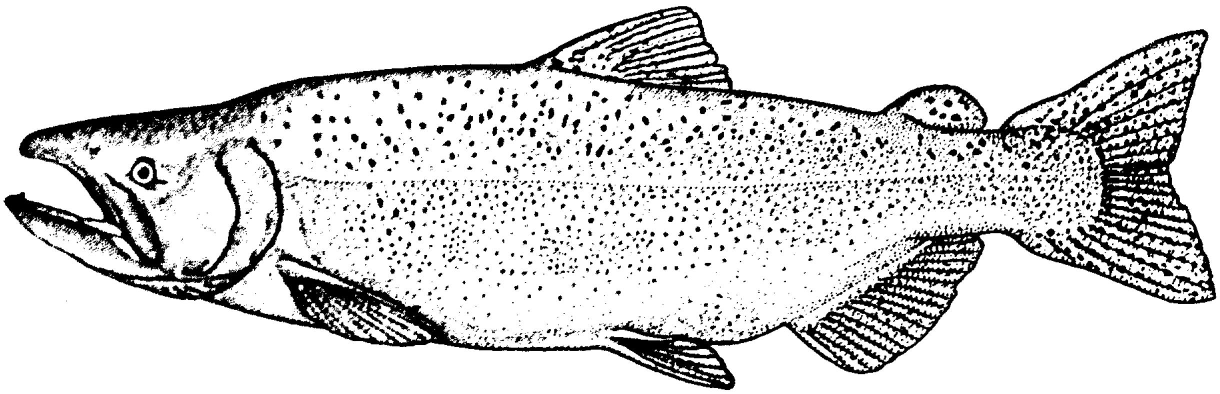
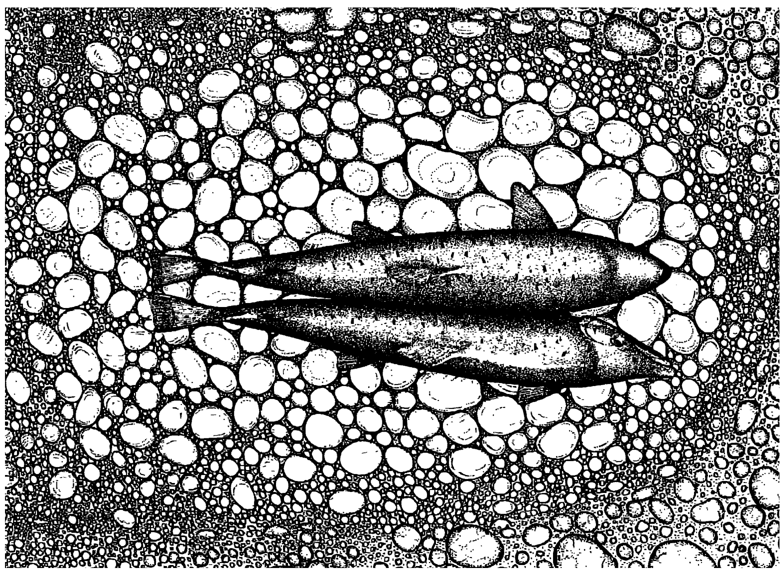
FLOW-HABITAT RELATIONSHIPS FOR SPRING-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING IN CLEAR CREEK BETWEEN WHISKEYTOWN DAM AND CLEAR CREEK ROAD





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CVPIA INSTREAM FLOW INVESTIGATIONS CLEAR CREEK SPRING-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING

PREFACE

The following is the final report for the U. S. Fish and Wildlife Service's investigations on anadromous salmonid spawning habitat in Clear Creek between Whiskeytown Dam and Clear Creek Road. These investigations are part of the Central Valley Project Improvement Act (CVPIA) Instream Flow Investigations, a 6-year 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 (CDFG). The purpose of these investigations is to provide scientific data to the U. S. Fish and Wildlife Service Central Valley Project Improvement Act Program to assist in developing such recommendations for Central Valley rivers.

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

ACKNOWLEDGMENTS

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ABSTRACT

Flow-habitat relationships were derived for spring-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek 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 three sites each in the Upper Alluvial and Canyon segments, which were among those which received the heaviest use by spawning spring-run Chinook salmon and steelhead/rainbow trout. Bed topography was collected for these sites using a total station. Additional data was collected to develop stage-discharge relationships at the upstream and downstream end of the sites as an input to RIVER2D. Velocities measured in the site were used to validate the velocity predictions of RIVER2D. The raw topography data was 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 and substrate measurements collected on 180 spring-run Chinook salmon redds and 212 steelhead/rainbow trout redds. The horizontal location of a subset of these redds, located in the six study sites, was measured with a total station to use in biological validation of the habitat models. Logistic regression, along with a technique to adjust spawning depth habitat utilization curves to account for low availability of deep waters with suitable velocities and substrates (Gard 1998), was used to develop the depth and velocity HSC. Substrate HSC were developed based on the relative frequency of redds with different substrate codes. Biological validation was accomplished by testing, with a Mann-Whitney U test, whether the combined suitability predicted by RIVER2D was higher at redd locations versus at locations where redds were absent. The optimum depths for spring-run Chinook salmon and steelhead/rainbow trout were, respectively, 6.0 to 6.2 feet and 1.4 to 1.5 feet, while optimum velocities were 2.9 to 3.1 ft/s and 1.6 to 1.7 ft/s and optimum substrates were 2-4 inches and 1-2 inches. The flow with the maximum habitat varied by segment, and ranged from 650 to 900 cfs for spring-run Chinook salmon and 350 to 600 cfs for steelhead/rainbow trout.

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. For Clear Creek, the Central Valley Project Improvement Act Anadromous 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). The Clear Creek study is a 5-year effort, the goals of which are 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 will be 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]. Spawning habitat study sites for the first phase of the study were selected that encompassed the upper two segments of the creek. The purpose of this study 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 spawning over a range of stream flows.

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 and Bartholow 1996). The decision variable generated by the IFIM is total habitat for each life stage (fry, juvenile and spawning) 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 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.

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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.

The following is a conceptual model of the link between spawning habitat and population change. Changes in flows result in changes in depths and velocities. These changes, in turn, along with the distribution of substrate, alter the amount of habitat area for adult spawning for anadromous salmonids. Changes in the amount of habitat for adult spawning could affect reproductive success through alterations in the amount of redd superposition. These alterations in reproductive success could ultimately result in changes in salmonid populations.

There are a variety of techniques available to evaluate spawning habitat, but they can be broken down into three general categories: 1) habitat modeling; 2) biological response correlations; and 3) demonstration flow assessment (Annear et al. 2002). Biological response correlations can be used to evaluate spawning habitat by examining the degree of redd superposition at different flows (Snider et al. 1996). 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 for intermediate levels of spawning – at low spawning levels, there will not be any redd superposition even at low habitat levels, while at high spawning levels, the amount of superposition cannot be determined because individual redds can no longer be identified; 4) the need to assume a linear relationship between superposition and flow between each observed flow; and 5) 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. Based on the above discussion, we concluded that habitat modeling was the best technique for evaluating anadromous salmonid spawning habitat in Clear Creek.

It is well-established in the literature (Rubin et al. 1991, Knapp and Preisler 1999, Parasiewicz 1999, Geist et al. 2000, Guay et al. 2000, Tiffan et al. 2002, McHugh and Budy 2004) that using a logistic regression is preferable to developing criteria with use data only. 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 substrate). One concern with this technique is the effect of availability of habitat on the observed frequency of habitat use. For example, if a substrate size is relatively rare in a stream, fish will be found primarily not using that substrate size simply because of the rarity of that substrate size, rather than because they are selecting areas without that substrate size. Rubin et al. (1991) proposed a modification of the above technique where depth, velocity, and substrate data are collected both in locations where redds are present and in locations where redds are absent, and a logistic regression is used to develop the criteria.

The results of this study are intended to support or revise the flow recommendations above. The range of Clear Creek flows to be evaluated for management generally falls within the range of 50 cfs (the minimum required release from Whiskeytown Dam) to 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 to be evaluated for management. The assumptions of this study are: 1) that physical habitat is the limiting factor for salmonid populations in Clear Creek; 2) that spawning habitat quality can be characterized by depth, velocity and substrate; 3) that the depths and velocities present during habitat suitability index (HSI) data collection were the same as when the redds were constructed; 4) that the six study sites are representative of anadromous salmonid spawning habitat in Clear Creek between Whiskeytown Dam and Clear Creek Bridge; 5) that the selected unoccupied locations were representative for the Upper Alluvial and Canyon Segments for the entire 3 year period for all the spawning data that were collected; and 6) that theoretical equations of physical processes along with a description of stream bathymetry provide sufficient input to simulate velocity distributions through a study site.

METHODS

A 2-dimensional (2-D) hydraulic and habitat model (RIVER2D) was used for this modeling, instead of the Physical Habitat Simulation (PHABSIM[3]) component of IFIM. The 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. The 2-D model avoids problems of transect placement, since the entire site can be modeled. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it 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 n and a velocity adjustment factor. Other advantages of 2-D modeling are that it can explicitly handle complex habitats, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions. 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. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data 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. Bed topography and substrate mapping data can be collected

[3] PHABSIM is the collection of one dimensional hydraulic and habitat models which are used to predict the relationship between physical habitat availability and streamflow over a range of river discharges.

at a very low flow, with the only data needed at high flow being water surface elevations at the top and bottom 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.

Study Segment Selection

Study segments were delineated within the study reach of Clear Creek (Figure 1), based on hydrology and other factors.

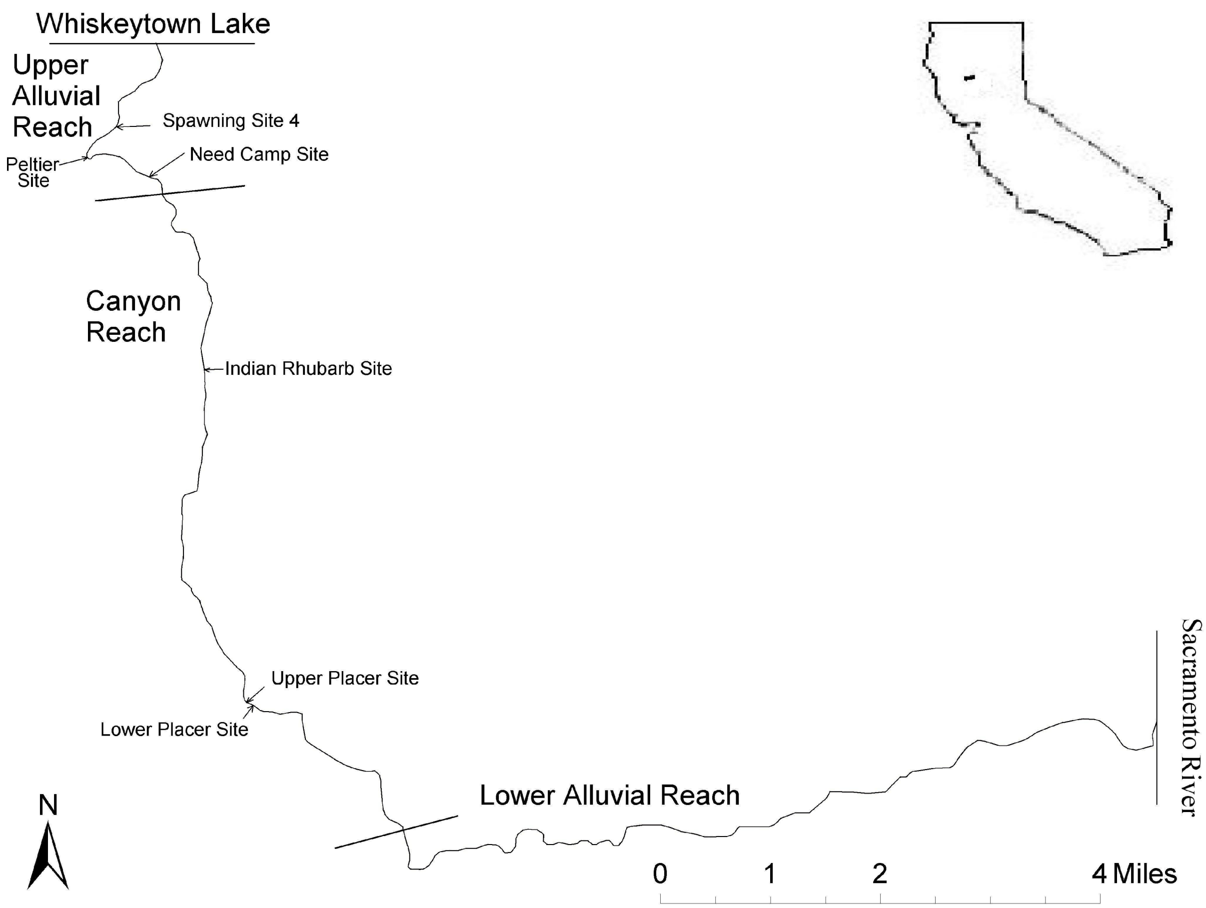
Study Site Selection

Spring-run Chinook salmon redd count data from 2000-2003 and steelhead/rainbow trout redd count data from 2001-2003, collected by the Red Bluff Fish and Wildlife Office, were used to select study sites. These sites were among those that received heaviest use by spawning spring-run Chinook salmon and steelhead/rainbow trout. In October 2003, we conducted a reconnaissance of the selected study sites in the upper two study segments to determine their viability as study sites. Each site was evaluated based on morphological and channel characteristics which facilitate the development of reliable hydraulic models. Also noted were riverbank and floodplain characteristics (e.g., steep, heavily vegetated berms or gradually sloping cobble benches) which might affect our ability to collect the necessary data to build these models. For 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 setup)

The study sites were established in February 2004. The study site boundaries (upstream and downstream) were generally selected to coincide with the upstream and downstream ends of the heavy spawning use areas. A PHABSIM transect was placed at the upstream and downstream end of each study 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 water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. Transect pins (headpins and tailpins) were marked on each river bank above the 900 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.

Figure 1. Clear Creek stream segments and spawning study sites.



Hydraulic and Structural Data Collection

Vertical benchmarks were established at each site to serve as the vertical elevations to which all elevations (streambed and water surface) were referenced. Vertical benchmarks consisted of lag bolts driven into trees and fence posts or painted bedrock points. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site to serve as the horizontal locations to which all horizontal locations (northings and eastings) were referenced.

Hydraulic and structural data collection began in February 2004 and was completed in March 2005. The data collected on the upstream and downstream transect included: 1) water surface elevations (WSELs), measured to the nearest 0.01 foot 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 bank-full discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. In between these transects, the following data were collected: 1) bed elevation; 2) horizontal location (northing and easting, relative to horizontal benchmarks); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the site. Table 1 gives the substrate codes and size classes used in this study, while Table 2 gives the cover codes and types used in this study.

Water surface elevations were measured along both banks and, when possible, in the middle of each transect. The water surface elevations at each transect were then derived by averaging the two-three values, except when the difference in elevation exceeded 0.1 foot. When the difference in water surface elevation between left and right banks exceeded 0.1 foot, the water surface elevation for the side of the river that was considered most representative was used. Mean water column velocities across the transects were collected as follows. Starting at the water's edge, water depths and velocities were made at measured intervals using a wading rod and Marsh-McBirney[R] model 2000 or Price AA velocity meter. The distance intervals of each depth and velocity measurement from the headpin or tailpin were measured using a hand held laser range finder[4]or measuring tape.

We collected the data between the top and bottom transects by obtaining the bed elevation and horizontal location of individual points with a total station, while the cover and substrate were visually assessed at each point. Substrate and cover along the transects were also determined visually. At each change in substrate size class or cover type, the distance from the headpin or tailpin was measured using a hand held laser range finder.

To validate the velocities predicted by the 2-D model, depth, velocities, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. These 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 per site.

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

Table 1. Substrate codes, descriptors and particle sizes.

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1 - 1
1.2	Medium Gravel	1 - 2
1.3	Medium/Large Gravel	1 - 3
2.3	Large Gravel	2 - 3
2.4	Gravel/Cobble	2 - 4
3.4	Small Cobble	3 - 4
3.5	Small Cobble	3 - 5
4.6	Medium Cobble	4 - 6
6.8	Large Cobble	6 - 8
8	Large Cobble	8 - 10
9	Boulder/Bedrock	> 12
10	Large Cobble	10-12

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 transect thalweg. This stage of zero flow downstream of the downstream transect acts as a control on the water surface elevations at the downstream transect. Because the true stage of zero flow is needed to accurately calibrate the water surface elevations on the downstream transect, this stage of zero flow in the thalweg downstream of the downstream transect was surveyed in using differential leveling.

Table 2. Cover coding system.

Cover Category	Cover Code
no cover	0.1
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

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

The upstream and downstream transects were modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. By calibrating the upstream and downstream transects with PHABSIM using the collected calibration 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 upstream transect at the highest simulation flow could also be used to ascertain calibration of the RIVER2D model at the highest simulation flow. Once calibration of the RIVER2D model was achieved 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 when running the RIVER2D model production run files for the simulation flows. The following describes the PHABSIM WSEL calibration process for the upstream and downstream transects.

All data were compiled and checked before entry into PHABSIM data files. A table of substrate ranges/values was created to determine the substrate for each vertical/cell (e.g, if the substrate size class was 2-4 inches 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 ASCII file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton) to get the PHABSIM input file and then translated into RHABSIM[5] files. A separate PHABSIM file was constructed for each study site. All of the measured WSELs were checked to make sure that water was not flowing uphill. The slope for each transect was computed at each measured flow as the difference in 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. A total of four or five WSEL sets at low, medium, and high flows were used. 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 data files. Calibration flows in the data files were the flows calculated from gage readings. The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. 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 each deck 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

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

stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the condition 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 given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot difference between measured and simulated WSELs[6]. *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 difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

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 an monotonic increase with an increase in flows.

RIVER2D Model Construction

After completing the PHABSIM calibration process to arrive at the simulation WSELs that will be used as inputs to the RIVER2D model, the next step is 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 substrate) 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 upsteam transect and within the study site.

[6] The first three criteria are from U.S. Fish and Wildlife Service (1994), while the fourth criterion is our own criterion.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point, while the substrate files contain the horizontal location, bed elevation and substrate code 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 3, with the bed roughness value for each point computed as the sum of the substrate bed roughness value and the cover bed roughness value for the point. The resulting initial bed roughness value for each point was therefore a combined matrix of the substrate and cover roughness values. The bed roughness values for substrate in Table 3 were computed as five times the average particle size[7]. The bed roughness values for cover in Table 3 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 substrate files were exported from the spreadsheet as ASCII files.

A utility program, R2D_BED (Steffler 2001a), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines[8] following longitudinal 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 (Steffler 2001b), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final bed files as an input. The first stage in creating the computational mesh was to define mesh breaklines[9] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and additional nodes were added as needed 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. The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Steffler 2001b). The final step with the R2D_MESH software was to generate the computational (cdg) files.

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[7] 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).

[8] 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 fall on the breaklines (Steffler 2001a).

[9] Mesh breaklines are a feature of the R2D_MESH program which force edges of the computation mesh elements to fall on the mesh breaklines and force the TIN of the computational mesh to linearly interpolate the bed elevation and bed roughness values of mesh nodes between the nodes at the end of each breakline segment (Steffler 2001b). A better fit between the bed and mesh TINs is achieved by having the mesh and bed breaklines coincide.

Table 3. Initial bed roughness values. For points with substrate code 9, we used bed roughnesses of 0.71 and 1.95, respectively, for cover codes 1 and 2. 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.

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	9	0.29
10	1.4	9.7	0.57
		10	3.05

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. 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 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 2001). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than 1[10]. 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 transect[11].

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 the velocities measured on the upstream and downstream transects, and the 50 velocities per site measured in between the upstream and downstream transects.

RIVER2D Model Simulation Flow Runs

After the River2D model was calibrated, the flow and downstream WSEL in the calibrated cdg file were changed to provide initial boundary conditions for simulating hydrodynamics of the sites at the simulation flows. The cdg file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each discharge 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 will usually have a Max F of less than 1.

Habitat Suitability Criteria (HSC) Data Collection

Habitat suitability curves (HSC or HSI Curves) are used within 2-D habitat modeling to translate hydraulic and structural elements of rivers into indices of habitat quality (Bovee 1986). The primary habitat variables which are used to assess physical habitat suitability for spawning Chinook salmon and steelhead/rainbow trout are water depth, velocity, and substrate composition. One HSC set for spring-run Chinook salmon and one HSC set for steelhead/

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[10] This criteria is based on the assumption that flow in low gradient streams is usually subcritical, where the Froude number is less than 1 (Peter Steffler, personal communication).

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

rainbow trout were used in this study. The spring-run Chinook salmon and steelhead/rainbow trout criteria were based on data collected by staff of the Red Bluff Fish and Wildlife Office on spring-run Chinook salmon and steelhead/rainbow trout redds in Clear Creek in 2003-2005.

For habitat suitability criteria data collection, all of the active redds (those not covered with periphyton growth) which could be distinguished were measured. Data were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. Depth was recorded to the nearest 0.1 foot and average water column velocity was recorded to the nearest 0.01 ft/s. Measurements were taken with a wading rod and a Marsh-McBirney® model 2000 velocity meter. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2 inches) at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. The substrate coding system used is shown in Table 1. All data were entered into spreadsheets for analysis and development of HSCs.

Biological Validation Data Collection

Biological validation data were collected to test the hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds were present versus locations where redds were absent. The compound suitability is the product of the depth suitability, the velocity suitability, and the substrate suitability. The collected biovalidation data were the horizontal locations of redds. Depth, velocity, and substrate size as described in the previous section on habitat suitability criteria data collection were also measured. The hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds were present versus locations where redds were absent was statistically tested with a Mann-Whitney U test.

