1.15
500	0.07%	< .000001	1.15
550	0.06%	< .000001	1.82
600	0.12%	< .000001	1.40
650	0.11%	< .000001	1.31
700	0.06%	< .000001	1.49
750	0.07%	< .000001	1.90
800	0.09%	< .000001	5.62
850	0.12%	< .000001	3.87
900	0.12%	< .000001	3.22

Above Igo

Flow (cfs)	Net Q	Sol	Max F
50	1.43%	< .000001	0.49
75	1.43%	< .000001	0.41
100	1.07%	< .000001	0.49
125	0.86%	< .000001	0.40
150	0.95%	< .000001	0.40
175	1.20%	< .000001	0.41
200	1.05%	< .000001	0.42
225	0.78%	< .000001	0.42
250	0.56%	< .000001	0.50
275	0.26%	< .000001	0.76
300	0.00%	< .000001	1.10
350	0.20%	< .000001	0.85
400	0.35%	.000001	1.07
450	0.39%	< .000001	5.48
500	0.21%	.000002	1.94
550	0.13%	< .000001	1.35
600	0.00%	.000003	1.10
650	0.11%	.000006	0.96
700	0.15%	< .000001	0.88
750	0.19%	< .000001	0.81
800	0.18%	.000004	0.78
850	0.08%	.000006	0.87
900	0.00%	.000009	1.10

Upper Placer Extension

Flow (cfs)	Net Q	Sol	Max F
50	2.50%	< .000001	2.53
75	0.95%	< .000001	2.84
100	0.64%	< .000001	2.05
125	0.29%	< .000001	3.37
150	0.19%	< .000001	3.39
175	0.20%	< .000001	3.11
200	0.18%	< .000001	2.88
225	0.17%	< .000001	2.71
250	0.14%	< .000001	2.80
275	0.10%	< .000001	3.21
300	0.15%	< .000001	4.75
350	0.31%	< .000001	4.53
400	0.26%	.000002	6.17
450	0.18%	< .000001	7.29
500	0.11%	< .000001	8.24
550	0.10%	< .000001	6.86
600	0.02%	< .000001	6.95
650	0.04%	< .000001	10.50
700	0.01%	< .000001	9.49
750	0.02%	.000001	9.44
800	0.40%	.000003	7.00
850	0.04%	< .000001	6.42
900	0.04%	< .000001	6.09

APPENDIX J
HABITAT SUITABILITY CRITERIA

Spring-run Chinook Salmon Fry Rearing

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value
0.00	1.00	0	0.00	0	0.00
0.10	0.84	0.1	1.00	0.1	0.19
0.20	0.70	0.2	0.95	1	0.19
0.30	0.58	0.3	0.89	2	0.19
0.40	0.48	0.4	0.84	3	1.00
0.50	0.40	0.5	0.78	3.7	1.00
0.60	0.33	0.6	0.73	4	0.19
0.70	0.28	0.7	0.68	4.7	1.00
0.80	0.24	0.8	0.63	5	0.19
0.90	0.20	0.9	0.58	5.7	0.19
1.00	0.18	1	0.53	7	0.19
1.10	0.16	1.1	0.48	8	1.00
1.20	0.14	1.2	0.44	9	0.19
1.30	0.13	1.3	0.40	9.7	0.19
1.40	0.12	1.4	0.36	10	0.19
1.50	0.11	1.5	0.33	11	0.00
1.60	0.10	1.6	0.30	100	0.00
3.60	0.10	1.7	0.27		
3.61	0.00	1.8	0.24		
100	0.00	1.9	0.21		
		2	0.19		
		2.1	0.17		
		2.2	0.15		
		2.3	0.14		
		2.4	0.12		
		2.5	0.11		
		2.6	0.10		
		2.7	0.09		
		2.8	0.08		
		2.9	0.07		
		3	0.06		
		3.1	0.05		
		3.2	0.05		
		3.3	0.04		
		3.4	0.04		
		3.5	0.03		
		3.7	0.03		
		3.8	0.02		
		4	0.02		
		4.1	0.00		
		100	0.00		