The horizontal location of the redds found in five study sites during the survey for spring-run Chinook salmon redds conducted on October 18 and 21, 2004 was recorded by sighting from the total station to a stadia rod and prism. The horizontal location of the redds found in three study sites during surveys for steelhead/rainbow trout redds conducted on March 3-4, 2004 were also recorded by sighting from the total station to a stadia rod and prism. All data for the spring-run Chinook salmon and steelhead/rainbow trout redds were entered into spreadsheets.

Habitat Suitability Criteria (HSC) Development

The collected redd depth and velocity data must be processed through a series of steps to arrive at the HSC that will be used in the RIVER2D model to predict habitat suitability. Using the spring-run Chinook salmon and steelhead/rainbow trout spawning HSC data that were collected in 2003-2005, we applied a method presented in Rubin et al. (1991) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability). Criteria are developed by using a logistic regression procedure, with presence or absence of redds as the dependent variable and depth and velocity as the independent variables, with all of the data (in both occupied and unoccupied locations) used in the regression. Velocity and depth data were obtained for locations within each site where redds were not found (unoccupied). These data were obtained by running a final River2D cdg file for each site at the average flow for the period leading up to the date the location of extant redds were recorded using a total station and the depth and velocity data were collected. After running the final River2D models for each study site, velocity and depth data at each node within the file were then downloaded. Using a random numbers generator, 300 unoccupied points for larger sites and 50 points for smaller sites were selected that had the following characteristics: 1) were more than three feet from a redd recorded during the 2004 survey; 2) were inundated; 3) were more than three feet from any other point that was selected; and 4) were located in the site, rather than in the upstream extension of the file. For those study sites where zero redds were measured, only the latter three characteristics were applicable to the randomly selected points. We then selected 200 points from the larger sites and used all unoccupied points (approximately 50) for the smaller sites.

We then 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:

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

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 included all of the terms. 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 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 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.

A technique to adjust depth habitat utilization curves for spawning to account for low availability of deep waters with suitable velocity and substrate (Gard 1998) was applied to the steelhead/ rainbow trout HSC data. The technique begins with the construction of multiple sets of HSC, differing only in the suitabilities assigned for optimum depth increments, to determine how the available creek area with suitable velocities and substrates varied with depth. Ranges of suitable velocities and substrates were determined from the velocity and substrate HSC curves, with suitable velocities and substrates defined as those with HSC values greater than 0.5. For substrate, we changed the definition of suitable substrate codes to be substrates with a suitability greater than 0.4. A range of depths is selected, starting at the depth at which the initial depth HSC reached 1.0, through the greatest depth at which there were redds or available habitat. A series of HSC sets are constructed where: 1) all of the sets have the same velocity and substrate HSC curves, with values of 1.0 for the suitable velocity and substrate range with all other velocities and substrates assigned a value of 0.0; and 2) each set has a different depth HSC curve. To develop the depth HSC curves, each HSC set is assigned a different half-foot depth increment within the selected depth range to have an HSC value of 1.0, and the other half-foot depth increments and depths outside of the depth range a value of 0.0 (e.g., 1.5-1.98 foot depth HSC value equal 1.0, < 1.5 foot and >1.98 foot depths HSC value equals 0.0 for a depth increment of 1.5-1.98 feet). Each HSC set is used in RIVER2D with the calibrated RIVER2D file for each study site at which HSC data were collected for that run. The resulting habitat output is used to determine the available river area with suitable velocities and substrates for all half-foot depth increments.

To modify the steelhead/rainbow trout HSC depth curve to account for the low availability of deep water having suitable velocities and substrates, a sequence of linear regressions (Gard 1998) was used to determine the relative rate of decline of use versus availability with increasing depth. Habitat use by spawning steelhead/rainbow trout is defined as the number of redds observed in each depth increment. Availability data were determined using the output of the calibrated hydraulic River2D files for the six spawning habitat modeling sites at which HSC data were collected, while redd data from these six sites were used to assess use. Availability and use are normalized by computing relative availability and use, so that both measures have a maximum value of 1.0. Relative availability and use are calculated by dividing the availability and use for each depth increment by the largest value of availability or use. To produce linearized values of relative availability and use at the midpoints of the depth increments (i.e., 1.74 feet for the 1.5-1.98 feet depth increment), we used linear regressions of relative availability and use versus the midpoints of the depth increments. Linearized use is divided by linearized availability for the range of depths where the regression equations predict positive relative use and availability. The resulting use-availability ratio is standardized so that the maximum ratio is 1.0. To determine the depth at which the depth HSC would reach zero (the depth at which the scaled ratios reach zero), we used a linear regression with the scaled ratios versus the midpoint of the depth increments.

Substrate criteria were developed by: 1) determining the number of redds with each substrate code (Table 1); 2) calculating the proportion of redds with each substrate code (number of redds with each substrate code divided by total number of redds); and 3) calculating the HSI value for each substrate code by dividing the proportion of redds in that substrate code by the proportion of redds with the most frequent substrate code.

Biological Validation

We compared the combined habitat suitability predicted by RIVER2D at each spring-run Chinook salmon redd location in five of the six study sites where data was collected on October 18 and 21, 2004. We also did the same for each steelhead/rainbow trout redd location in three of the six study sites where data was collected on March 3-4, 2004. We ran the RIVER2D cdg files at the average flows for the period from the start of the spawning season up to the end of redd location data collection as described previously in the Habitat Suitability Criteria Development section to determine the combined habitat suitability at individual points for RIVER2D. We used the horizontal location measured for each redd to determine the location of each redd in the RIVER2D sites. We used a random number generator to select locations without redds in each site. Locations were eliminated that: 1) were less than 3 feet from a previously-selected location; 2) were less than 3 feet from a redd location; 3) were not located in the wetted part of the site; and 4) were located in the site, rather than in the upstream extension of the file. We used Mann-Whitney U tests (Zar 1984) to determine whether the compound suitability predicted by RIVER2D was higher at redd locations versus locations where redds were absent.

Habitat Simulation

The final step was to simulate available habitat for each site. A preference curve file was created containing the digitized HSC developed for the Clear Creek spring-run salmon and steelhead/rainbow trout (Appendix H). RIVER2D was used with the final cdg production files, the substrate file and the preference curve file to compute WUA for each site over the desired range of simulation flows for all sites. The process for determining WUA from the HSC was to multiply together the suitability of each of the three variables, and then multiply this product by the area represented by each node. The sum for all of the nodes of this product is the WUA. The WUA values for the sites in each segment were added together and multiplied by the ratio of total redds counted in the segment to number of redds in the modeling sites for that segment to produce the total WUA per segment. The spring-run Chinook salmon and steelhead/rainbow trout multipliers were calculated using redd counts from, respectively, 2000-2005 and 2001-2005.

Sensitivity Analysis

We conducted a sensitivity analysis on the spring-run Chinook salmon depth HSC by comparing the flow-habitat results from the original depth HSC with the flow-habitat results from two alternative depth HSC. For both alternative depth HSC, we used the results of the logistic regression discussed above under HSC development up to the first maximum of the regression. We then applied the Gard (1998) depth correction method to determine the value at which the first alternative depth HSC reached zero. The second alternative depth HSC used the same value as for steelhead where the depth suitability reached zero. We used both alternative depth HSC along with the original spring-run Chinook salmon velocity and substrate HSC in RIVER2D with the final cdg production files and the substrate file to compute WUA for each site over the desired range of simulation flows for all sites. The WUA values for the sites in each segment were added together and multiplied by the ratio of total redds counted in the segment to number of redds in the modeling sites for that segment to produce the total WUA per segment.

RESULTS

Study Segment Selection

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.

Study Site Selection

After reviewing the field reconnaissance notes and considering time and manpower constraints, six study sites (Table 4 and 5) were selected for modeling in Upper Alluvial and Canyon Segments (three sites in each segment). Upper Alluvial Segment: 1) Spawn Area 4; 2) Peltier; and 3) NEED Camp. Canyon Segment: 4) Indian Rhubarb; 5) Upper Placer; and 6) Lower Placer.

Hydraulic and Structural Data Collection

Water surface elevations were measured at all sites at the following flow ranges: 70-71 cfs, 200-255 cfs, 446-454 cfs, and 623-750 cfs. Depth and velocity measurements on the transects were collected at the Spawn Area 4 and Peltier transects at 200 cfs, NEED Camp transects at 213 cfs, Indian Rhubarb transects at 214 cfs, and Upper Placer transects at 251 cfs. Depth and velocity measurements were collected at the Lower Placer downstream transect at 255 cfs and at the

Table 4.Top-ranked mesohabitat units for spring-run Chinook salmon spawning based on 2000-2003 redd survey data.

Site Name	Stream Segment	2000	2001	2002	2003
Spawn Area 4	Upper Alluvial	0	0	4	0
Peltier	Upper Alluvial	0	1	9	2
NEED Camp	Upper Alluvial	2	0	17	2
Indian Rhubarb	Canyon	0	0	5	3
Upper Placer	Canyon	0	3	2	0
Lower Placer	Canyon	0	0	2	1

Table 5. Top-ranked mesohabitat units for steelhead/rainbow trout spawning based on 2001-2003 redd survey data. Steelhead/rainbow trout spawn primarily in the Upper Alluvial Segment.

Site Name	Stream Segment	2001	2002	2003
Spawn Area 4	Upper Alluvial	5	7	7
Peltier	Upper Alluvial	4	24	25
NEED Camp	Upper Alluvial	2	5	2
Indian Rhubarb	Canyon	0	0	1
Upper Placer	Canyon	0	1	0
Lower Placer	Canyon	0	0	0

upstream transect at 253 cfs. The number and density of points collected for each site are given in Table 6. Validation velocities were collected at a flow range of 200-300 cfs. The exception was Indian Rhubarb, where a portion of the validation velocities were measured at a flow of 71 cfs.

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

No problems with water flowing uphill were found for any of the six study sites. A total of four WSEL sets at low, medium, and high flows were used, except for the Indian Rhubarb downstream transect, where five sets of WSELs were used. Calibration flows (the initial creek discharge values from Whiskeytown Dam for Spawn Area 4 and Peltier sites, combined Whiskeytown Dam and Page-Boulder Creek gage discharge values for NEED Camp and Indian Rhubarb, and IGO gage discharge values for Upper and Lower Placer) in the PHABSIM data

Table 6. Number and density of data points collected for each site.

Site Name	Number of Points: Points on Transects	Number of Points: Points Between Transects Collected with Total Station	Density of Points (points/100 m^2)
Spawn Area 4	62	624	14.2
Peltier	76	2189	17.3
NEED Camp	68	952	19.7
Indian Rhubarb	57	128	48.1
Upper Placer	76	124	47.5
Lower Placer	54	232	32.9

files and the SZFs used for each transect are given in Appendix A. For a majority of the transects, *IFG4* met the criteria described in the methods for *IFG4* (Appendix A). In the cases of the Peltier and Indian Rhubarb downstream transects, we needed to simulate low and high flows with different sets of calibration WSELs (Appendix A) to meet the *IFG4* criteria. For the Indian Rhubarb downstream transect, where we had measured five sets of WSELs, *IFG4* could be run for the low flows using the three lowest calibration WSELs, and run for high flows using the three highest calibration WSELs. For the Peltier downstream transect, where we had measured only four sets of WSELs, we were forced to run *IFG4* for the low flows using the three lowest calibration WSELs and for the high flows using the three highest WSELs. However, using *IFG4* for the three highest WSELs did not meet the measured-simulated WSEL criterion for the 446 cfs calibration flow with a simulated WSEL value that differed from the measured by 0.11. *MANSQ* worked successfully for the two transects where it was used, meeting the criteria described in the methods for *MANSQ* (Appendix A). *WSP* worked successfully for the remaining transect, meeting the criteria described in the methods for *WSP*. None of the transects deviated significantly from the expected pattern of VAFs (Appendix B). Minor deviations in the expected pattern were observed with the Peltier and Upper Placer downstream transects. VAF values (ranging from 0.34 to 2.52) were all within an acceptable range for all transects.

RIVER2D Model Construction

The bed topography of the sites is shown in Appendix C. The finite element computational mesh (TIN) for each of the study sites are shown in Appendix D. As shown in Appendix E, the meshes for all sites had QI values of at least 0.30. The percentage of the original bed nodes for which the mesh differed by less than 0.1 foot (0.03 m) from the elevation of the original bed nodes ranged from 90% to 95% (Appendix E).

The sites were calibrated at 900 cfs, the highest simulation flow. The calibrated cdg files all had a solution change of less than 0.00001, with the net Q for all sites less than 1% (Appendix E). The calibrated cdg file for all study sites, with the exception of Upper Placer site, had a maximum Froude Number of greater than 1 (Appendix E). Four of the six study sites had calibrated cdg files with WSELs that were within 0.1 foot (0.031 m) of the PHABSIM predicted WSELs (Appendix E). For Upper Placer site, the RIVER2D predicted WSEL near the water's edge along the right bank was exactly 0.1 foot (0.031 m) lower than the PHABSIM predicted WSEL, while along the left bank the RIVER2D predicted WSEL was higher by 0.11 foot (0.035 m) compared to the PHABSIM predicted WSEL. In the case of the Peltier site, we attempted calibration at the highest simulation flow of 900 cfs and at the highest measured flow of 750 cfs. In both cases, the WSELS were off by 0.13 foot (0.04 m).

RIVER2D Model Velocity Validation

See Appendix F for velocity validation statistics. Although there was a strong correlation between predicted and measured velocities, there were significant differences between individual measured and predicted velocities. In general, the simulated and measured velocities profiles at the upstream and downstream transects (Appendix F) were relatively similar in shape. Overall, the simulated velocities for Spawn Area 4 transects 1 and 2 were relatively similar to the measured velocities. However, in both cases, it is apparent that the simulated velocities were higher on the east side of the channel, with the simulated velocities for the middle portion of the channel being somewhat lower than the measured velocities. In the case of Peltier transect 1, the velocity simulated by RIVER2D at the farthest west side of the channel was much higher than the measured velocity for that location. Several of the other simulated velocities on the west side of the channel were significantly lower than the measured values. For Peltier transect 2, the velocities simulated by RIVER2D in the middle part of the channel were significantly lower than the measured velocities. For NEED Camp transect 1, the velocities simulated by RIVER2D on the south side of the channel were similar to the measured velocities, with the exception of one value at the far south end of the channel that was significantly higher than the measured velocities. In the case of NEED Camp transect 2, RIVER2D under-predicted the velocities on the far south side and the middle of the channel, while over-predicting the velocities on the north side of the channel. In the case of Indian Rhubarb transect 1, the simulated and measured velocities for the most part matched relatively well, with somewhat higher measured velocities along the transect. Indian Rhubarb transect 2 was the reverse of transect 1, with the RIVER2D model under-predicting the velocities on the far west side of the channel and over-predicting the velocities for most of the rest of the transect. Overall, the RIVER2D simulated velocities for Upper Placer transect 1 compared relatively well with the measured velocities, with somewhat lower measured velocities on the west side of the channel and somewhat higher measured velocities on the east side of the channel**.** For Upper Placer transect 2, the simulated velocities were relatively similar to the measured velocities, the differences in magnitude falling within the expected amount of variation. The measured and simulated velocities for Lower Placer transect

1 were relatively similar, the differences in magnitude falling within the expected amount of variation. For Lower Placer transect 2, RIVER2D significantly under-predicted the velocities throughout most of the middle portion of the transect and over-predicted the velocities on both sides of the transect.

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 10 flows for Peltier, 3 flows for NEED Camp, 4 flows for Upper Placer, and 1 flow for Lower Placer (Appendix G). In the case of Peltier, two of the production files had Net Q values that exceeded 5%. The maximum Froude Number was greater than 1 for all of the simulated flows for Peltier, Spawn Area 4, NEED Camp, and Lower Placer, 14 simulated flows for Indian Rhubarb, and 10 simulated flows for Upper Placer (Appendix G).

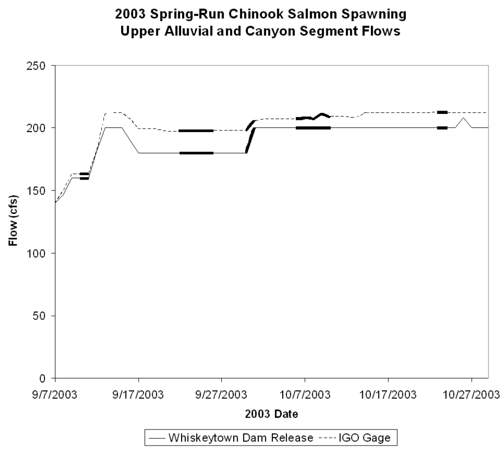
Habitat Suitability Criteria (HSC) Data Collection

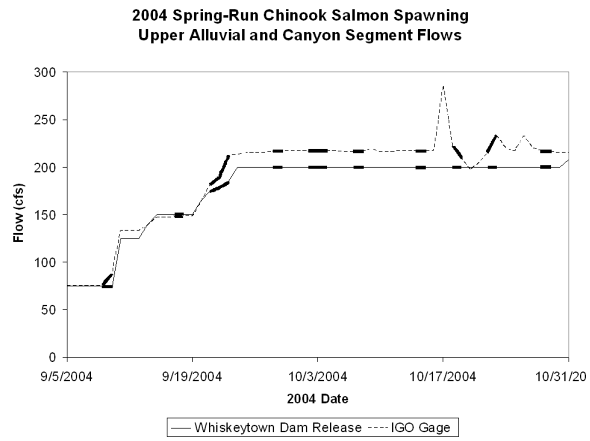
The location of depth and velocity measurements was generally about 2 to 4 feet upstream of the pit of the redd; however on rare occasions it was necessary to make measurements at a 45 degree angle upstream. The data were almost always collected within 5 feet of the pit of the redd.

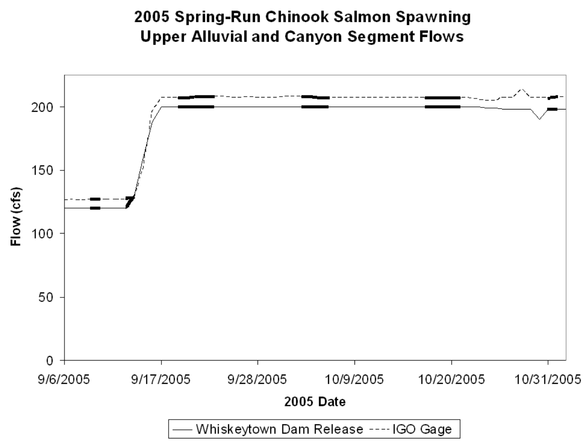
Data relative to depth, velocity, and substrate size were collected for a total of 180 spring-run Chinook salmon redds in Clear Creek on September 8-October 23, 2003, September 9-October 23, 2004 and September 6-October 21, 2005 in the Upper Alluvial and Canyon Segments. However, for some of the redds, one or more of the above variables were not measured. Velocities, depths and substrates were measured for, respectively, 170, 177 and 166 redds. Data relative to the above variables were measured for a total of 212 steelhead/rainbow trout redds in Clear Creek on January 2-June 19, 2003, January 12-July 16, 2004 and December 21-May 2, 2005 in the Upper Alluvial and Canyon Segments. As with the spring-run Chinook salmon redds, one or more of the above variables were not measured for some redds. Velocities, depths and substrates were measured for, respectively, 186, 211 and 191 redds.

During 2003-2005, flows in the Upper Alluvial and Canyon Segments fluctuated during the September-October periods when spring-run Chinook salmon spawning data were collected. In 2003-2005, Upper Alluvial Segment flow ranges were as follows: 147-200 cfs, 75-200 cfs, and 120-200 cfs. In the Canyon Segment, flows ranges were as follows for 2003-2005: 150-213 cfs, 75-286 cfs, and 126-208 cfs (Figure 2). During 2003-2005, flows in the Upper Alluvial Segment remained stable at 200 cfs during the months that the steelhead/rainbow trout spawning data were collected. The only significant fluctuations in flow for the Upper Alluvial Segment were during 2003: January 27 and 28, when flows spiked to 725 cfs and 869 cfs, respectively and May 28-

Figure 2. 2003-2005 Clear Creek flows in the Upper Alluvial and Canyon Segments during spring-run Chinook salmon spawning data collection. The thicker lines show the sampling periods.







June 19, when flows decreased to 140 cfs (Figure 3). In the Canyon Segment, flows fluctuated during the months when steelhead/rainbow trout spawning data were collected in 2003-2005: 159-3590 cfs in 2003, 72-2440 cfs in 2004, and 222-1490 cfs in 2005.

The spring-run salmon HSC data had depths ranging from 0.8 to 7.0 feet deep, velocities ranging from 0.70 to 4.40 ft/s, and substrate sizes ranging from 1-2 inches to 4-6 inches. The steelhead/rainbow trout HSC data had depths ranging from 0.4 to 4.0 feet deep, velocities ranging from 0.61 to 3.89 ft/s, and substrate sizes ranging from 0.1-1 inch to 4-6 inches.

Biological Validation Data Collection

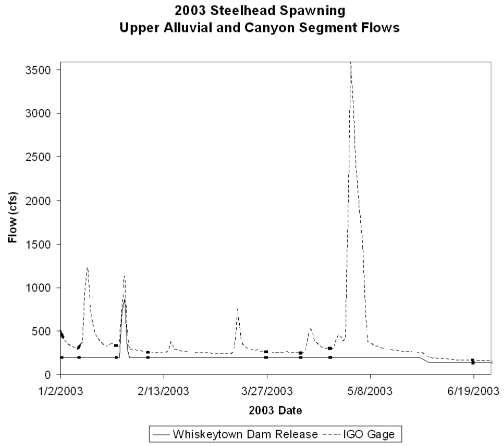
During the survey for spring-run Chinook salmon redds conducted on October 18 and 21, 2004, we measured 0 redds at Spawn Area 4, 2 redds at Peltier, 2 redds at NEED Camp, 1 redd at Indian Rhubarb, 1 redd at Lower Placer, and 1 redd at Upper Placer, for a total of 7 redds for the six study sites. While conducting the March 3-4, 2004, steelhead/rainbow trout redd surveys, we measured 5 redds at Spawn Area 4, 19 redds at Peltier, 2 redds at NEED Camp, 0 redds at Indian Rhubarb, 0 redds at Lower Placer, and 0 redds at Upper Placer, for a total of 26 redds for the six study sites.

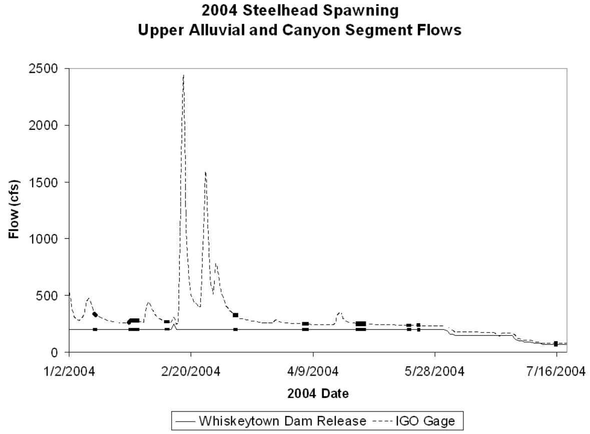
Habitat Suitability Criteria (HSC) Development

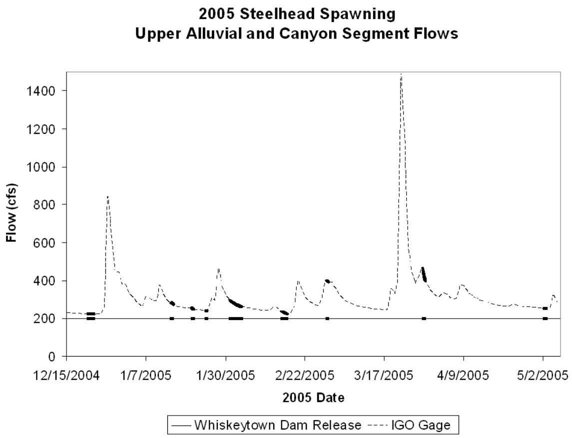
For the seven spring-run Chinook salmon occupied points (Spawn Area 4 = 0 redds, Peltier = 2 redds, NEED Camp = 2 redds, Indian Rhubarb = 1 redd, Lower Placer = 1 redd, Upper Placer = 1 redd) collected on October 18, 2004, the flows were averaged from September 1-October 18, 2004, for all the sites with the exception of Indian Rhubarb. This was done since spring-run Chinook salmon spawning typically starts in September and October 18 was the day when the data was collected for the redds where the locations were recorded with total station. In the case of Indian Rhubarb, the data on the redd where the location was recorded with total station were not collected until October 21, 2004, so the flows were averaged from September 1-October 21, 2004. The averaged flows used for the final River2D files were 161 cfs for Spawn Area 4 and Peltier, 164 cfs for NEED Camp, 166 cfs for Indian Rhubarb, and 172 cfs for Lower and Upper Placer. For the twenty-six steelhead/rainbow trout occupied points (Spawn Area 4 = 5 redds, Peltier = 19 redds, NEED Camp = 2 redds, Indian Rhubarb = 0 redds, Lower Placer = 0 redds, Upper Placer = 0 redds) collected on March 3-4, 2004, the flows were averaged from January 1-March 4, 2004. The average flows used for the final River2D files were 200 cfs for Spawn Area 4 and Peltier, 262 cfs for NEED Camp and Indian Rhubarb, and 466 cfs for Lower and Upper Placer.

Initially, 300 unoccupied points for the larger sites (Spawn Area 4, Peltier and NEED Camp) and 50 points for the smaller sites (Indian Rhubarb, Lower Placer and Upper Placer), were selected. We ended up with fewer than 50 unoccupied points for each of the smaller sites because the

Figure 3. 2003-2005 Clear Creek Flows in the Upper Alluvial and Canyon Segments during steelhead/rainbow trout spawning data collection. The thicker lines show the sampling periods.







random selection process of selecting these points resulted in duplicates of some of the points which were eliminated. For the spring-run Chinook salmon unoccupied data, we ended up with 200 points for Spawn Area 4, 200 points for Peltier, 200 points for NEED Camp, 43 points for Indian Rhubarb, 49 points for Lower Placer, and 44 points for Upper Placer. For the steelhead/rainbow trout unoccupied data, we ended up with 200 points for Spawn Area 4, 200 points for Peltier, 200 points for NEED Camp, 47 points for Indian Rhubarb, 49 points for Lower Placer, and 42 points for Upper Placer.

The coefficients for the final logistic regressions for depth and velocity for each run are shown in Table 7. The p values for all of the non-zero coefficients in Table 7 were less than 0.05, as were the p values for the overall regressions.

The initial steelhead/rainbow trout HSC showed suitability rapidly decreasing for depths greater than 1.5 feet. For steelhead/rainbow trout, suitable velocities were between 0.98 and 3.38 ft/s, while suitable substrate codes were 1.2 and 1.3. The results of the initial regressions showed that availability dropped with increasing depth, but not as quickly as use (Figure 4). The result of the final regression conducted to modify the HSC depth curve to account for the low availability of deep water having suitable velocities and substrate was that the scaled ratio reached zero at 28.6 feet; thus, the steelhead/rainbow trout depth criteria were modified to have a linear decrease in suitability from 1.5, the greatest depth in the original criteria which had a suitability of 1.0, to a suitability of 0.0 at 28.6 feet. For spring-run Chinook salmon, the depth suitability from the logistic regression reached a suitability of 1.0 at 6.0 feet. Since the deepest spring-run redd in our study sites had a depth of 3.0 feet, we were unable to apply the Gard (1998) depth correction method.

The final depth and velocity criteria for the spring-run Chinook salmon and steelhead/rainbow trout, along with the frequency distributions of occupied and unoccupied locations, are shown in Figures 5-8 and Appendix H. The final spring-run Chinook salmon and steelhead/rainbow trout substrate criteria are shown in Figures 9-10 and Appendix H.

Biological Validation

We had a total of 7 locations (Spawn Area 4 = 0 redds, Peltier = 2 redds, NEED Camp = 2 redds, Indian Rhubarb = 1 redd, Lower Placer = 1 redd, Upper Placer = 1 redd) with spring-run Chinook salmon redds and 719 locations without redds for the 5 out of 6 study sites where redds were located on October 18 and 21, 2004. The flow averages were based on initial creek discharge values from Whiskeytown Dam for Spawn Area 4 and Peltier sites, combined Whiskeytown Dam and Page-Boulder Creek gage discharge values for NEED Camp and Indian Rhubarb, and IGO gage discharge values for Upper and Lower Placer. For the spring-run Chinook salmon redds, the average flows used for the RIVER2D files were 161 cfs for Spawn Area 4 and Peltier, 164 cfs for NEED Camp, 166 cfs for Indian Rhubarb, and 172 cfs for Upper and Lower Placer.

Table 7. Logistic regression coefficients and R^2 values. The R^2 values are McFadden's Rho-squared values.

race	parameter	I	J	K	L	M	R^2
spring-run	depth	-7.475189	8.867835	-4.260705	0.832263	-0.054822	0.09
spring-run	velocity	-5.949073	3.752918	-0.623307	---	---	0.18
steelhead	depth	-6.042356	10.972161	-7.681852	2.274331	-0.254833	0.09
steelhead	velocity	-11.545338	19.824193	-12.883852	3.618983	-0.378801	0.15

Figure 4. Relations between relative availability and use and depth for steelhead/ rainbow trout. Points are relative use, relative availability, or the standardized ratio of linearized use to linearized availability. Lines are the results of the linear regressions of the depth increment midpoint versus relative availability, relative use, and the standardized ratio of linearized use to linearized availability. Availability dropped with increasing depth, but not as quickly as use. The use-availability regression reached zero at 28.6 feet.

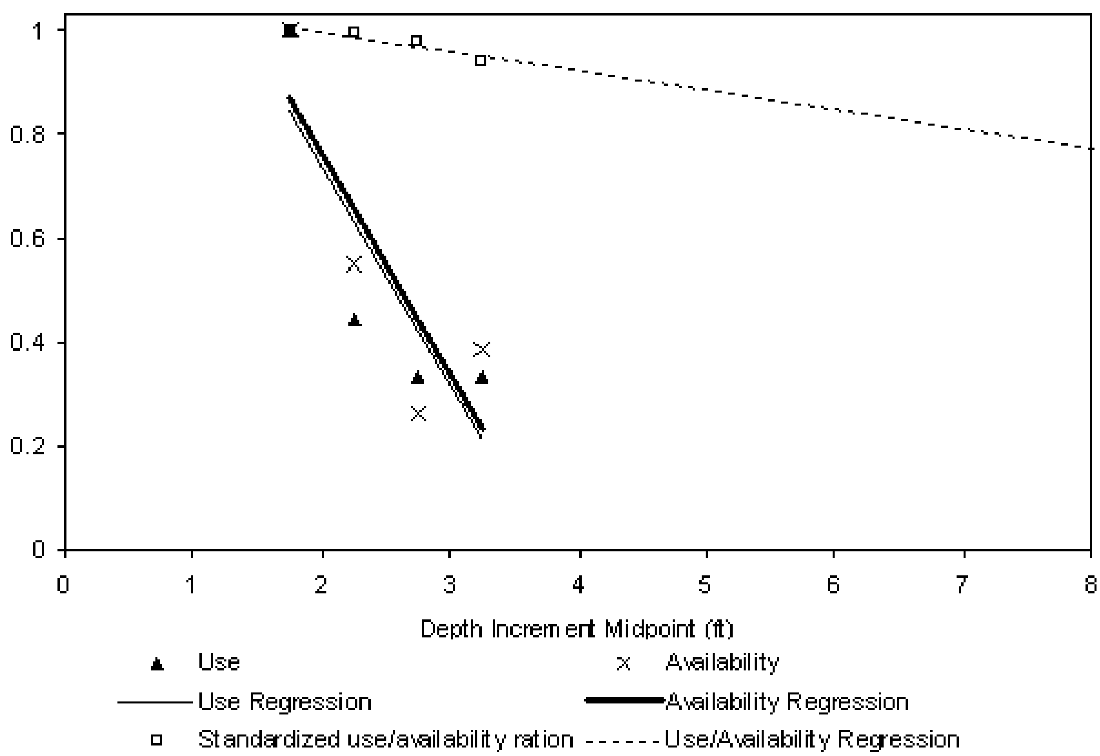


Figure 5. Spring-run Chinook salmon spawning depth HSI. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for depths of 0.8 to 7.0 feet and an optimum suitability at depths of 6.0 to 6.2 feet.

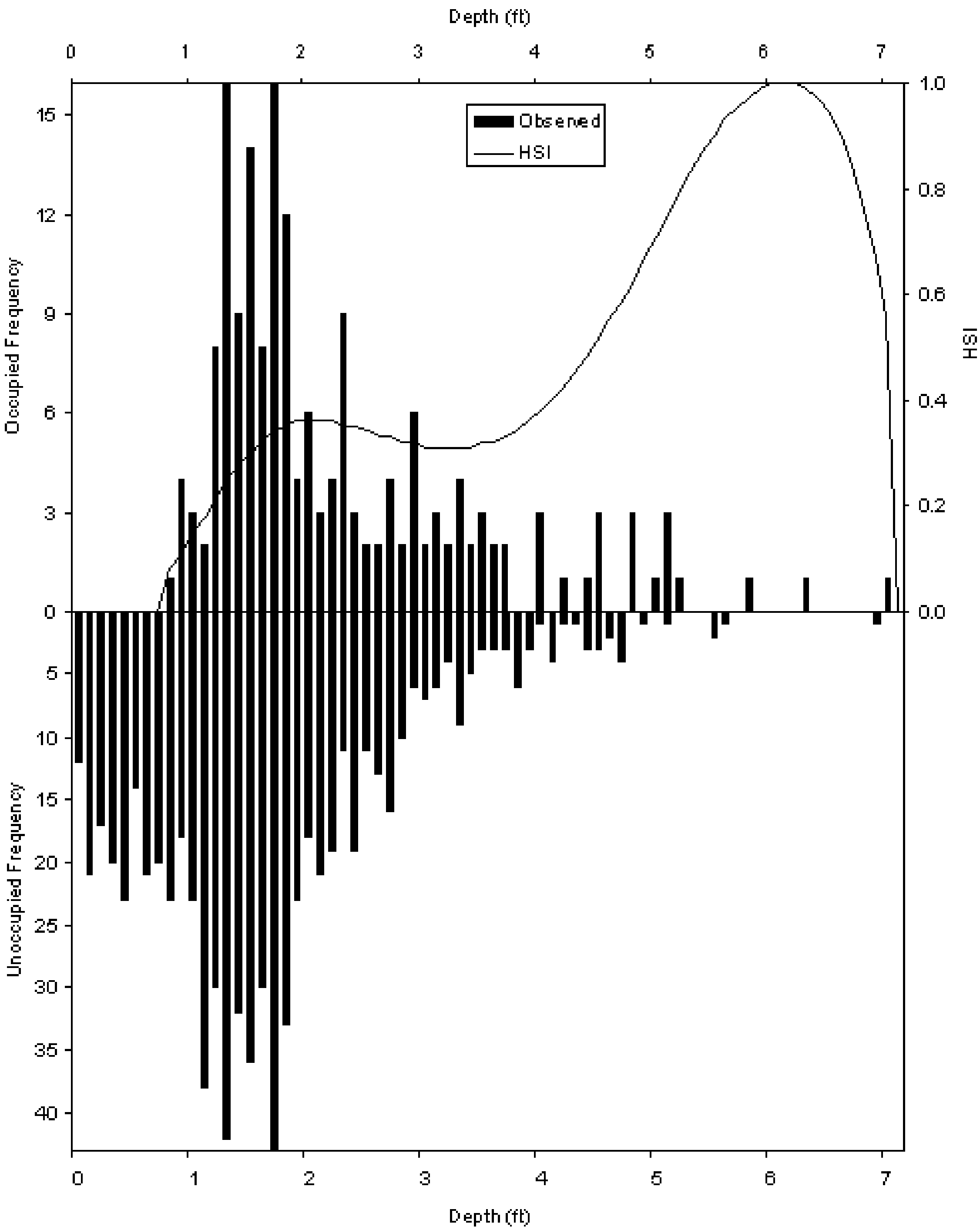


Figure 6. Spring-run Chinook salmon spawning velocity HSI. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for velocities of 0.70 to 4.40 feet/sec and an optimum suitability at velocities of 2.90 to 3.10 feet/sec.

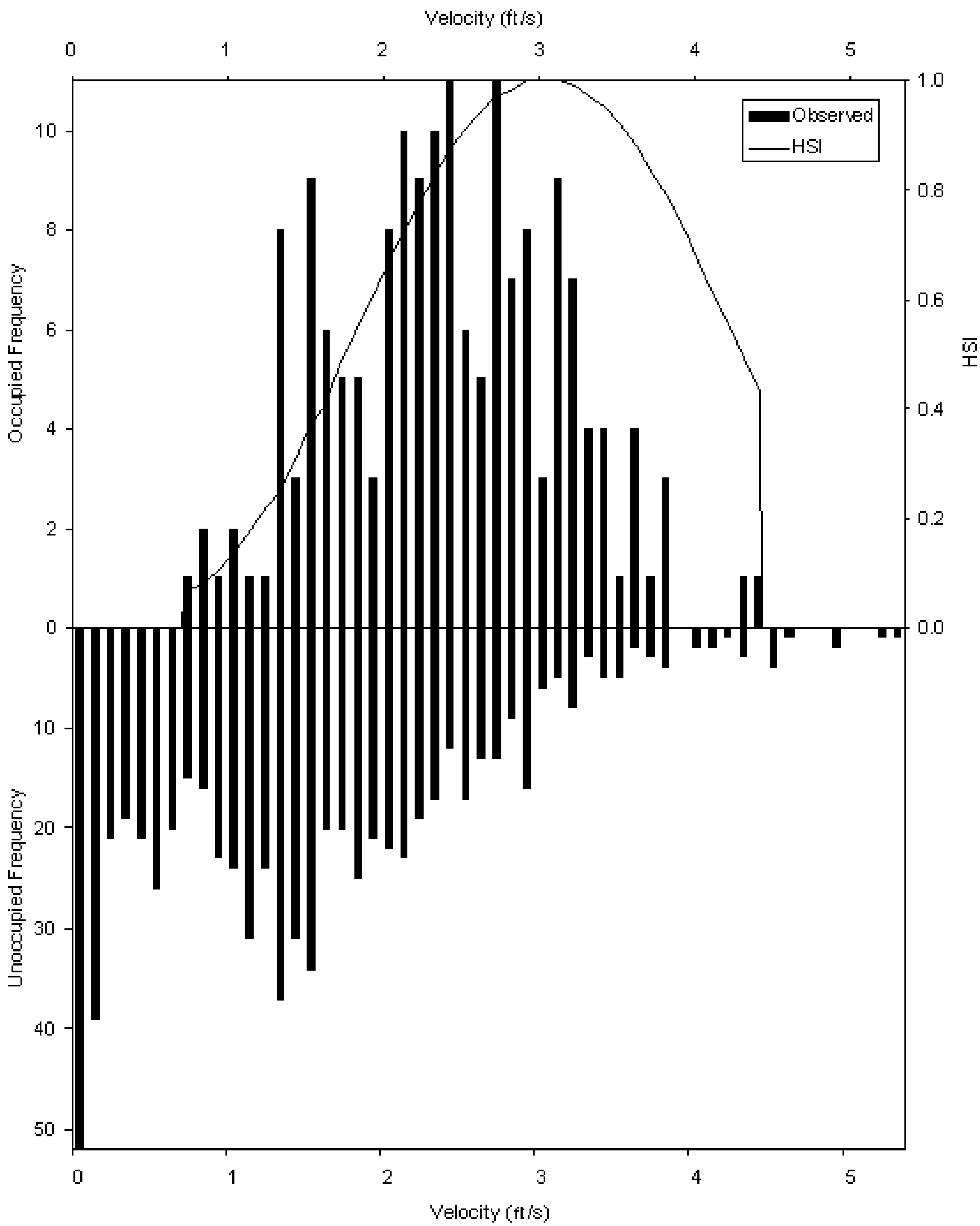


Figure 7. Steelhead/rainbow trout spawning depth HSI. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for depths of 0.4 to 28.5 feet and an optimum suitability at depths of 1.4 to 1.5 feet.

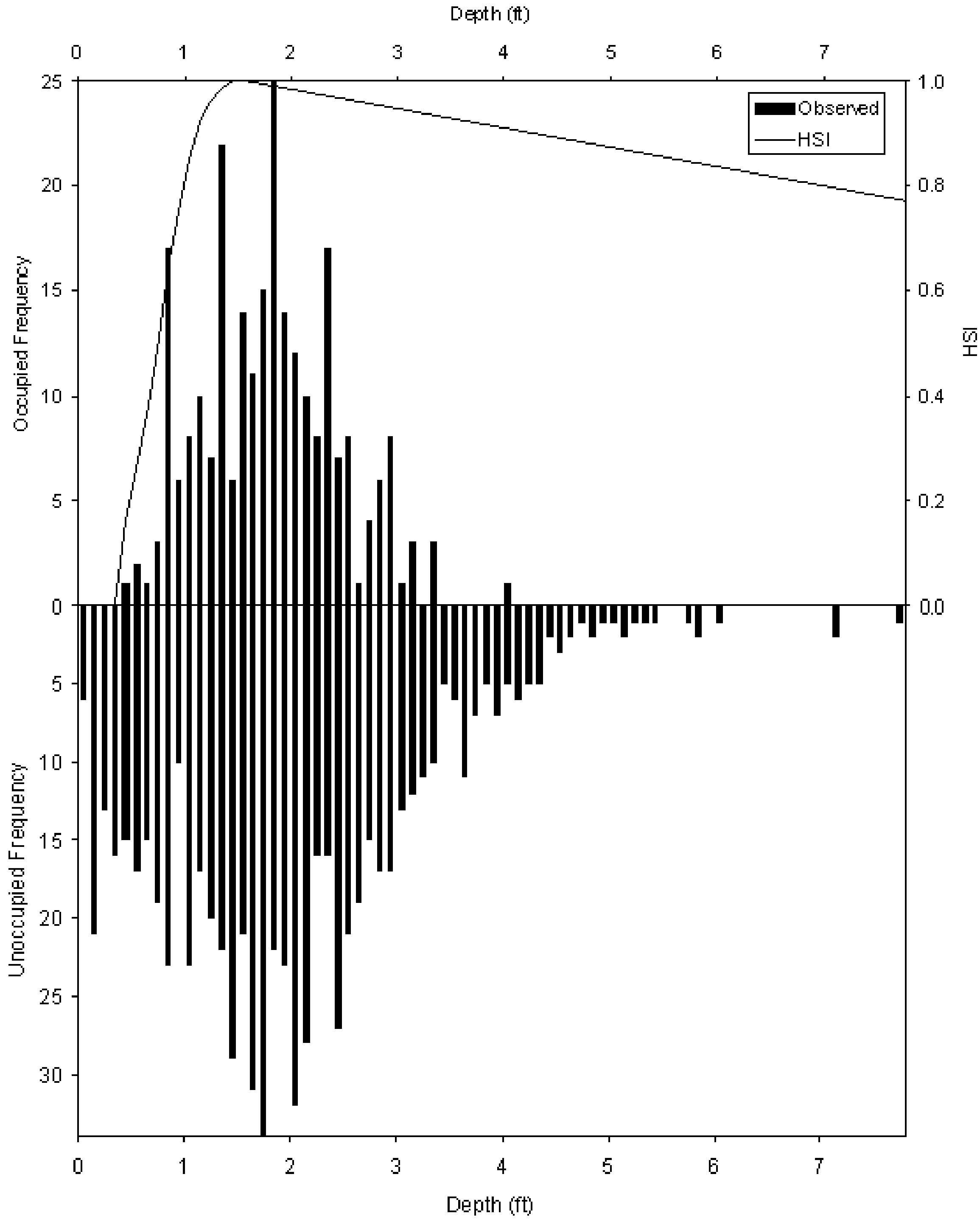


Figure 8. Steelhead/rainbow trout spawning velocity HSI. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for velocities of 0.61 to 3.89 feet/sec and an optimum suitability at velocities of 1.60 to 1.70 feet/sec.