Spring-run Chinook Salmon/Steelhead/Rainbow Trout Juvenile Rearing

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.03
0.80	1.00	0.2	0.00	0.1	0.40	7.95	1.00
0.90	0.99	0.3	0.36	1	1.00	100	1.00
1.10	0.99	0.6	0.45	2	0.40		
1.20	0.98	0.7	0.49	3	0.40		
1.40	0.98	0.9	0.55	3.7	1.00		
1.50	0.97	1.0	0.59	4	1.00		
1.60	0.96	1.2	0.65	4.7	1.00		
1.70	0.96	1.3	0.69	5	1.00		
1.80	0.95	1.4	0.72	5.7	0.40		
1.90	0.94	1.7	0.81	7	1.00		
2.00	0.93	1.9	0.87	8	1.00		
2.10	0.92	2.3	0.95	9	0.40		
2.20	0.91	2.4	0.96	9.7	0.40		
2.30	0.90	2.5	0.98	10	0.40		
2.40	0.88	2.6	0.99	11	0.00		
2.50	0.87	2.7	0.99	100	0.00		
2.60	0.85	2.8	1.00				
2.70	0.84	3.0	1.00				
3.50	0.68	3.1	0.99				
3.60	0.65	3.2	0.99				
3.80	0.61	3.4	0.97				
3.90	0.58	3.9	0.87				
4.00	0.56	4.1	0.81				
4.10	0.53	4.2	0.79				
4.20	0.51	4.3	0.76				
4.40	0.45	4.4	0.72				
4.50	0.43	4.6	0.66				
4.60	0.40	4.7	0.62				
4.70	0.38	4.8	0.59				
4.80	0.36	4.9	0.56				
4.90	0.33	5.0	0.52				
5.40	0.23	5.2	0.46				
5.50	0.21	5.3	0.42				
5.53	0.20	5.5	0.36				
5.54	0.00	5.6	0.00				
100	0.00	100	0.00				

Steelhead/Rainbow Trout Fry Rearing

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0.00	1.00	0	0.00	0	0.00	0.00	0.59
0.10	0.84	0.1	1.00	0.1	0.14	6.77	1.00
0.20	0.70	0.2	0.95	1	0.14	100	1.00
0.30	0.58	0.3	0.89	2	0.14		
0.40	0.48	0.4	0.84	3	0.66		
0.50	0.40	0.5	0.78	3.7	1.00		
0.60	0.33	0.6	0.73	4	0.66		
0.70	0.28	0.7	0.68	4.7	1.00		
0.80	0.24	0.8	0.63	5	1.00		
0.90	0.20	0.9	0.58	5.7	1.00		
1.00	0.18	1	0.53	7	0.66		
1.10	0.16	1.1	0.48	8	1.00		
1.20	0.14	1.2	0.44	9	0.66		
1.30	0.13	1.3	0.40	9.7	0.66		
1.40	0.12	1.4	0.36	10	0.14		
1.50	0.11	1.5	0.33	11	0.00		
1.60	0.10	1.6	0.30	100	0.00		
3.60	0.10	1.7	0.27				
3.61	0.00	1.8	0.24				
100	0.00	1.9	0.21				
		2.2	0.15				
		2.3	0.14				
		2.4	0.12				
		3.1	0.05				
		3.2	0.05				
		3.3	0.04				
		3.4	0.04				
		3.5	0.03				
		3.7	0.03				
		3.8	0.02				
		4	0.02				
		4.1	0.00				
		100	0.00				

APPENDIX K
HABITAT MODELING RESULTS

Dog Gulch Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	3,990	2,318	2,266
75	3,919	2,456	2,968
100	4,198	2,497	3,570
125	4,364	2,535	4,111
150	4,363	2,524	4,581
175	4,417	2,495	5,017
200	4,026	2,185	5,363
225	4,787	2,513	5,618
250	4,829	6,405	6,004
275	4,861	2,563	7,179
300	4,927	2,611	6,229
350	4,929	2,613	6,529
400	4,858	2,640	6,771
450	4,977	2,632	6,943
500	5,312	2,735	7,081
550	5,540	2,890	7,178
600	5,807	3,042	7,266
650	5,867	3,180	17,730
700	5,995	3,273	7,274
750	6,018	3,368	7,255
800	5,393	2,970	7,329
850	5,383	3,033	7,297
900	5,409	3,007	7,300