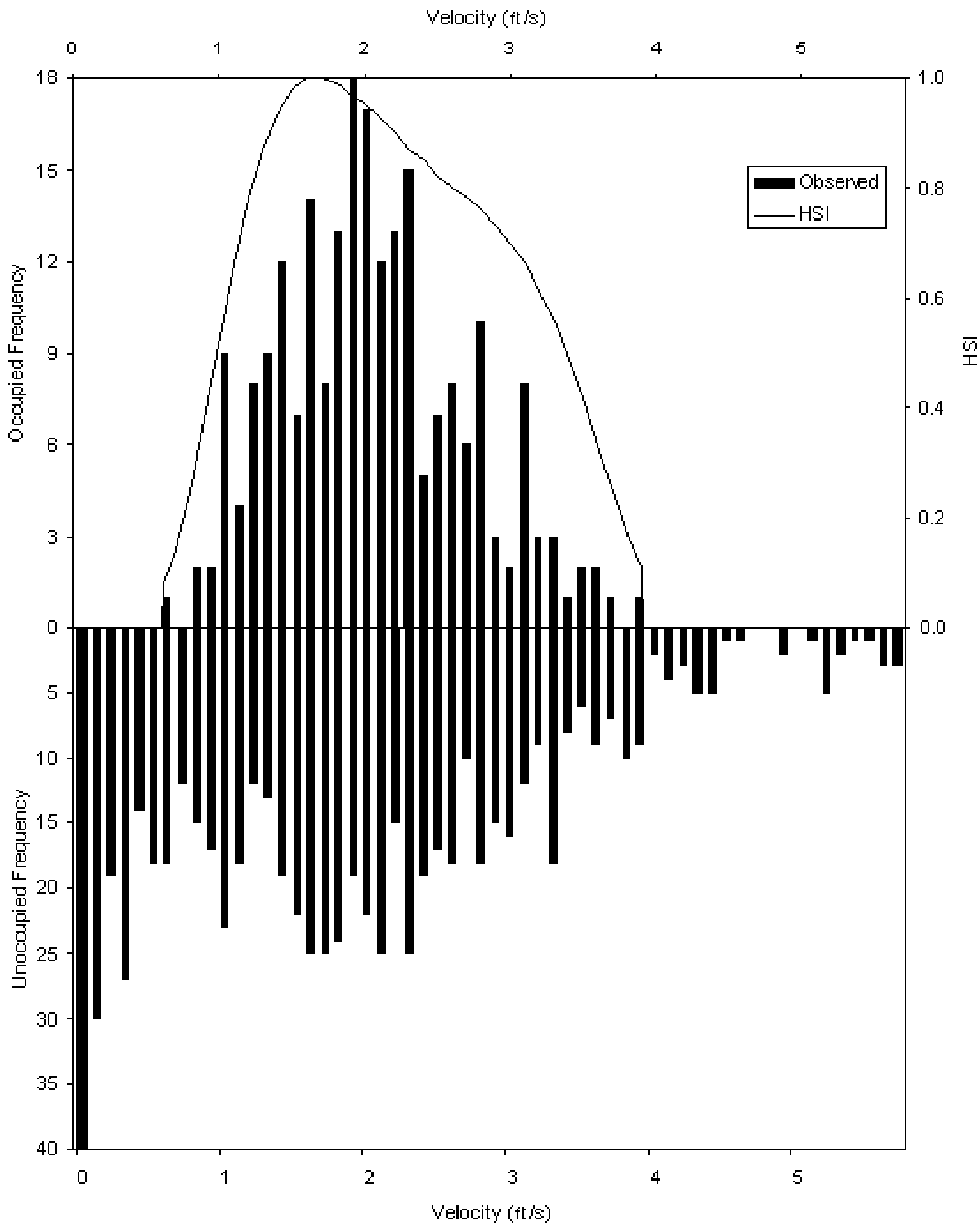


Figure 9. Spring-run Chinook salmon HSI curve for substrate. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for substrate codes 1.2 to 4.6 and an optimum suitability for substrate code 2.4.

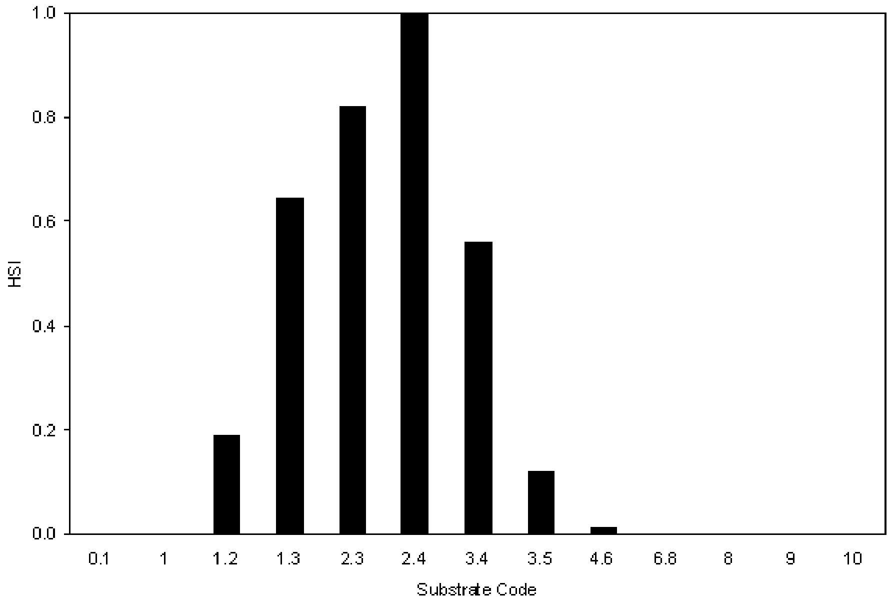
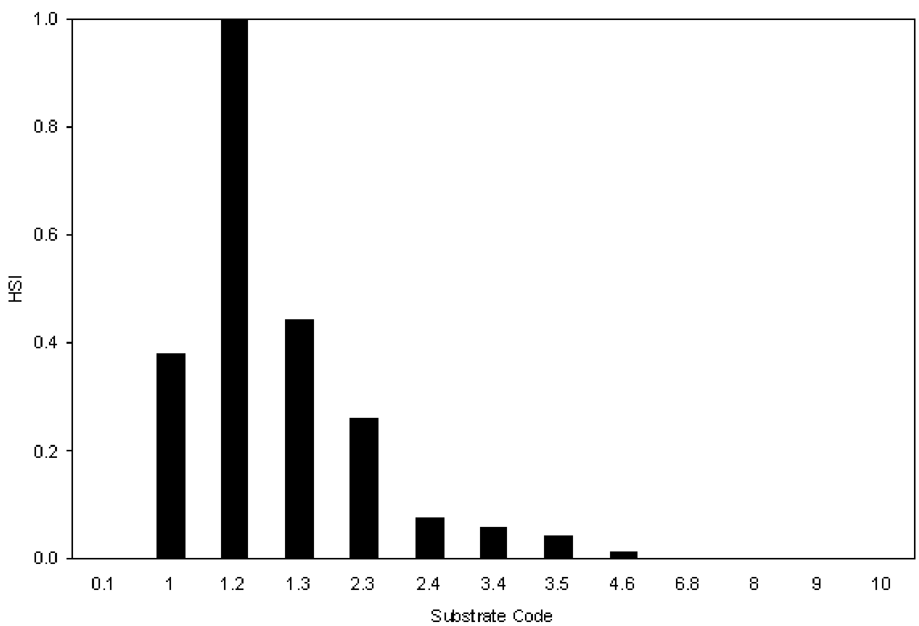


Figure 10. Steelhead/rainbow trout HSI curve for substrate. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for substrate codes 1 to 4.6 and an optimum suitability for substrate code 1.2.



The combined habitat suitability predicted by the 2-D model was significantly higher for the locations with spring-run Chinook salmon redds (median = 0.1599) than for locations without redds (median = 0.0000), based on the Mann-Whitney U test ($p<0.026$). The frequency distribution of combined habitat suitability predicted by the 2-D model for locations with spring-run Chinook salmon redds is shown in Figure 11, while the frequency distribution of combined habitat suitability for locations without spring-run Chinook salmon redds is shown in Figure 12. The location of spring-run Chinook salmon redds relative to the distribution of combined suitability is shown in Appendix J.

We had a total of 26 locations (Spawn Area 4 = 5 redds, Peltier = 19 redds, NEED Camp = 2 redds, Indian Rhubarb = 0 redds, Lower Placer = 0 redds, Upper Placer = 0 redds) with steelhead/rainbow trout redds and 875 locations without redds for the 3 out of 6 study sites where redds were located on March 3-4, 2004. For the steelhead/rainbow trout redds, the average flows used for the RIVER2D files were 200 cfs for Spawn Area 4 and Peltier, 262 cfs for NEED Camp and Indian Rhubarb, and 466 cfs for Lower and Upper Placer. The combined habitat suitability predicted by the 2-D model was significantly higher for the locations with steelhead/rainbow trout redds (median = 0.0563) than for cells without redds (median = 0.0008), based on the Mann-Whitney U test ($p<0.000001$). The frequency distribution of combined habitat suitability predicted by the 2-D model for locations with steelhead/rainbow trout redds is shown in Figure 13, while the frequency distribution of combined habitat suitability for locations without steelhead/rainbow trout redds is shown in Figure 14. The location of steelhead/rainbow trout redds relative to the distribution of combined suitability is shown in Appendix J.

For the one spring-run Chinook salmon redd location that the 2-D model predicted had a combined suitability of zero (14.3%), the combined suitability of zero can be attributed to the predicted depth (0.54 foot) being too shallow and the predicted velocity (0.12 ft/sec) being too slow. Of the three steelhead/rainbow trout redd locations that the 2-D model predicted had a combined suitability of zero (11.5%), one had a combined suitability of zero because the location was predicted to be dry by the 2-D model, one had a combined suitability of zero due to the predicted substrate being too small (substrate code 0.1) and one had a combined suitability of zero due to the predicted substrate being too large (substrate code 6.8).

Habitat Simulation

Habitat was simulated for the following flows: 50 cfs to 300 cfs by 25 cfs increments, and 300 cfs to 900 cfs by 50 cfs increments. The WUA values for the spring-run Chinook salmon and steelhead/rainbow trout calculated for each site are contained in Appendix I. The ratios of total redds counted in the segment to number of redds in the modeling sites for that segment were as follows: spring-run Chinook salmon Upper Alluvial Segment = 2.23, spring-run Chinook salmon Canyon Segment = 3.43, steelhead/rainbow trout Upper Alluvial Segment = 5.41,

Figure 11. Spring-run Chinook salmon combined suitability for 2-D model locations with redds. The median combined suitability for occupied locations was 0.1599.

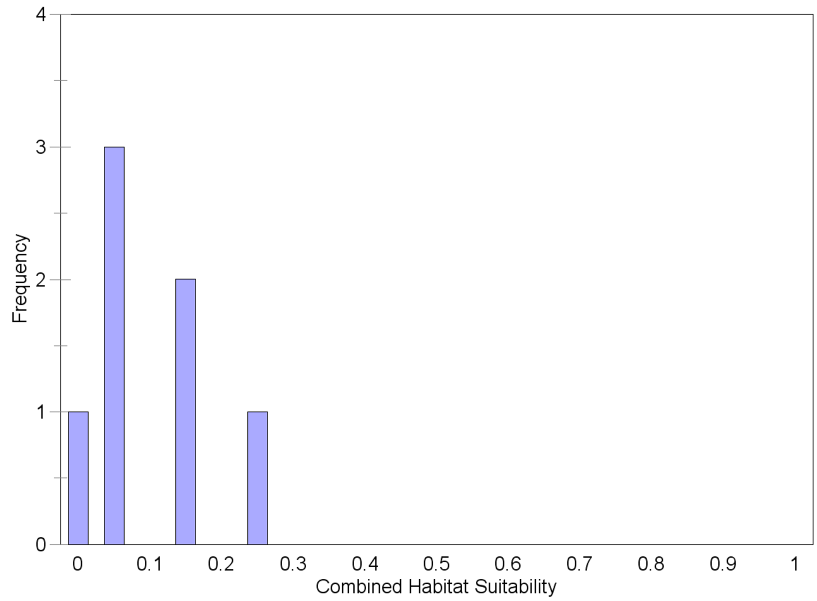


Figure 12. Spring-run Chinook salmon combined suitability for 2-D model locations without redds. The median combined suitability for unoccupied locations was 0.0000.

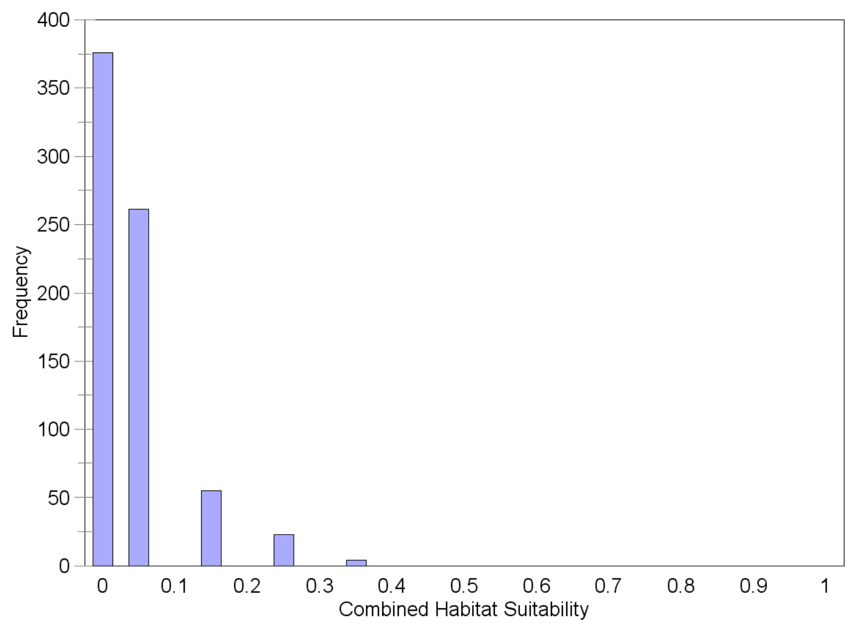


Figure 13. Steelhead/rainbow trout combined suitability for 2-D model locations with redds. The median combined suitability for occupied locations was 0.0563.

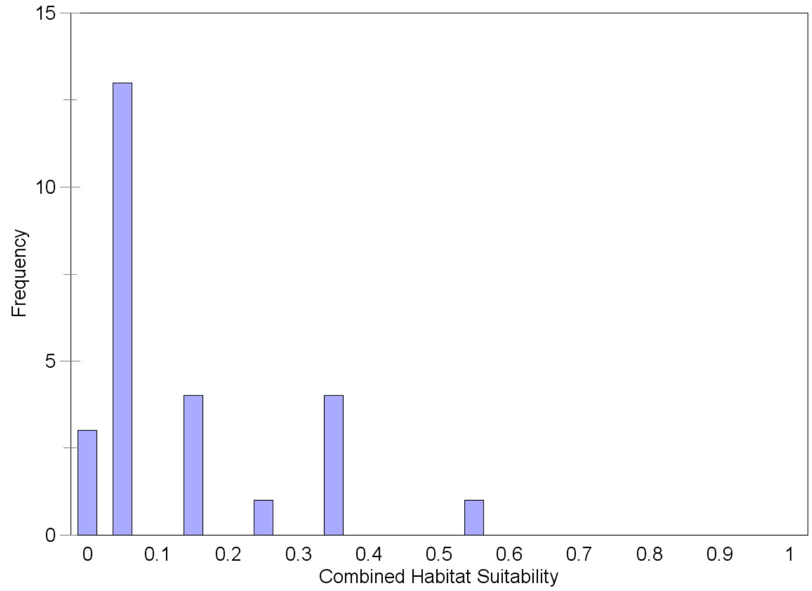
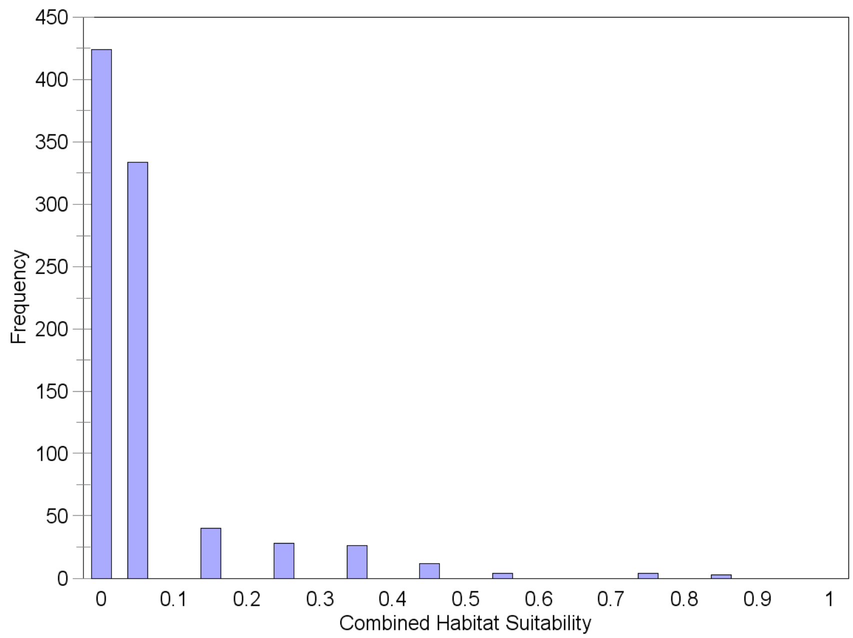


Figure 14. Steelhead/rainbow trout combined suitability for 2-D model locations without redds. The median combined suitability for unoccupied locations was 0.0008.



steelhead/rainbow trout Canyon Segment = 18. The flow-habitat relationships for spring-run Chinook salmon are shown in Figures 15 and 16 and Appendix I. In the Upper Alluvial Segment, the 2-D model predicts the highest total WUA at the highest modeled flow of 900 cfs, with the total WUA value still continuing to increase. For the Canyon Segment, the total WUA peaks at 650 cfs. The flow-habitat relationships for steelhead/rainbow trout are shown in Figures 17 and 18. In the Upper Alluvial Segment, the 2-D model predicts the highest total WUA at 350 cfs. In the Canyon Segment, the total WUA highest peak is at 600 cfs.

Sensitivity Analysis

The spring-run Chinook salmon spawning depth logistic regression had its first maximum at 2.1 feet (Figure 5). A total of 15 spring-run Chinook salmon redds were found in the six study sites during 2003 to 2005 (Table 8). However, only six of these redds had depths greater than 2.1 feet. For spring-run Chinook salmon, suitable velocities were between 1.74 and 4.28 ft/s, while suitable substrate codes were 1.3 to 3.4. The results of the initial regressions showed that availability dropped with increasing depth, but not as quickly as use (Figure 19). The result of the final linear regression to determine the depth at which the scaled ratios reach zero was that the scaled ratio reached zero at 6.49 feet. However, there was one redd which had a depth greater than 6.49 feet. As a result, the first alternative spring-run Chinook salmon depth criteria was modified to have a linear decrease in suitability from 1.0 at 2.1 feet to a suitability of 0.02 at 6.4 feet; the suitability of 0.02 was continued through 7.0 feet (the depth of the deepest spring-run Chinook salmon redd) with suitability reaching zero at 7.1 feet. The second alternative spring-run Chinook salmon depth criteria had a linear decrease in suitability from 1.0 at a depth of 2.1 feet to a suitability of 0.0 at 28.6 feet. The original and the two alternative depth HSC are shown in Figure 20. The flow-habitat results from the original depth HSC and the two alternative depth HSC are shown in Figure 21.

DISCUSSION

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

We still used *IFG4* for the Peltier downstream transect, even though we only had four sets of WSELs and were forced to run *IFG4* for the low flows using the three lowest calibration WSELs and for the high flows using the three highest WSELs. In addition, using *IFG4* for the three highest WSELs did not meet the measured-simulated WSEL criterion for the 446 cfs calibration flow with a simulated WSEL value that differed from the measured by 0.11. However, calibrating in this manner for the Peltier downstream transect using *IFG4* was preferable to using *MANSQ*, which gave greater errors and *WSP* could not be used because it was the downstream-most transect in the site.