Spawning Site 4 WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	2,504	1,872	1,450
75	2,434	1,856	1,931
100	2,461	1,774	2,334
125	2,510	1,745	2,691
150	2,444	1,727	3,040
175	2,553	1,772	3,415
200	2,617	1,807	3,699
225	2,591	1,815	3,959
250	2,594	1,801	4,189
275	2,725	1,777	4,391
300	2,835	1,846	4,579
350	3,028	1,911	4,914
400	3,289	2,065	5,184
450	3,770	2,319	5,399
500	4,171	2,452	6,003
550	4,415	2,654	6,181
600	4,545	2,801	6,358
650	4,334	2,682	6,518
700	4,368	2,708	6,609
750	4,428	2,697	6,693
800	4,340	2,767	6,754
850	4,364	2,763	6,817
900	4,284	1,872	6,878

Peltier Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	4,498	2,872	2,959
75	4,167	2,737	3,897
100	4,317	2,777	4,655
125	4,730	3,070	5,306
150	4,956	3,227	5,897
175	5,176	3,228	6,484
200	5,785	3,462	6,934
225	5,818	3,746	7,359
250	5,917	3,731	7,732
275	6,239	3,854	8,055
300	6,557	3,996	8,376
350	6,948	4,428	8,858
400	7,229	4,433	9,199
450	7,573	4,852	9,481
500	7,441	4,744	9,711
550	7,665	4,695	9,901
600	8,017	4,939	10,067
650	7,808	5,037	10,191
700	7,355	4,842	10,301
750	7,500	4,688	10,402
800	7,286	4,778	10,472
850	7,225	4,625	10,491
900	7,333	4,615	10,518

Need Camp Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	2,986	1,853	1,802
75	2,639	1,730	2,395
100	2,770	1,561	2,939
125	3,143	1,670	3,428
150	3,464	1,932	3,918
175	3,964	2,188	4,420
200	4,205	2,373	4,813
225	4,526	2,448	5,179
250	4,703	2,587	5,534
275	4,809	2,715	5,899
300	4,915	3,105	6,239
350	5,508	2,910	6,856
400	6,295	3,126	7,431
450	7,533	4,135	8,016
500	8,850	4,761	8,567
550	10,038	5,516	9,041
600	11,912	5,899	9,524
650	12,399	6,607	9,993
700	11,920	6,717	10,464
750	11,298	6,676	10,859
800	10,402	6,295	11,273
850	9,369	5,895	11,595
900	8,417	5,495	11,910

Upper Canyon Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	451	324	523
75	469	346	712
100	418	323	854
125	386	289	963
150	405	300	1,051
175	377	299	1,127
200	357	274	1,186
225	355	256	1,219
250	387	251	1,251
275	415	287	1,267
300	398	311	1,277
350	375	289	1,276
400	356	268	1,261
450	493	298	1,226
500	542	371	1,187
550	615	398	1,167
600	763	415	1,128
650	803	526	1,098
700	778	525	1,070
750	806	521	1,035
800	927	515	1,007
850	1,038	622	989
900	1,187	688	986

Indian Rhubarb Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	116	78	163
75	119	76	212
100	117	71	256
125	116	75	294
150	113	68	326
175	122	71	358
200	133	83	382
225	136	84	403
250	129	82	403
275	125	84	433
300	119	76	443
350	114	77	449
400	117	79	449
450	113	78	443
500	104	75	431
550	102	68	416
600	108	68	401
650	116	72	382
700	130	80	358
750	156	91	328
800	158	104	296
850	143	106	276
900	117	81	256

Narrows Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	123	89	604
75	133	95	587
100	145	110	523
125	155	116	457
150	167	119	408
175	212	134	383
200	212	154	378
225	211	151	368
250	231	150	356
275	242	168	338
300	258	174	322
350	269	187	306
400	257	181	301
450	238	171	291
500	229	159	291
550	238	159	292
600	215	153	293
650	203	141	295
700	211	139	297
750	200	141	305
800	182	130	313
850	165	123	319
900	152	111	324