Figure 15. Spring-run Chinook salmon flow-habitat relationships, Upper Alluvial Segment. Habitat continued to increase up to the maximum simulated flow of 900 cfs.

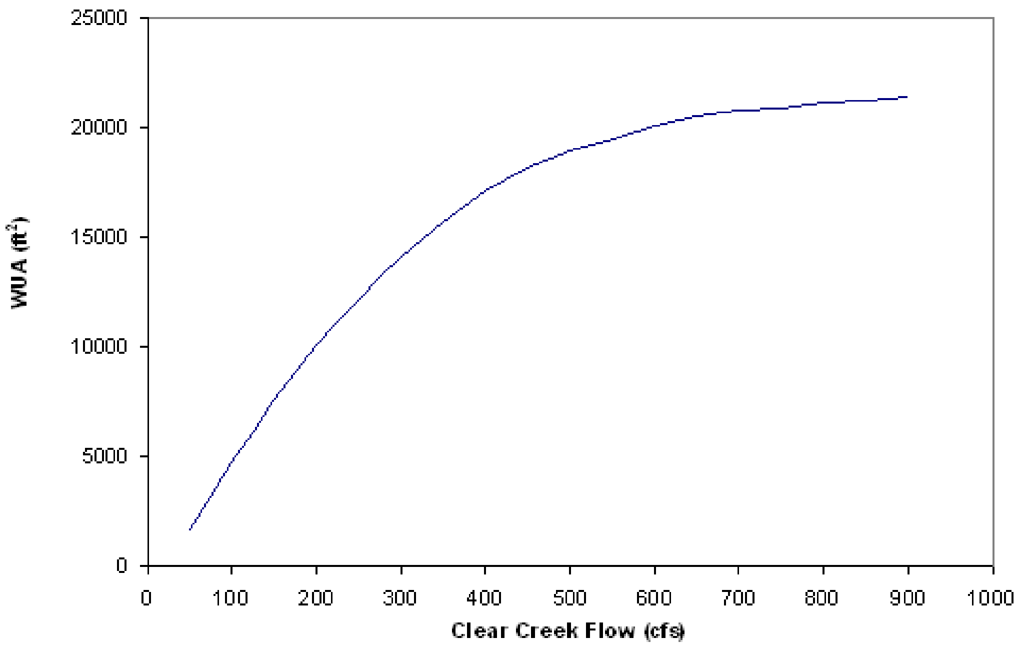


Figure 16. Spring-run Chinook salmon flow-habitat relationships, Canyon Segment. The flow with the maximum spring-run Chinook salmon spawning habitat was 650 cfs.

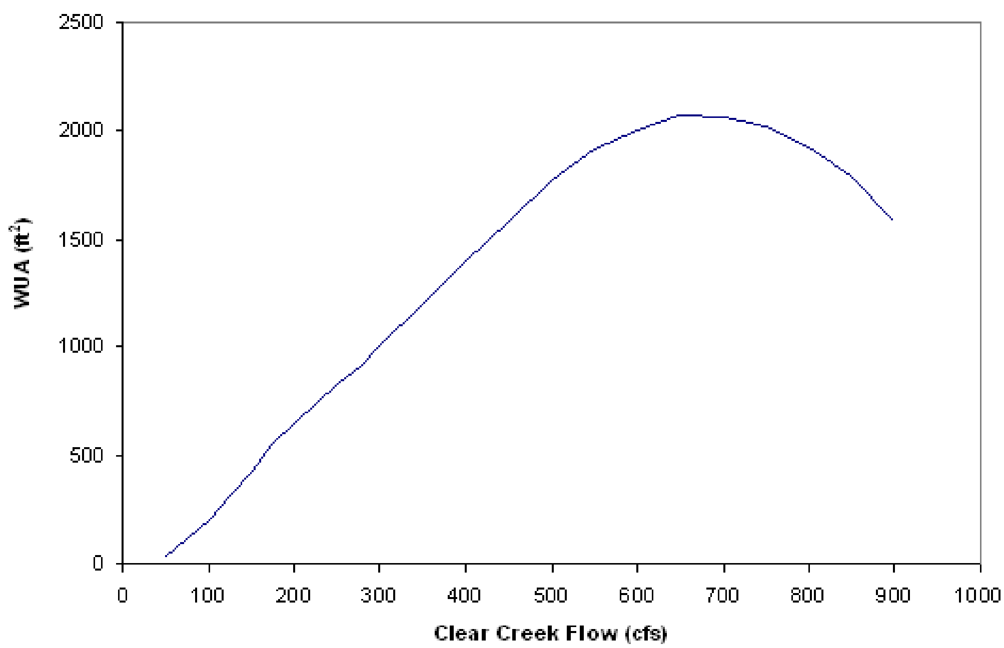


Figure 17. Steelhead/rainbow trout flow-habitat relationships, Upper Alluvial Segment. The flow with the maximum steelhead/rainbow trout spawning habitat was 350 cfs.

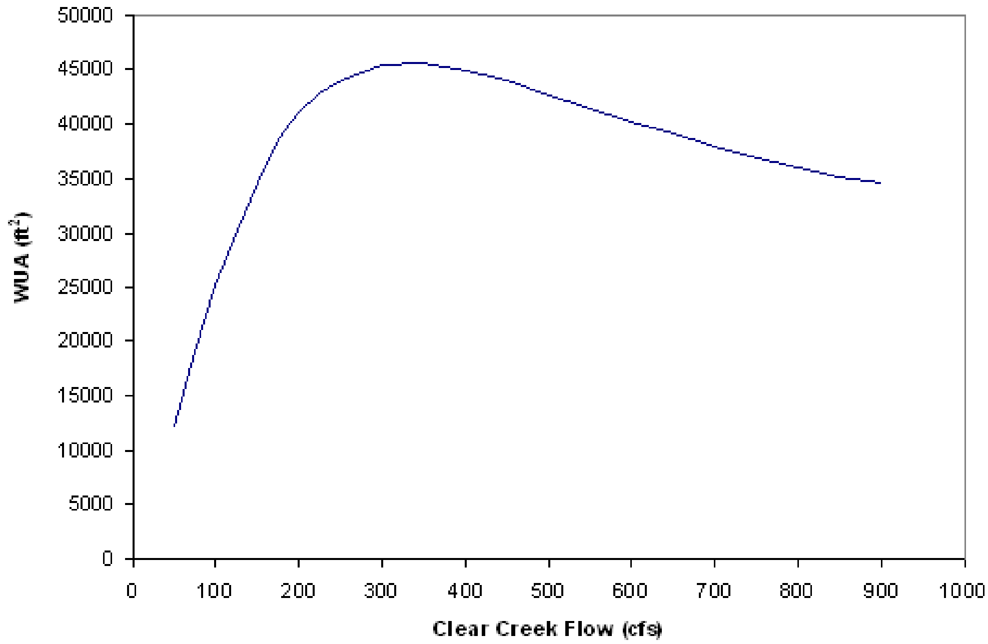


Figure 18. Steelhead/rainbow trout flow-habitat relationships, Canyon Segment**.** The flow with the maximum steelhead/rainbow trout spawning habitat was 600 cfs.

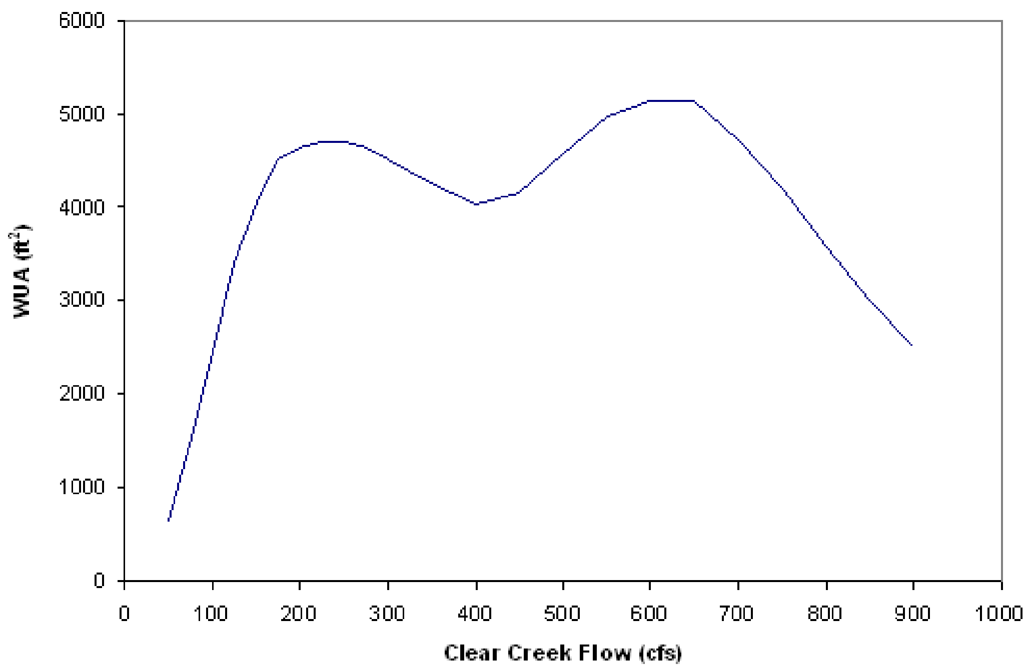


Table 8. Number of spring-run Chinook salmon redds and average flows for the six study sites for 2003 to 2005. Sites without an entry in the table for a given year did not have any spring-run Chinook salmon redds that year.

Year	Site Name	Time Period	Average Flow (cfs)	Number of Redds
2005	Spawn Area 4	9/9-11/1	190	2
2004	Peltier	9/9-11/2	184	2
2005	Peltier	9/9-11/1	190	2
2005	NEED Camp	9/9-11/1	195	2
2004	NEED Camp	9/9-11/2	189	1
2003	NEED Camp	9/8-10/23	196	1
2003	Indian Rhubarb	9/8-10/23	196	2
2004	Upper Placer	9/9-11/2	198	1
2005	Lower Placer	9/9-11/1	197	1
2003	Lower Placer	9/8-10/23	203	1

For the Peltier downstream transect, the deviation in the VAF pattern shown on page 70 can be attributed to dividing the calibration flows into separate calibration files. For the Upper Placer downstream transect, the deviation in the pattern can be attributed to RHABSIM's inferior ability to simulate velocities at low flows. As previously described in the methods, VAFs typically increase monotonically with increasing flows as higher flows produce higher water velocities. In the case of the Upper Placer downstream transect, the model, in mass balancing, was obviously increasing water velocities at low flows so that the known discharge would pass through the decreased cross-sectional area. We did not regard the atypical VAF patterns as problematic since RHABSIM was only used to simulate WSELs and not velocities.

RIVER2D Model Construction

In most cases, the areas of the mesh where there were greater than a 0.1 foot (0.03 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.03 m) vertically of the bed file within 1 foot (0.3 m) horizontally of the bed file location. Given that we had a 1 foot (0.3 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file.

Figure 19. Relations between relative availability and use and depth for spring-run Chinook salmon. Points are relative use, relative availability, or the standardized ratio of the linearized used to linearized availability. Lines are the results of the linear regressions of the depth increment midpoint versus relative availability, relative use, and the standardized ratio of linearized use to linearized availability. Availability dropped with increasing depth, but not as quickly as use. The use-availability regression reached zero at 6.49 feet.

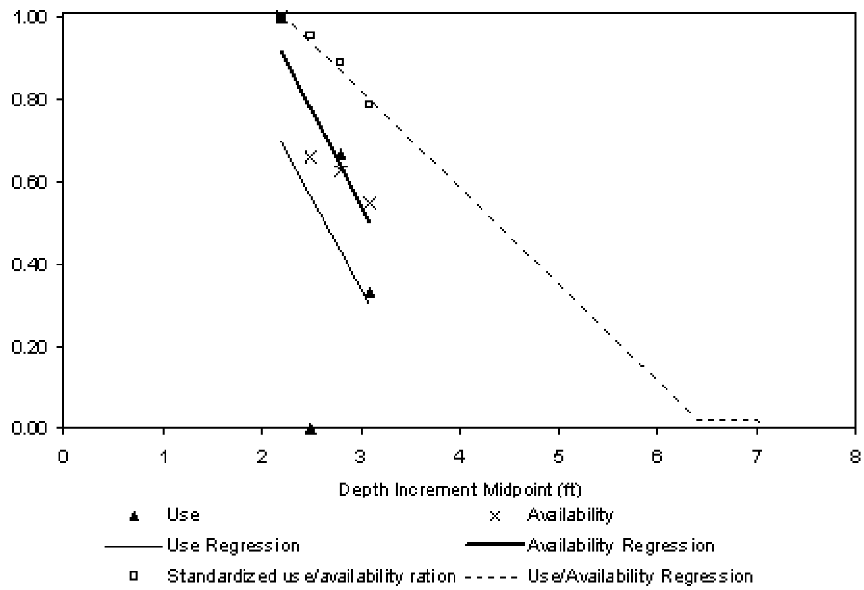


Figure 20. Original and two alternative spring-run Chinook salmon depth HSC.

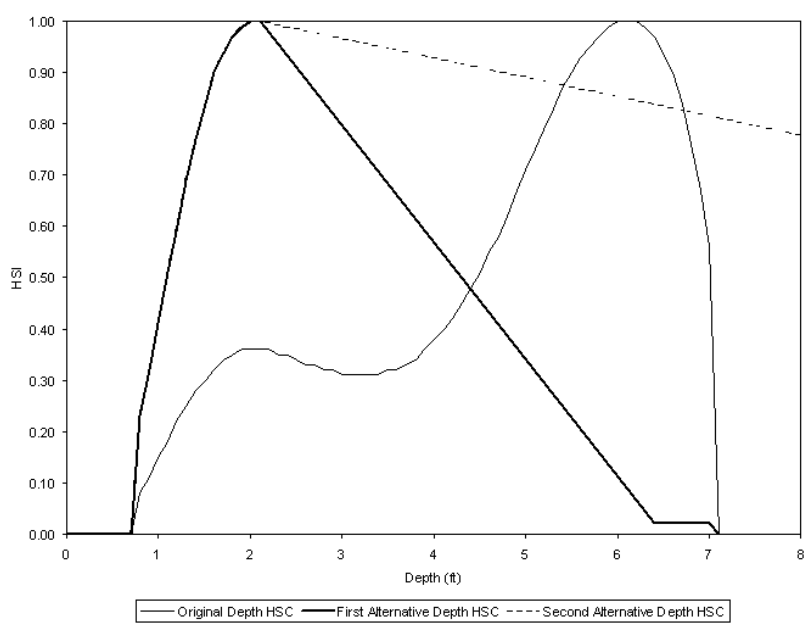
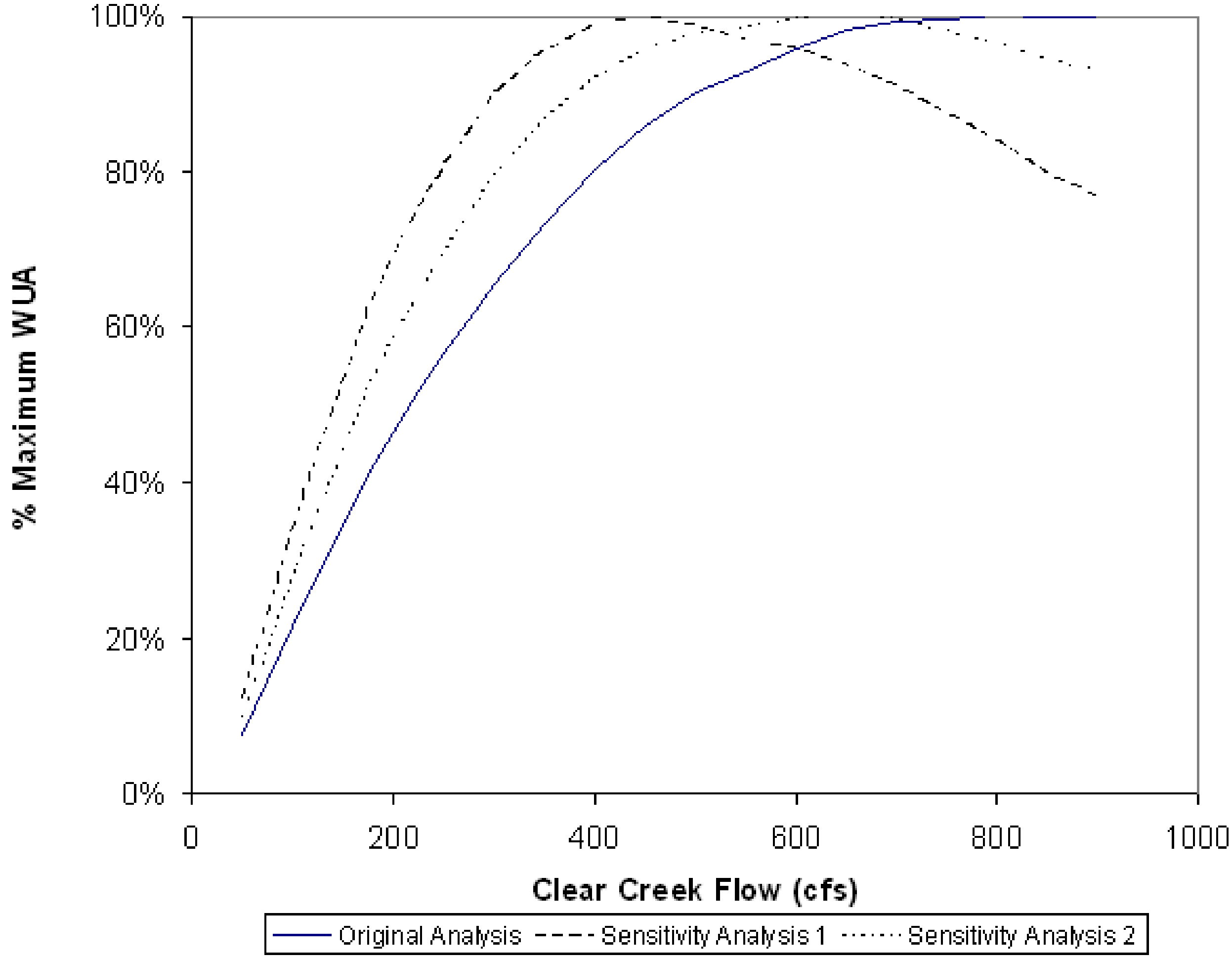


Figure 21. Flow-habitat relationships from original and two alternative spring-run Chinook salmon depth HSC. All three flow-habitat relationships show habitat increasing up to 450 cfs, but differ in pattern for flows greater than 450 cfs.



RIVER2D Model Calibration

We considered the solutions for all five study sites with Froude Numbers greater than 1 to be acceptable since the Froude Number was only greater than 1 at a few nodes, with the vast majority of the site having Froude Numbers less than 1. Furthermore, these nodes were located either at 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.

With regards to the problems with calibrating the Upper Placer and Peltier site cdg files, for Upper Placer site, by reducing the bed roughness, we could have achieved a better fit for the RIVER2D predicted left bank WSEL, but this would have resulted in the RIVER2D predicted right bank WSEL being off by more than 0.1 foot (0.031 m). Given that the average RIVER2D predicted WSEL was within less than 0.1 foot (0.031 m) of the PHABSIM predicted WSEL and the maximum difference was 0.15 foot (0.046 m), we deemed this acceptable. In the case of the Peltier site, the error in the simulated WSELs on the upper transect was likely due to the bed topography data collected for the study site not adequately characterizing the bed topography. Consequently, the results for the Peltier site should be viewed as somewhat questionable since the calibrated cdg file did not meet the calibration requirement of the WSEL on the upper transect being within 0.1 foot (0.031 m) of the PHABSIM predicted WSELs.

RIVER2D Model Velocity Validation

Differences in magnitude in most cases are likely due to: (1) operator error during data collection, i.e., the probe was not facing precisely into the direction of current; (2) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the average velocity values calculated in the model simulations; (3) 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 the velocity[12]; (4) 0.6 depth measurement may not accurately reflect conditions at the measured point; (5) mean column 2-D model simulation lacks secondary currents and vertical turbulency; and (6) the effect of the velocity distribution at the upstream boundary of the site[13].

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.

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

[13] RIVER2D distributes velocities across the upstream boundary in proportion to depth, so that the fastest velocities are at the thalweg. In contrast, the bed topography of a site may be such that the fastest measured velocities may be located in a different part of the channel. Since we did not measure the bed topography above a site, this may result in RIVER2D improperly distributing the flow across the top of the site. As discussed above, we added artificial upstream extensions to the sites to try to address this issue.

The higher simulated velocities on the east side of the channel and the lower simulated velocities in the middle portion of the channel compared to the measured velocities for Spawn Area 4 transects 1 and 2 may have been the result of features that were upstream of the study site along the east side of the channel likely acting to reduce the velocities on that side of the channel and increase velocities more toward the middle portion 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.

In the case of Peltier transect 1, where the velocity simulated by RIVER2D at the farthest west side of the channel was much higher than the measured velocity for that location and several of the other simulated velocities on the west side of the channel were significantly lower than the measured values, the bed topography of Peltier site was extremely complex, with many isolated small islands and very irregular areas of bedrock. As a result, this made data collection and characterization of the bed topography extremely difficult. It is likely that errors in how the high and low points in the irregular bedrock features and islands were characterized in RIVER2D resulted in the erroneous velocities simulated on the west side of the channel. Examination of the transect 1 boundary showed that an eddy was present at the same location where the model was significantly over and under-predicting the velocities. This eddy was not present in the measured data. The presence of this eddy may also explain the Net Q values being higher than 1% for 10 of the simulation files. The generation of the eddy by the model may be the result of boundary condition effects. Adding an artificial downstream extension of the bed topography might have improved the simulation of the velocities in this area, but would have likely had negligible effects on the overall flow-habitat relationship for this site due to the small size of this area. In the case of Peltier transect 2, where the velocities simulated by RIVER2D in the middle part of the channel were significantly lower than the measured velocities, these errors in the simulated velocities can be attributed to high points in the irregular bedrock that were present throughout much of the upper portion of Peltier site. The artificial extension that was constructed in RIVER2D extends upstream the bed topography features found on transect 2, resulting in those features influencing the velocities at transect 2. In reality, it appears that these high points in the mid-channel portion of the bed topography did not extend upstream of transect 2, resulting in higher measured velocities at this location.

For NEED Camp transect 1, where one velocity value at the far south end of the channel was significantly higher than the measured velocities, this single significantly higher simulated velocity was likely due to an error in the construction of the bed topography of the model. The under-predicted velocities on the north side of the model can be attributed to errors in the velocity measurements on the transect (being too high) or the gaged discharge was in error. For example, in this situation, the gaged discharge was 213 cfs. However, the measured discharge on transect 1 was 247.8 cfs and on transect 2 it was 222.3 cfs. For NEED Camp transect 2, the deviations in the predicted velocities from the measured velocities is likely due to the nature of the bed topography at the upstream end of the study site and upstream of the site. In these areas of the creek channel, the bottom is littered with many large boulders. The data points collected along transect 2 may not have accurately captured these boulders along the transect, resulting in velocities that may have been inaccurate in those locations. In addition, the influence of boulders and other bed features upstream of transect 2 (outside of the study site) on the measured velocities, was not present in the RIVER2D model.

In the case of Indian Rhubarb transect 1, the somewhat higher measured velocities along the transect can be attributed to errors either in how the velocities were measured or error in the gage measured discharge. In this example, the gaged discharge was 214 cfs, while measured discharge on transect 1 was 235.8 cfs. Given that the RIVER2D model was run using a flow of 214 cfs, it is not surprising that the velocities along the transect were lower overall, while retaining a similar pattern to the measured velocities. The RIVER2D model's under-prediction of the velocities on the far west side of the channel for Indian Rhubarb transect 2 and over-prediction of the velocities for most of the rest of the transect was also likely due to either errors in measuring the velocities on the transect or error in the gage measured discharge. In this example, the gaged discharge was 214 cfs, while the measured discharge was 171.5 cfs. By running the RIVER2D model at 214 cfs, this resulted in higher simulated velocities than were measured. In addition, there likely existed features in the bed topography upstream of the study site that influenced the flow along the east side of the channel, pushing more of the flow toward the west side and increasing the measured velocities on that side of the channel.

Upper Placer transect 1's somewhat lower measured velocities on the west side of the channel and somewhat higher measured velocities on the east side of the channel may be attributed to a feature in the bed topography that was not adequately captured in the bed file used to construct the RIVER2D model. This feature likely forced the flow toward the east side of the channel, decreasing the measured velocities on the west side of the channel while increasing the measured velocities on the east side of the channel.

Lower Placer transect 2's significant deviations in simulated velocity can likely be attributed to features and differences in the width of the creek channel upstream of transect that concentrated more of the flow toward the middle part of the channel, increasing the measured velocities toward the middle of the channel at transect 2 and decreasing the measured velocities toward the east and west sides of the channel. Because these features and differences in the channel width were upstream of the study site, their influences were not reflected in the RIVER2D model of the study site.

RIVER2D Model Simulation Flow Runs

Peltier and NEED Camp had eddies on the downstream boundary which were likely responsible for those files with Net Q exceeding 1%. In the case of the Upper Placer and Lower Placer files where the Net Q exceeded 1%, a small area of bed topography that was higher in elevation than the surrounding bed topography and dry at the lower flows being simulated appears to have caused a slight eddy upstream of the boundary that likely resulted in the Net Q exceeding 1%. With the exception of Peltier, we still considered these production cdg files for these sites 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 greater than the accuracy for USGS gages, and is considered acceptable. In the case of Peltier, where two of the production files had Net Q values that exceeded 5%, given the error in WSEL calibration, we believe that the bed topography data collected for Peltier site did not adequately characterize the bed topography. The errors in the modeled bed topography likely were also a likely cause, along with the previously described eddy on the downstream boundary, for the high number of Net Q values that exceeded 1%. We considered the production runs where the maximum Froude Number was greater than 1 to be acceptable since the maximum Froude Number was only greater than 1 at a few nodes, with the vast majority of the area within the sites having maximum Froude Numbers less than 1. Also, as described previously, these nodes were located either at water's edge or where water depth was extremely shallow, typically approaching zero and would be expected to have an insignificant effect on the model results.

Habitat Suitability Criteria (HSC) Data Collection

Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. For spring-run Chinook salmon, the unsteady flow conditions resulted in some uncertainty that the measured depths and velocities were the same as those present at the time of redd construction. However, the Red Bluff Office staff were conducting spawning surveys approximately every 2 weeks and thus any redds measured were constructed within the last 2 weeks, increasing the likelihood that the measured depths and velocities were the same as those present during redd construction. For steelhead/rainbow trout in the Upper Alluvial Segment, the steady flow conditions increased the likelihood that the measured depths and velocities in this segment were the same as those present at the time of redd construction. However, for steelhead/rainbow trout in the Canyon Segment the unsteady flow conditions resulted in some uncertainty that the measured depths and velocities were the same as those present at the time of redd construction. As with the spring-run Chinook salmon spawning data collection, the Red Bluff Office staff were conducting spawning surveys approximately every 2 weeks and thus any redds measured were constructed within the last 2 weeks, increasing the likelihood that the measured depths and velocities were the same as those present during redd construction.

Habitat Suitability Criteria (HSC) Development

Only 50 unoccupied points were selected for the smaller sites because their small size limited the number of available points. The small number of points to be selected from in the smaller sites necessitated the use of all unoccupied points (approximately 50) resulting from the random selection process for those sites.

It should be noted that normally the occupied data points (locations of the redds) are recorded with total station and the depth, velocity and substrate data are collected during a specific time period when flows are relatively constant. Therefore, when one runs the final River2D files for the study sites, one can, with some confidence, assume that the unoccupied locations and accompanying depth, velocity and substrate values selected within the files accurately reflect the conditions present where spawning did not occur. However, in this study, both spring-run Chinook salmon and steelhead/rainbow trout spawning data were collected over a three year period (2003-2005) over varying flow ranges. The precise locations of these redds were not identified using total station, with the exception of the 7 spring-run Chinook salmon redds and the 26 steelhead/rainbow trout redds described in the Biological Validation Data Collection section that were used as the occupied data points in this analysis. These occupied data points represent the spawning that had occurred in those sites for a limited time period in 2004. A majority of the redd depths, velocities, and substrate values used in developing the spawning HSC for spring-run Chinook salmon and steelhead/rainbow trout came from different years or time periods, habitat units outside of the study sites, under widely fluctuating flows and without any way of verifying their precise location relative to unoccupied points. The unoccupied data likely includes habitat that is suitable and would be used if more spawners were available to seed the habitat. However, we do not feel that this is a problem, since the logistic regression uses the relative distribution of occupied and unoccupied depths and velocities – as long as fish are selecting their preferred habitat conditions, occupied locations will have a higher suitability than unoccupied locations. A large assumption was made that the selected unoccupied locations were representative for the Upper Alluvial and Canyon Segments for the entire three year period for all the spawning data that were collected, despite the inability to precisely identify the location of a majority of the redds or flows under they were built. Given the potential for the locations where spawning occurs to vary depending on a variety of factors, including flow, temperature, spawning adult numbers, etc. from year to year, it is questionable whether this assumption is valid.

The rapidly decreasing suitability of the initial steelhead/rainbow trout depth criteria for depths greater than 1.8 feet was likely due to the low availability of deeper water in Clear Creek with suitable velocities and substrates rather than a selection by steelhead/rainbow trout of only shallow depths for spawning. The change of the definition of suitable substrate codes in the Gard (1998) depth correction method was because the only substrate code with a suitability greater than 0.5 was 1-2 inches. This substrate code was rare within our study sites. By lowering the suitable substrate cutoff to 0.4, we significantly increased the amount of suitable substrate within our sites, increasing the statistical power of the depth correction method. We concluded for spring-run Chinook salmon that the logistic regression corrected for the low availability of suitable velocities and substrates in deep water.

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 5-8. In general, the spring-run Chinook salmon and steelhead/rainbow trout 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. The main exception to this trend, as discussed below, was for spring-run Chinook salmon depth HSC. We investigated whether data at the upper tails of the distribution had a substantial effect on the spring-run Chinook salmon depth HSC by conducting two alternative logistic regressions: one that eliminated the upper five % of all occupied and unoccupied observations, and one that eliminated all occupied and unoccupied observations with depths greater than 3.7 feet (the value of the 95^{th} percentile unoccupied measurement). This analysis was selected as analogous to what has sometimes been used with Type III HSC (calculated by dividing use by availability), where the upper five % of the data are eliminated to get rid of the inordinate effect of observations at the extremes of the distribution. As shown in Figures 22 and 23, both alternatives still resulted in an optimal suitability at 6 feet. Accordingly, we conclude that the upper tails of the distributions did not have a substantial effect on the spring-run Chinook salmon depth HSC.

Figures 24 to 26 compare the two sets of HSC from this study. The most noticeable difference between the criteria was that spring-run Chinook salmon selected much deeper conditions than steelhead/rainbow trout. As shown in Figure 5, the frequency distribution of occupied and unoccupied locations for spring-run Chinook salmon is similar for depths up to around 3.5 feet, while the relative frequency for depths greater than 3.5 feet is greater for occupied locations than for unoccupied locations. This pattern of data resulted in the logistic regression having lower suitabilities at shallower depths and suitabilities increasing up to 6.0 feet. Even the occupied data showed significant differences between the steelhead/rainbow trout and spring-run Chinook salmon redds – there was only one steelhead/rainbow trout redd with a depth of more than 3.5 feet, while 13% of the spring-run Chinook salmon redds had depths greater than 3.5 feet. However, after the application of the Gard (1998) depth correction method, the steelhead/ rainbow trout and spring-run Chinook salmon have similar suitabilities at 6 feet (0.83 for steelhead/rainbow trout versus 1.00 for spring-run Chinook salmon), suggesting that the logistic regression for spring-run Chinook salmon and the Gard (1998) depth correction method for steelhead/rainbow trout are accomplishing the same result, namely adjusting for the limited availability of deeper waters.

Spring-run Chinook salmon selected faster velocities and larger substrates than steelhead/ rainbow trout. We attribute this to the larger size of adult spring-run Chinook salmon, versus steelhead/rainbow trout. Bioenergetic considerations and physical abilities of adult salmonids

Figure 22. Comparison of spring-run Chinook salmon depth HSC from this study with an alternative depth HSC computed from data that excluded the upper five percent of occupied and unoccupied observations.

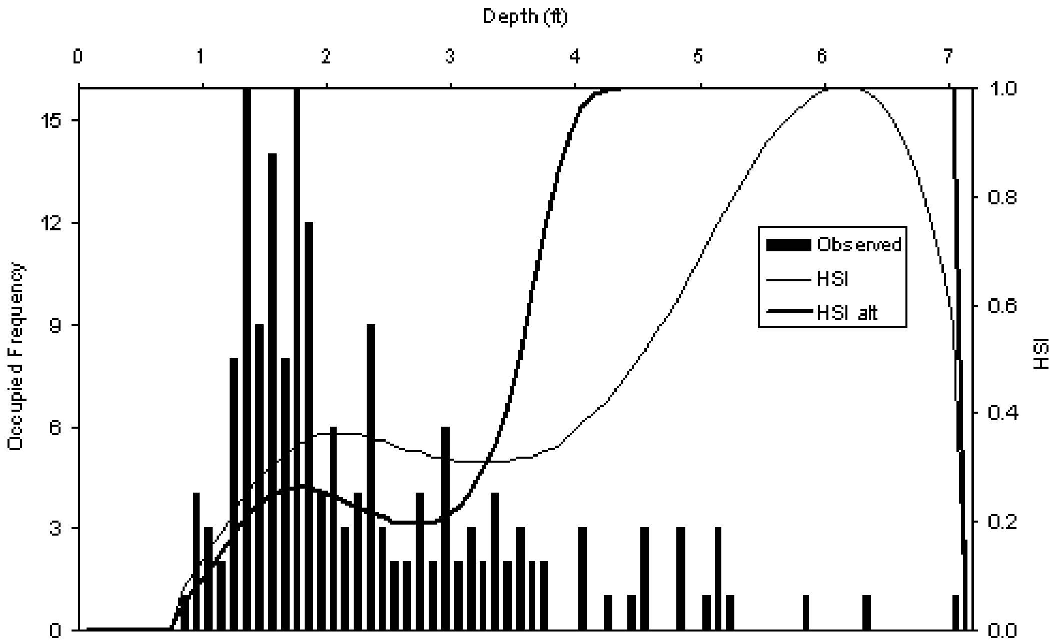


Figure 23. Comparison of spring-run Chinook salmon depth HSC from this study with an alternative depth HSC computed from data that excluded occupied and unoccupied observations with depths greater than 3.7 feet (the value of the 95th percentile unoccupied measurement).

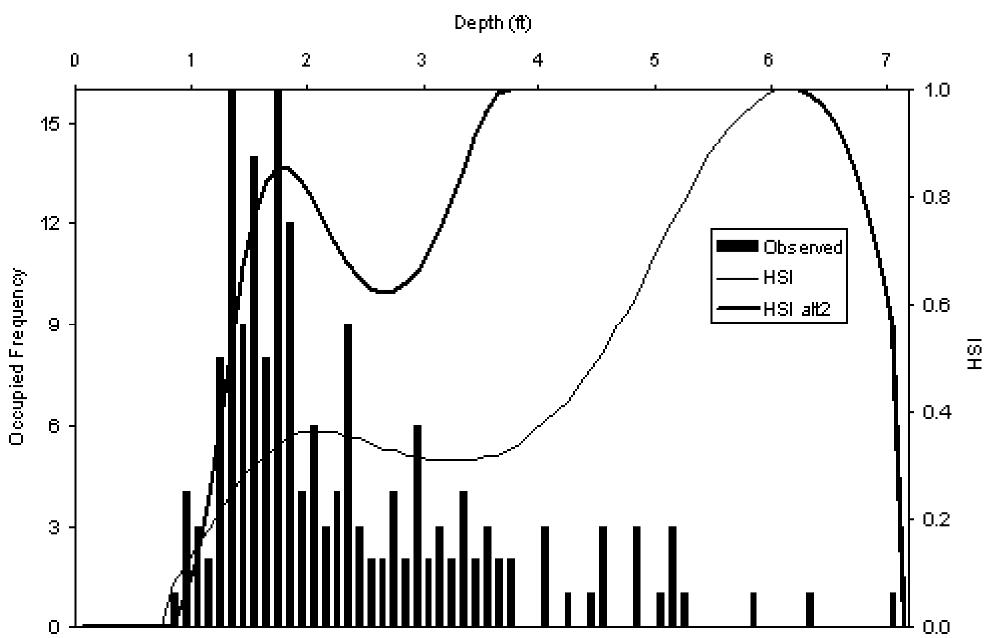


Figure 24. Comparison of depth HSC from this study. These criteria indicate that spring-run Chinook salmon selected deeper conditions than steelhead/rainbow trout.

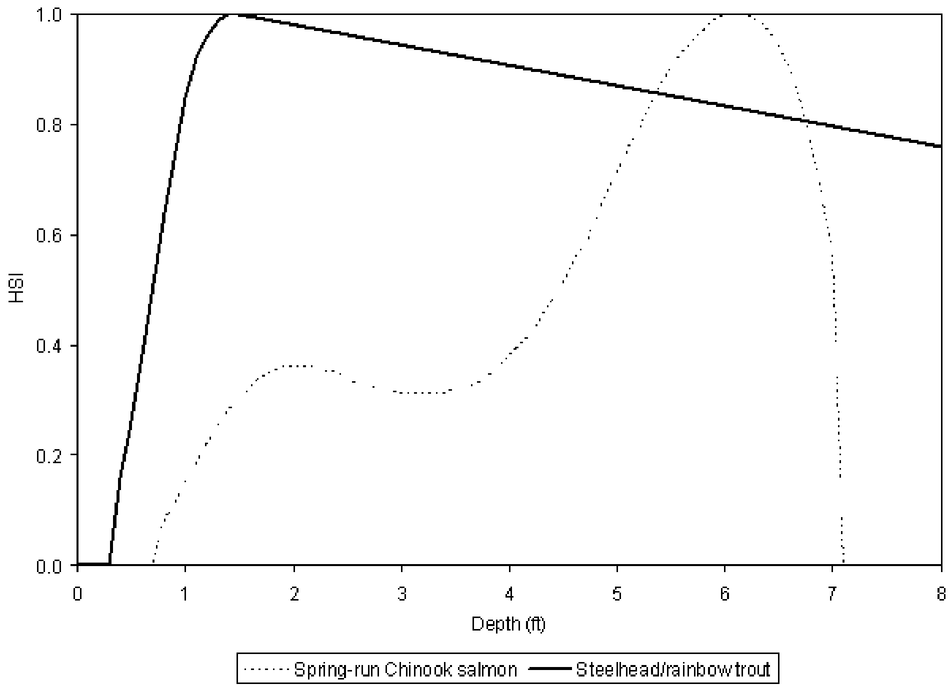


Figure 25. Comparison of velocity HSC from this study. These criteria indicate that spring-run Chinook salmon selected faster velocities than steelhead/rainbow trout.

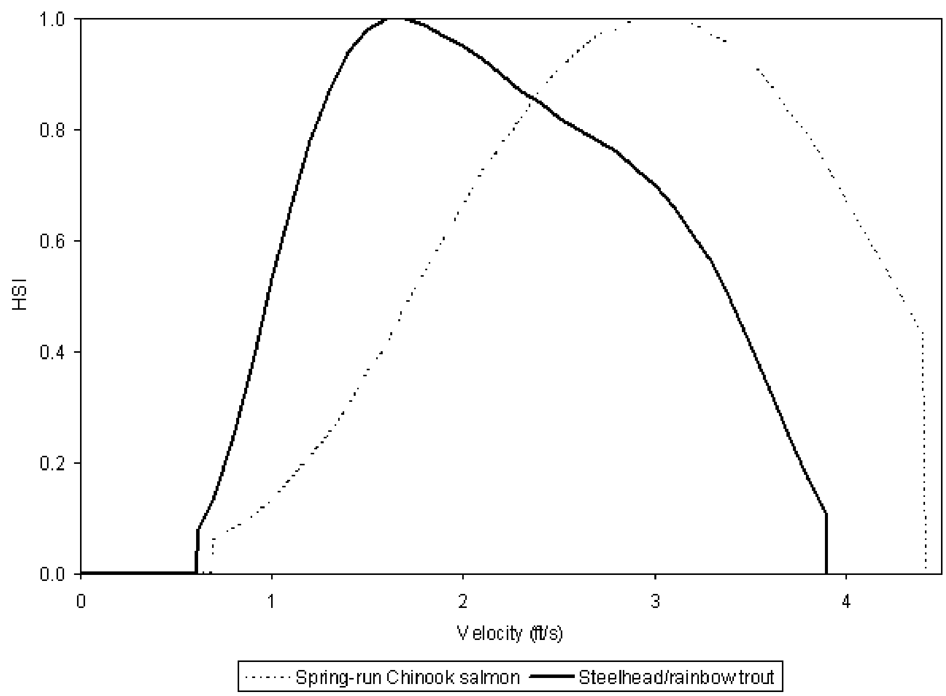
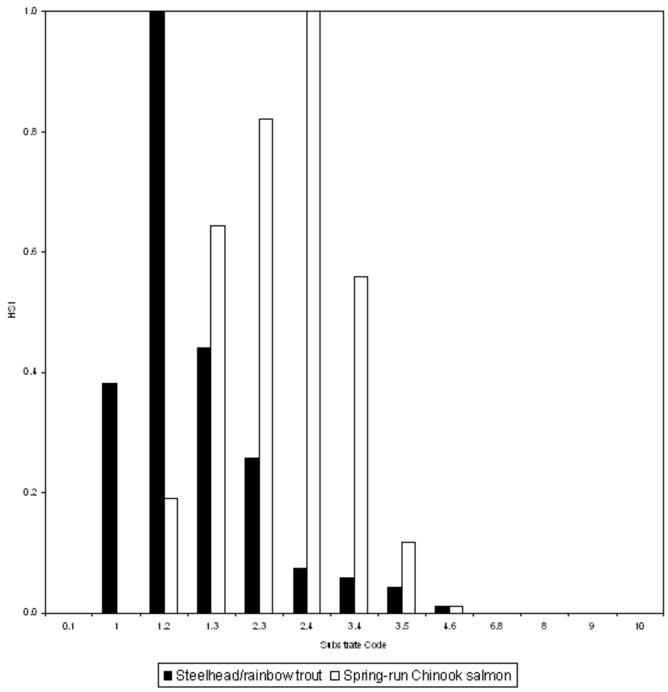


Figure 26. Comparison of substrate HSC from this study. These criteria indicate that spring-run Chinook salmon selected larger substrates than steelhead/rainbow trout.



will limit the maximum velocity and substrate size used for spawning, while requirements for the developing eggs and larvae for sufficient intragravel velocities will set a lower limit on the velocities and substrate size used for spawning (Gard 1998). It is logical that chinook salmon, with larger body sizes, could construct redds in faster conditions and with larger substrate sizes, than the smaller steelhead/rainbow trout. Similarly, the larger egg size of chinook salmon would require higher intragravel velocities, versus the smaller eggs of steelhead/rainbow trout. This would translate into chinook salmon constructing their redds in faster conditions and with larger substrate sizes than steelhead/rainbow trout.