Kanaka Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	293	189	292
75	382	254	155
100	374	252	168
125	374	241	178
150	400	250	187
175	385	251	199
200	380	244	209
225	390	244	220
250	395	249	228
275	392	251	236
300	392	249	245
350	405	254	262
400	405	258	280
450	394	256	297
500	408	258	315
550	410	269	332
600	386	262	352
650	399	255	374
700	393	264	393
750	398	259	410
800	386	263	428
850	375	260	441
900	372	251	452

Above Igo Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	1,655	1,299	789
75	1,663	1,245	945
100	1,626	1,222	1,081
125	1,572	1,144	1,205
150	1,519	1,103	1,314
175	1,457	1,046	1,431
200	1,436	1,001	1,515
225	1,466	981	1,591
250	1,494	987	1,665
275	1,518	987	1,732
300	1,671	1,011	1,781
350	1,968	1,199	1,881
400	2,144	1,310	1,960
450	2,294	1,353	2,027
500	2,410	1,441	2,095
550	2,578	1,478	2,138
600	2,534	1,563	2,189
650	2,414	1,539	2,225
700	2,249	1,467	2,272
750	2,139	1,381	2,309
800	2,080	1,327	2,355
850	2,128	1,304	2,393
900	2,201	1,312	2,434

Upper Placer Extension Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	2,246	1,251	1,793
75	2,362	1,330	2,338
100	2,455	1,395	2,802
125	2,456	1,438	3,213
150	2,527	1,448	3,577
175	2,540	1,493	3,939
200	2,566	1,495	4,210
225	2,610	1,525	4,454
250	2,911	1,644	4,663
275	3,268	1,772	4,878
300	3,722	2,032	5,090
350	3,969	2,338	5,470
400	4,073	2,414	5,749
450	4,140	2,471	5,953
500	4,152	2,499	6,115
550	4,081	2,482	6,232
600	4,133	2,443	6,303
650	4,235	2,528	6,356
700	4,366	2,605	6,380
750	4,435	2,672	6,362
800	4,526	2,746	6,301
850	4,937	3,079	6,209
900	5,076	3,108	6,214

Lower Placer Site WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	165	88	318
75	141	93	399
100	121	83	461
125	122	78	509
150	114	79	551
175	109	76	591
200	118	73	619
225	117	82	656
250	111	79	684
275	144	74	707
300	188	88	711
350	183	133	708
400	160	117	695
450	196	107	683
500	226	146	672
550	244	129	678
600	288	171	683
650	278	165	683
700	255	151	662
750	263	160	657
800	239	156	621
850	221	134	611
900	235	125	602

Upper Alluvial Segment WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	111,496	69,405	41,405
75	105,592	68,867	54,279
100	107,039	67,107	65,641
125	112,173	70,706	76,214
150	114,039	72,571	86,324
175	118,857	73,787	96,403
200	121,064	73,936	104,687
225	129,437	81,008	111,553
250	131,840	81,542	119,125
275	136,603	83,088	124,187
300	140,071	87,584	130,221
350	144,634	88,916	141,343
400	146,540	88,073	152,816
450	155,367	94,518	163,383
500	161,976	96,337	174,861
550	173,547	101,880	183,485
600	188,689	108,040	190,954
650	188,431	112,254	197,707
700	181,605	112,639	203,598
750	179,584	111,018	208,808
800	169,701	107,855	214,871
850	164,082	104,947	218,808
900	157,886	102,170	222,601

Canyon Segment WUA (ft^2)

Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	66,475	44,378	54,914
75	68,700	45,607	67,067
100	67,915	45,096	78,942
125	66,400	43,888	89,087
150	66,973	43,499	97,980
175	65,761	43,120	106,763
200	65,873	42,101	113,358
225	67,663	42,180	119,145
250	71,629	43,741	123,982
275	77,850	45,863	128,942
300	86,557	50,188	132,951
350	93,609	57,337	139,729
400	96,938	59,321	144,433
450	102,656	61,180	147,453
500	106,005	64,624	149,726
550	109,174	65,393	151,456
600	112,289	66,998	152,296
650	113,402	69,604	152,743
700	112,727	69,955	152,587
750	112,707	69,885	151,682
800	114,554	70,116	149,932
850	121,330	75,246	148,278
900	126,192	76,214	148,226