Figures 27 to 31 compare the criteria from this study with the criteria from other studies. We compared all of the depth and velocity criteria with those from Bovee (1978), since the Bovee (1978) criteria are commonly used in instream flow studies as reference criteria. For spring-run Chinook salmon spawning, the only two additional criteria we were able to identify, in addition to criteria we developed on Butte Creek, were from the Yakima River in Washington (Stempel 1984) and Panther Creek in Idaho (Reiser 1985). We also compared the spring-run Chinook salmon criteria from this study to the fall-run Chinook salmon criteria used on a previous instream flow study on Clear Creek (California Department of Water Resources 1985). The previous study did not model habitat for spring-run Chinook salmon. For steelhead/rainbow trout spawning, we compared the criteria from this study with those used on the Feather River (California Department of Water Resources 2004) and on the Carmel River (Dettman and Kelley

Figure 27. Comparison of spring-run Chinook salmon depth HSC from this study with other spring-run Chinook salmon spawning depth HSC and the fall-run Chinook salmon spawning depth HSC used in the previous instream flow study on Clear Creek. The criteria from this study show a substantial shift to more suitability at greater depths than the criteria from other studies.

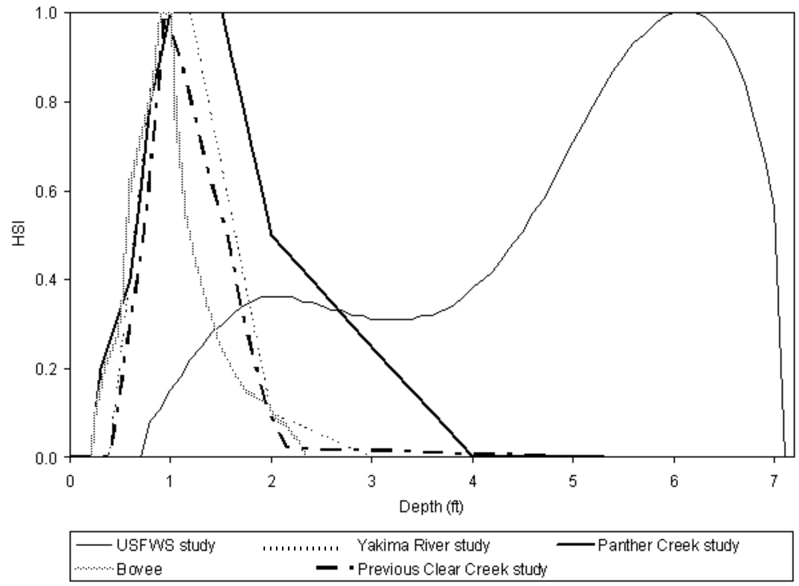


Figure 28. Comparison of spring-run Chinook salmon velocity HSC from this study with other spring-run Chinook salmon spawning velocity HSC and the fall-run Chinook salmon spawning velocity HSC used in the previous instream flow study on Clear Creek. The criteria from this study show a shift to more suitability at higher velocities than for other studies.

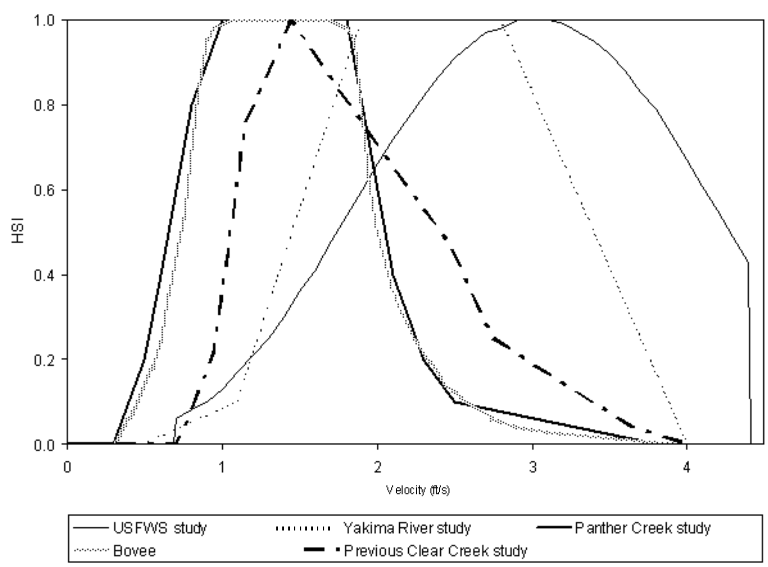


Figure 29. Comparison of steelhead/rainbow trout depth HSC from this study with other steelhead/rainbow trout spawning depth HSC. The criteria from this study show a higher suitability at greater depths than the criteria from other studies.

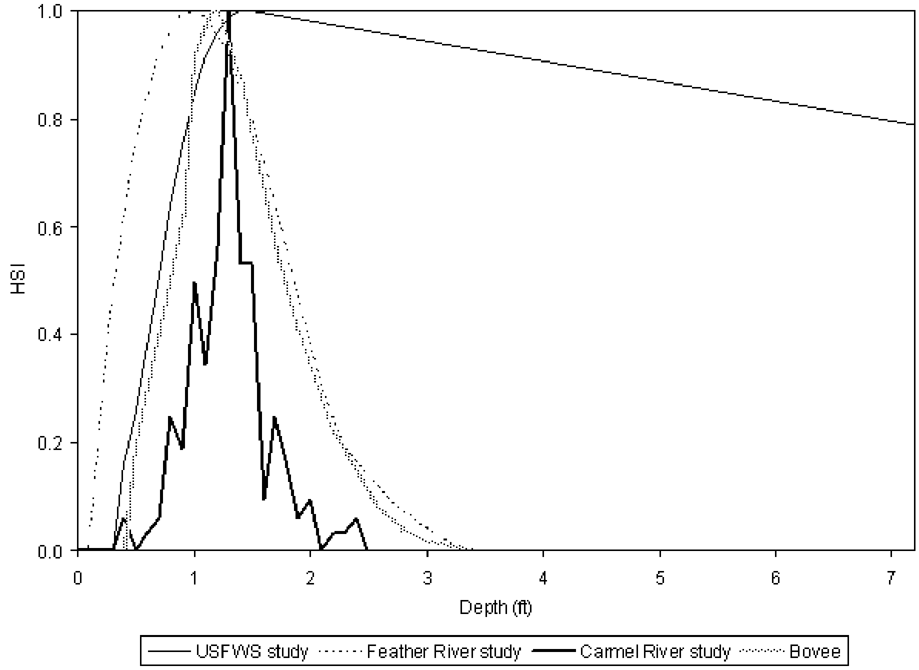


Figure 30. Comparison of steelhead/rainbow trout velocity HSC from this study with other steelhead/rainbow trout spawning velocity HSC. The criteria from this study show suitability extending to higher velocities than for other studies.

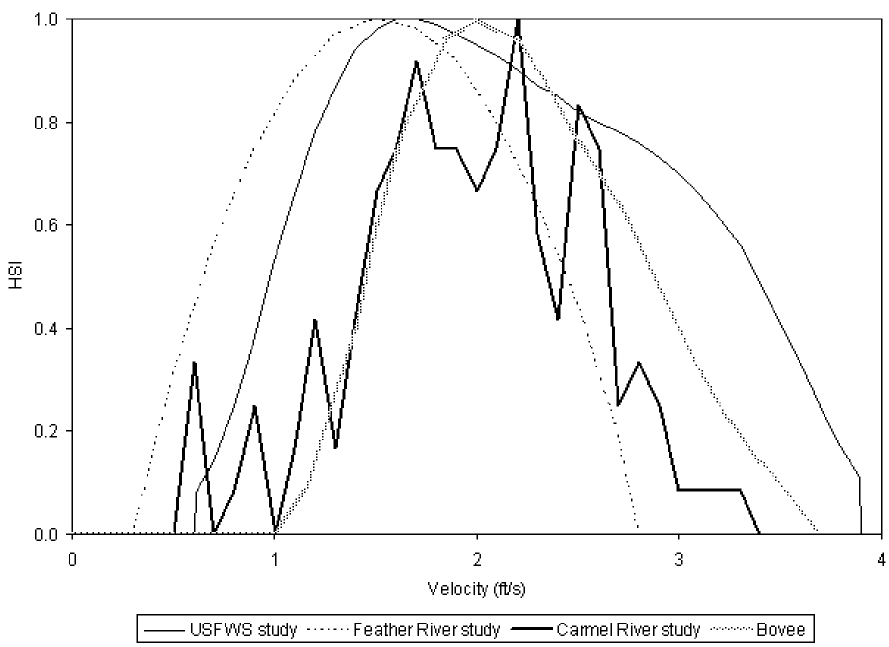
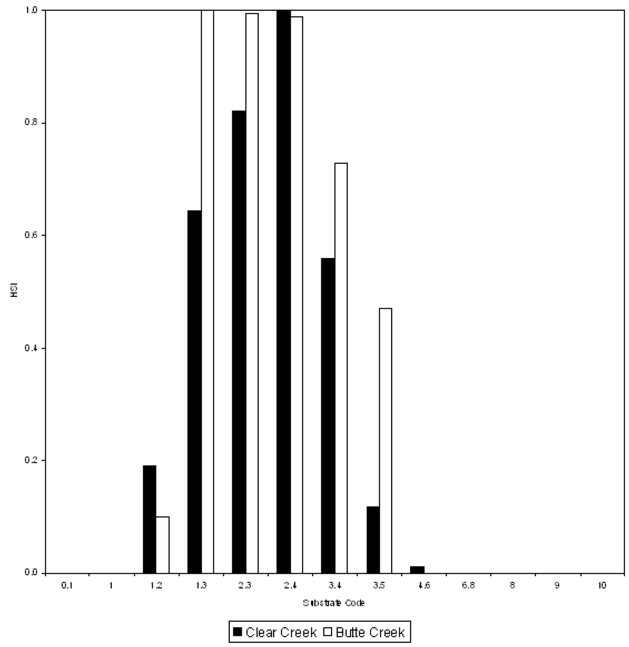


Figure 31. Comparison of spring-run Chinook salmon substrate HSC from this study with other spring-run Chinook salmon spawning substrate HSC.



1986), the only other steelhead spawning criteria sets from California that we were able to identify. The previous instream flow study on Clear Creek used the Bovee (1978) steelhead criteria. For substrate, we were limited to comparing the criteria from this study to criteria we had developed on other studies, due to the unique substrate coding system we used. We compared the spring-run Chinook salmon spawning criteria from this study to the criteria we developed on Butte Creek (U.S. Fish and Wildlife Service 2003a). We have not previously developed criteria for steelhead/rainbow trout spawning.

The spring-run Chinook salmon depth criteria from this study show a substantial shift to more suitability at greater depths than the criteria from other studies. We attribute this to the greater availability of deeper-water conditions with suitable velocities and substrates in Clear Creek versus the rivers where the other criteria were developed, the use in this study of a logistic regression to address availability, and that the other sets of criteria underestimate the suitability of deeper waters. The differences between the spring-run Chinook salmon depth criteria from this study, versus from other studies, can be attributed to the same reasons as the difference between the spring-run Chinook salmon and steelhead/rainbow trout criteria from this study, as discussed above. The spring-run Chinook salmon velocity criteria from this study show greater suitability at higher velocities than the other criteria. We surmise that the limited availability of faster conditions in the Yakima River, Panther Creek and the streams used for the Bovee (1978) criteria biased these criteria towards slower conditions. The fall-run Chinook salmon criteria used in the earlier instream flow study on Clear Creek were developed on Battle Creek (Vogel

1982). The Battle Creek velocity criteria were based on velocities measured at 0.5 foot from the substrate, rather than on mean column velocities. The velocity at 0.5 foot off the bottom would be expected to be less than the mean column velocity for depths greater than 1.2 feet. As a result, the Battle Creek velocity criteria are biased towards lower velocities. The steelhead/rainbow trout depth criteria from this study show a slower decline in suitability with increasing depth than the criteria from other studies. We attribute this to the use in this study of the Gard (1998) method to correct for availability, and that the other sets of criteria underestimate the suitability of deeper waters. The steelhead/rainbow trout velocity criteria from this study show suitability extending to higher velocities than the criteria from other studies. We attribute this to the use in this study of a logistic regression to address availability, and that the other criteria, developed using use data, underestimate the suitability of faster conditions (in the range of 3 to 4 feet/sec) because they do not take availability into account.

Although there are differences in suitabilities for specific substrate codes for the spring-run Chinook salmon spawning substrate criteria in this study versus the Butte Creek criteria, there are no substantial differences in the patterns of the criteria. Accordingly, we attribute differences between the two substrate criteria to river-specific differences in substrate availability.

Biological Validation

The plots of combined suitability of redd locations in Appendix J are similar to the methods used for biovalidation in Hardy and Addley (2001). In general, Hardy and Addley (2001) found a better agreement between redd locations and areas with high suitability than we found in this study. We attribute this difference to Hardy and Addley's (2001) use of polygons to map substrate. We feel that our results could have been as good as Hardy and Addley's (2001) if we had mapped substrate polygons using a total station or RTK GPS.

An increased density of substrate points would have been required to more accurately represent the substrate and thus the predicted combined suitability of redd locations in the 2-D model. However, this would likely had little effect on the resulting flow-habitat relationship. Specifically, flow-habitat relationships are not very sensitive to substrate data, since substrate does not change with flow. The only effect of substrate data on flow-habitat relationships is when depths and velocities in areas with suitable substrates differ from the depths and velocities in areas with unsuitable substrates. For example, if the substrates are suitable in the thalweg (where the highest depths and velocities typically are found) but unsuitable in the remaining portion of the channel, the peak WUA will be at a lower flow than if the substrates are unsuitable in the thalweg but suitable in the remaining portion of the channel. The 2-D model interpolates substrate at a given location by the substrate at the nearest point in the substrate file. If substrate data varies more laterally (across the channel) than longitudinally (upstream and downstream), adding longitudinal breaklines and/or increasing node density in the substrate file to force the 2-D model to predict substrate at a given location based on the nearest longitudinal point can improve the ability of the 2-D model to predict compound suitability (U.S. Fish and Wildlife Service 2003b). In our test of this technique on the Lower American River, the WUA predicted with the modified substrate file differed little from the WUA predicted by the original substrate file (U.S. Fish and Wildlife Service 2003b). The prediction by the 2-D model that redd locations were dry or too shallow can be attributed to either: 1) the model under-predicting the WSELs in the site at the flow at which redd data was collected; or 2) to longitudinal curvature in the bed topography which was not captured by the data collection, for redds that were located near the water's edge.

The statistical tests used in this report for biological validation differ from those used in Guay et al. (2000). In Guay et al. (2000), biological validation was accomplished by testing for a statistically significant positive relationship between fish densities, calculated as the number of fish per area of habitat with a given range of habitat suitability (i.e. 0 to 0.1), and habitat quality indexes. We were unable to apply this approach in this study because of the low number of redds and low area of habitat with high values of habitat quality. As a result, the ratio of redd numbers to area of habitat for high habitat quality values exhibits significant variation simply due to chance. Both the number of redds and amount of habitat at high values of habitat quality is quite sensitive to the method used to calculate combined suitability. When combined suitability is calculated as the product of depth, velocity and substrate suitability, as is routinely done in instream flow studies, there will be very low amounts of high habitat quality values. For example, if depth, velocity and substrate all have a high suitability of 0.9, the combined suitability would be only 0.7. In contrast, Guay et al. (2000) calculated combined suitability as the geometric mean of the individual suitabilities; for the above example, the combined suitability calculated as a geometric mean would be 0.9. The successful biological validation in this study increases the confidence in the use of the flow-habitat relationships from this study for fisheries management in Clear Creek.

Habitat Simulation

An earlier study (California Department of Water Resources 1985) modeled fall-run Chinook salmon and steelhead spawning 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 spawning habitat and did not have any study sites in the Upper Alluvial Segment, although there was one study site in the Canyon Segment (just upstream of our Upper Placer 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 only placing sites for spawning in heavy spawning-use areas. 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 29 and 30, the results from this study predicted a peak amount of habitat at higher flows than the California Department of Water Resources (1985) study. When the results of our study for only the Canyon Segment are compared to the California Department of Water Resources (1985) study (Figures 31 and 32), there is less of a difference between the two studies. 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 apply the method used in this report for correcting depth HSC for availability; 3) sites for the California Department of Water Resources (1985) study were placed using a representative reach approach, as opposed to only placing sites in high-spawning-use areas, as was employed in this study; and 4) 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 correcting depth HSC for availability, were biased towards slower and shallower conditions. Using a representative reach approach for modeling spawning habitat fails to take into account salmonids' preference for spawning in areas with high gravel permeability (Vyverberg et al. 1996), while having sites only in high-use spawning areas indirectly takes preference for high gravel permeability. The assumption is that high-use spawning areas have high gravel permeability since salmonids are selecting these areas for spawning. We were not able to compare the difference in magnitude of the results from this study versus the California Department of Water Resources (1985) study because the California Department of Water Resources (1985) study only gives habitat results expressed as the percentage of maximum WUA for the reach from Clear Creek Road Bridge to Whiskeytown Dam (the combination of our Upper Alluvial and Canyon Segments).

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 138 different hydrograph management scenarios (each of the 23 simulation flows in each of the 6 spawning months – September to October for spring-run, and January to April for steelhead/rainbow trout). For example, increasing flows from 200 cfs to 400 cfs in September would result in an increase of 71.9% of habitat during this month for spring-run Chinook salmon spawning. Based on the conceptual model presented in the introduction, this increase in spawning habitat could decrease redd superposition, increasing reproductive success which could result in an increase in spring-run Chinook salmon 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 and for fall-run Chinook salmon spawning, which will be addressed in future

Figure 29. Comparison of fall-run Chinook salmon flow-habitat relationship from California Department of Water Resources (1985) and spring-run 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.

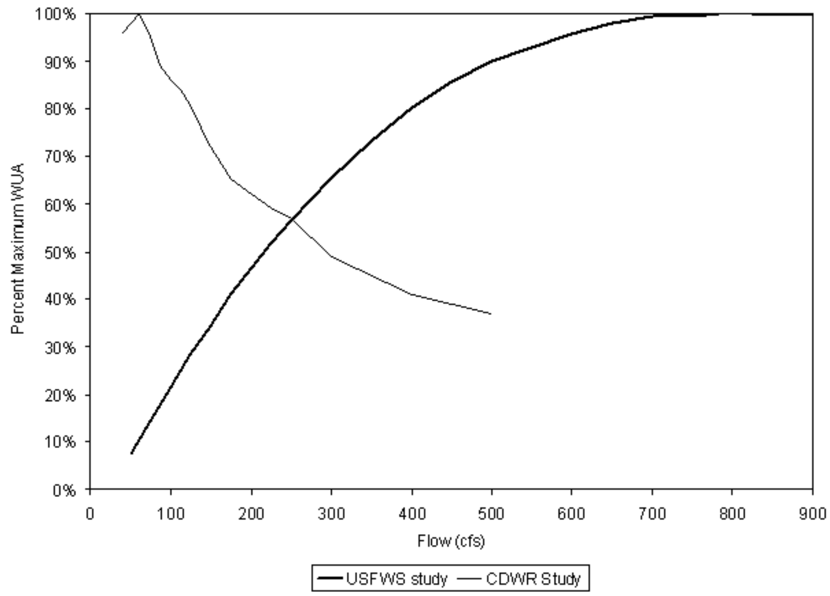


Figure 30. Comparison of steelhead/rainbow trout flow-habitat relationships from California Department of Water Resources (1985) and for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.

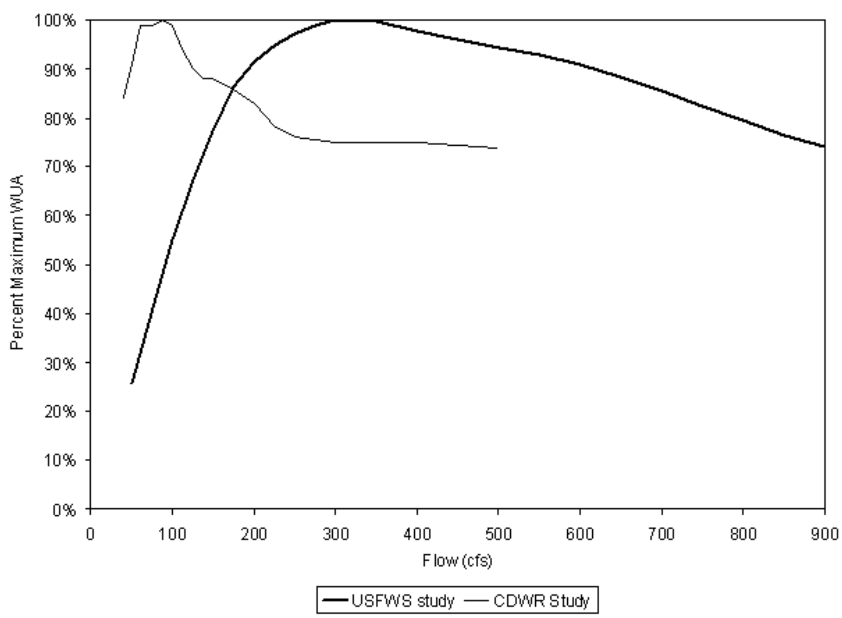


Figure 31. Comparison of fall-run Chinook salmon flow-habitat relationship from California Department of Water Resources (1985) and spring-run Chinook salmon flow-habitat relationship for the Canyon Segment from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.

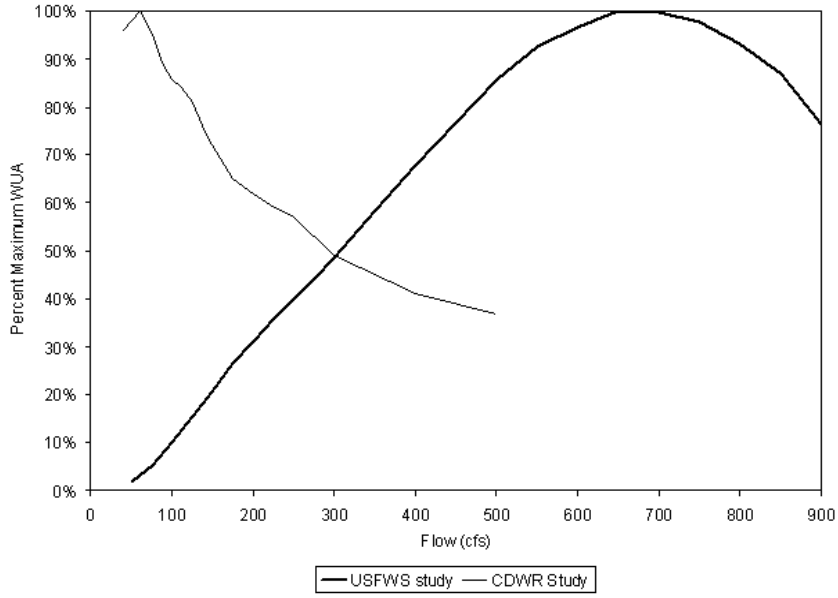
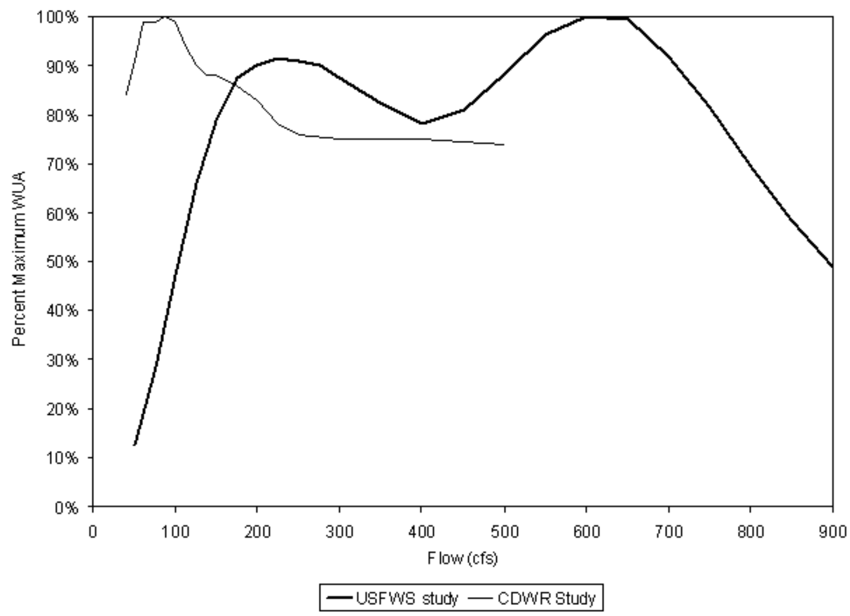


Figure 32. Comparison of steelhead/rainbow trout flow-habitat relationships from California Department of Water Resources (1985) and for the Canyon Segment from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.



reports. We do not feel that there are any significant limitations of the model. This study supported and achieved the objective of producing models predicting the availability of physical habitat in Clear Creek between Whiskeytown Dam and Clear Creek Road Bridge for spring-run Chinook salmon and steelhead/rainbow trout spawning over a range of stream flows.

The results of this study are intended to support or revise the flow recommendations in the introduction. Based on the results of this study, it appears that the flow recommendations in the introduction during the spring-run Chinook salmon spawning and incubation period of September-December (150 cfs or less in September and 200 cfs October-December), particularly in the Upper Alluvial Segment, are significantly reducing the amount of habitat available to the spawning spring-run Chinook salmon. Our results indicate that flows exceeding 600 cfs in the Upper Alluvial and Canyon Segments are needed throughout September-December to increase the habitat availability and productivity of the spring-run Chinook salmon population in Clear Creek. Our results also indicate that flows of 600 cfs or greater will provide greater than 96% of the maximum WUA. With regards to steelhead/rainbow trout, the results of our study suggest that the flow recommendations in the introduction during the steelhead/rainbow trout spawning and incubation period of January-June (200 cfs) may be close to achieving maximum habitat availability and productivity for spawning steelhead/rainbow trout in Clear Creek (greater than 91% of maximum WUA).

Sensitivity Analysis

The first alternative depth HSC should be taken with a great deal of caution due to the small sample size of use observations (6 redds) used in applying the Gard (1998) depth correction methodology. This small sample size resulted in use frequencies of, respectively, 3, 0, 2 and 1 for the four depth increments, and as a result, a p-value of 0.6 for the relative use regression. Based on the logistic regression showing a clear preference for deeper waters (on the order of 6 feet), we conclude that the original depth HSC best represents the depth habitat selection by spring-run Chinook salmon spawning in Clear Creek. The results of the sensitivity analysis indicate that the depth HSC only influenced the shape of the flow-habitat curve for flows greater than around 450 cfs. We conclude that the rapid increase in the amount of spring-run Chinook salmon spawning habitat from 200 to 450 cfs is due to the velocity HSC. Specifically, at 450 cfs, the available velocities in the six study sites reach the optimum spring-run Chinook salmon spawning velocities of 2.9 to 3.1 feet/sec. As a result, the amount of spawning habitat increases with increasing flows up to 450 cfs for all three of the depth HSC.

REFERENCES

Annear, T., I. Chirholm, H. Beecher, A. Locke, P. Aarestad, N. Burkhart, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, C. Stalnaker and R. Wentworth. 2002. Instream Flows for Riverine Resource Stewardship. Instream Flow Council, Cheyenne, WY.

Bovee, K.D. 1978. Probability of use criteria for the family salmonidae. Instream Flow Information Paper 4. U.S. Fish and Wildlife Service FWS/OBS-78/07. 80 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U.S. Fish and Wildlife Service Biological Report 86(7). 235 pp.

Bovee, K.D. and J.M. Bartholow. 1996. IFIM phase III study implementation. Pages 138-185 in KD. Bovee, editor. The Complete IFIM: A Coursebook for IF 250. U.S. Geological Survey, Fort Collins, CO.

California Department of Water Resources. 1985. Clear Creek fishery study appendix, instream flow needs data, June 1985. California Department of Water Resources, Northern District, Red Bluff, CA.

California Department of Water Resources. 2004. Phase 2 report evaluation of project effects on instream flows and fish habitat, SP F-16, Oroville Facilities Relicensing FERC Project No. 2100. California Department of Water Resources, Sacramento, CA.

Clackamas Instream Flow/Geomorphology Subgroup (CIFGS) 2003. Estimating salmonid habitat availability in the lower oak grove fork using expert habitat mapping, summary of methods and preliminary results. Report prepared by McBain and Trush Inc., Arcata, California, for Clackamas Instream Flow/Geomorphology Subgroup, March 5, 2003.

Dettman, D.H., and D.W. Kelley. 1986. Assessment of the Carmel River steelhead resource. Vol 1: Biological investigations. Report to Monterey Peninsula Water Management District. Monterey, CA.

Gard, M. 1998. Technique for adjusting spawning depth habitat utilization curves for availability. Rivers: 6(2):94-102.

Geist, D.R., J. Jones and D.D. Dauble. 2000. Suitability criteria analyzed at the spatial scale of redd clusters improved estimates of fall Chinook salmon (Oncorhynchus tshawytscha) spawning habitat use in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57:1636-1646.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1995. Two-dimensional modeling of flow in aquatic habitats. Water Resources Engineering Report 95-S1, Department of Civil Engineering, University of Alberta, Edmonton, Alberta. March 1995.

Guay, J.C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (Salmo salar). Canadian Journal of Fisheries and Aquatic Sciences 57:2065-2075.

Hardy, T.B. and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River, phase II, final report. Prepared for U.S. Department of the Interior. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, UT.

Knapp, R.A. and H.K. Preisler. 1999. Is it possible to predict habitat use by spawning salmonids? A test using California golden trout (Oncorhynchus mykiss aguabonita). Canadian Journal of Fisheries and Aquatic Sciences 56:1576-1584.

McHugh, P., and P. Budy. 2004. Patterns of spawning habitat selection and suitability for two populations of spring chinook salmon, with an evaluation of generic verses site-specific suitability criteria. Transactions of the American Fisheries Society 133:89-97.

Milhous, R. T., M. A. Updike and D. M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U. S. Fish and Wildlife Service Biological Report 89(16).

Parasiewicz, P. 1999. A hybrid model – assessment of physical habitat conditions combining various modeling tools. In: Proceedings of the Third International Symposium on Ecohydraulics, Salt Lake City, UT.

Payne and Associates. 1998. RHABSIM 2.0 for DOS and Window’s User’s Manual. Thomas R. Payne and Associates, Arcata, CA.

Reiser, DW. 1985. Panther Creek, Idaho. Habitat rehabilitation - final report. Contract No. DE-AC79-84BP17449. Bonneville Power Administration, Portland, OR.

Rubin, S. P., T. C. Bjornn and B. Dennis. 1991. Habitat suitability curves for juvenile Chinook salmon and steelhead development using a habitat-oriented sampling approach. Rivers: 2(1): 12-29.

Snider, B., K. Vyverberg and S. Whiteman. 1996. Chinook salmon redd survey lower American river fall 1994. California Department of Fish and Game, Environmental Services Division, Stream Flow and Habitat Evaluation Program, Sacramento, CA. 55 pp.

Steffler, P. 2001a. RIVER2D_Bed. Bed topography file editor - version 1.23. User's manual. University of Alberta, Edmonton, Alberta. 24 pp. http://bertram.civil.ualberta.ca/download.htm

Steffler, P. 2001b. R2D_Mesh - mesh generation program for RIVER2D two-dimensional depth averaged finite element hydrodynamic model - version 2.01. User's manual. University of Alberta, Edmonton, Alberta. 22 pp. http://bertram.civil.ualberta.ca/download.htm

Steffler, P. and J. Blackburn. 2001. RIVER2D: Two-dimensional depth averaged model of river hydrodynamics and fish habitat. Introduction to depth averaged modeling and user's manual. University of Alberta, Edmonton, Alberta. 88 pp. http://bertram.civil.ualberta.ca/download.htm

Stempel, J.M. 1984. Development of fish preference curves for spring chinook and rainbow trout in the Yakima River Basin. U.S. Fish & Wildlife Service, Moses Lake, WA.

Tiffan, K.E., R.D. Garland and D.W. Rondorf. 2002. Quantifying flow-dependent changes in subyearling fall Chinook salmon rearing habitat using two-dimensional spatially explicit modeling. North American Journal of Fisheries Management 22:713-726.

U. S. Fish and Wildlife Service. 1994. Using the computer based physical habitat simulation system (PHABSIM). U. S. Fish and Wildlife Service, Fort Collins, CO.

U. S. Fish and Wildlife Service. 2000. Effects of the January 1997 flood on flow-habitat relationships for steelhead and fall-run Chinook salmon spawning in the Lower American River. U. S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2001. Final restoration plan for the anadromous fish restoration program. A plan to increase natural production of anadromous fish in the Central Valley of California. January 9, 2001. Prepared for the U. S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. U.S. Fish and Wildlife Service, Stockton, CA.

U. S. Fish and Wildlife Service. 2003a. Flow-habitat relationships for spring-run Chinook salmon spawning in Butte Creek. U. S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2003b. Comparison of PHABSIM and 2-D modeling of habitat for steelhead and fall-run Chinook salmon spawning in the Lower American River. U. S. Fish and Wildlife Service, Sacramento, CA.

Vogel, D.A. 1982. Preferred spawning velocities, depths, and substrates for fall chinook salmon in Battle Creek, California. U.S. Fish & Wildlife Service, Red Bluff, CA.

Vyverberg, K., B. Snider and R.G. Titus. 1996. Lower American river Chinook salmon spawning habitat evaluation October 1994. California Department of Fish and Game, Environmental Services Division, Stream Flow and Habitat Evaluation Program, Sacramento, CA. 120 pp.

Yalin, M. S. 1977. Mechanics of Sediment Transport. Pergamon Press, New York.

Zar, J. H. 1984. Biostatistical Analysis, Second Edition. Prentice-Hall, Inc, Englewood Cliffs, NJ.

APPENDIX A
PHABSIM WSEL CALIBRATION

Stage of Zero Flow Values

Study Site	XS #	SZF
Spawn Area 4	1	94.90
Spawn Area 4	2	97.60
Peltier	1	94.10
Peltier	2	99.50
NEED Camp	1	95.90
NEED Camp	2	98.20
Indian Rhubarb	1, 2	93.40
Upper Placer	1	93.90
Upper Placer	2	95.32
Lower Placer	1	89.70
Lower Placer	2	90.29

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range	Calibration Flows	Method	Parameters
Spawn Area 4	1	50-900	70, 200, 446, 711	IFG4	—
Spawn Area 4	2	50-900	70, 200, 446, 705	IFG4	—
Peltier	1	50-450	70, 200, 446	IFG4	—
Peltier	1	500-900	200, 446, 750	IFG4	—
Peltier	2	50-900	70, 200, 446, 750	IFG4	—
NEED Camp	1	50-900	71, 213, 447, 712	IFG4	—
NEED Camp	2	50-900	71, 213, 447, 712	IFG4	—
Indian Rhubarb	1	50-225	71, 214, 232	IFG4	—
Indian Rhubarb	1	250-900	232, 447, 612	IFG4	—
Indian Rhubarb	2	50-900	71, 232, 447, 612	IFG4	—
Upper Placer	1	50-900	72, 251, 454, 656	IFG4	—
Upper Placer	2	50-900	72, 251, 454, 656	MANSQ	β = 0.36, CALQ = 72 cfs
Lower Placer	1	50-900	72, 255, 454, 666	MANSQ	β = 0.00, CALQ = 454 cfs
Lower Placer	2	50-900	72, 252, 454, 666	WSP	n = 0.04, 72 RM = 3.08, 253 RM = 1.87, 454 RM = 1.49, 666 RM = 1.28

Spawn Area 4

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 70 cfs	200 cfs	446 cfs	711 cfs	Difference (measured vs. pred. WSELs) 70 cfs	200 cfs	446 cfs	711 cfs
1	2.14	2.27	0.8	0.5	4.7	3.2	0.01	0.01	0.07	0.07

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 70 cfs	200 cfs	446 cfs	705 cfs	Difference (measured vs. pred. WSELs) 70 cfs	200 cfs	446 cfs	705 cfs
2	2.82	5.10	3.7	3.6	6.9	6.3	0.02	0.03	0.08	0.09

Peltier

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 70 cfs	200 cfs	446 cfs	Difference (measured vs. pred. WSELs) 70 cfs	200 cfs	446 cfs
1	2.79	2.90	2.0	4.5	2.3	0.02	0.05	0.03

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 200 cfs	446 cfs	750 cfs	Difference (measured vs. pred. WSELs) 200 cfs	446 cfs	750 cfs
1	2.28	4.14	2.9	6.4	3.3	0.04	0.11	0.08

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 70 cfs	200 cfs	446 cfs	750 cfs	Difference (measured vs. pred. WSELs) 70 cfs	200 cfs	446 cfs	750 cfs
2	2.15	2.54	2.2	3.0	2.1	2.8	0.02	0.04	0.04	0.06

NEED Camp

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 71 cfs	213 cfs	447 cfs	712 cfs	Difference (measured vs. pred. WSELs) 71 cfs	213 cfs	447 cfs	712 cfs
1	2.87	7.01	5.8	7.7	6.8	7.6	0.03	0.06	0.07	0.10

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 71 cfs	213 cfs	447 cfs	712 cfs	Difference (measured vs. pred. WSELs) 71 cfs	213 cfs	447 cfs	712 cfs
2	3.60	5.69	2.8	2.9	8.8	7.21	0.02	0.02	0.07	0.08

Indian Rhubarb

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 71 cfs	214 cfs	232 cfs	Difference (measured vs. pred. WSELs) 71 cfs	214 cfs	232 cfs
1	2.99	6.74	2.1	7.7	10.7	0.01	0.09	0.08

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 232 cfs	447 cfs	612 cfs	Difference (measured vs. pred. WSELs) 232 cfs	447 cfs	612 cfs
1	2.81	4.63	2.9	7.2	3.9	0.03	0.09	0.06

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 71 cfs	214 cfs	447 cfs	612 cfs	Difference (measured vs. pred. WSELs) 71 cfs	214 cfs	447 cfs	612 cfs
2	2.67	4.74	3.9	6.5	3.3	5.4	0.03	0.07	0.05	0.01

Upper Placer

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 72 cfs	251 cfs	454 cfs	656 cfs	Difference (measured vs. pred. WSELs) 72 cfs	251 cfs	454 cfs	656 cfs
1	2.38	1.52	0.9	1.5	1.5	2.2	0.00	0.02	0.03	0.04

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 72 cfs	251 cfs	454 cfs	656 cfs	Difference (measured vs. pred. WSELs) 72 cfs	251 cfs	454 cfs	656 cfs
2	---	1.55	0.0	5.9	0.0	0.3	0.00	0.08	0.00	0.01

Lower Placer

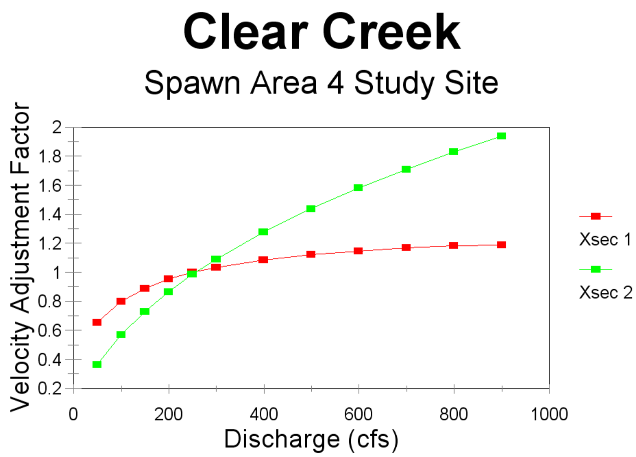
XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 72 cfs	255 cfs	454 cfs	666 cfs	Difference (measured vs. pred. WSELs) 72 cfs	255 cfs	454 cfs	666 cfs
1	---	4.50	14.0	3.0	0.0	1.0	0.09	0.05	0.00	0.03

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 72 cfs	255 cfs	454 cfs	666 cfs	Difference (measured vs. pred. WSELs) 72 cfs	255 cfs	454 cfs	666 cfs
2	---	---	---	---	---	---	0.01	0.01	0.01	0.01

APPENDIX B
VELOCITY ADJUSTMENT FACTORS

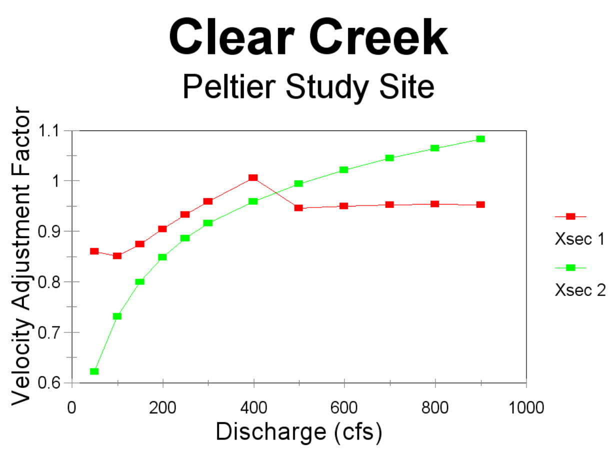
Spawn Area 4

Velocity Adjustment Factors		
Discharge	Xsec 1	Xsec 2
50	0.66	0.36
100	0.80	0.57
150	0.89	0.73
200	0.96	0.87
250	1.00	0.99
300	1.04	1.09
400	1.08	1.28
500	1.12	1.44
600	1.15	1.58
700	1.17	1.71
800	1.18	1.83
900	1.19	1.94



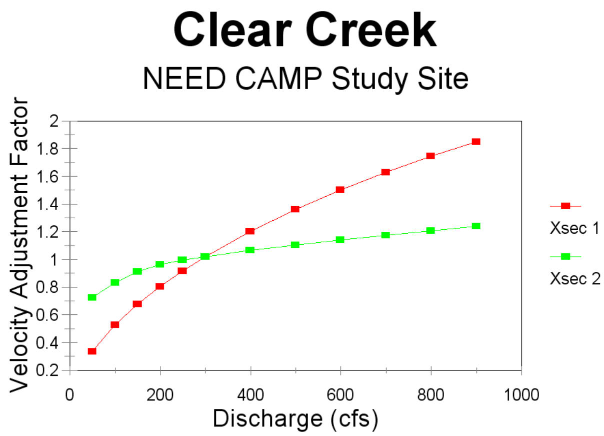
Peltier

Velocity Adjustment Factors		
Discharge	Xsec 1	Xsec 2
50	0.86	0.62
100	0.85	0.73
150	0.88	0.80
200	0.91	0.85
250	0.93	0.89
300	0.96	0.92
400	1.01	0.96
500	0.95	1.00
600	0.95	1.02
700	0.95	1.05
800	0.95	1.07
900	0.95	1.08



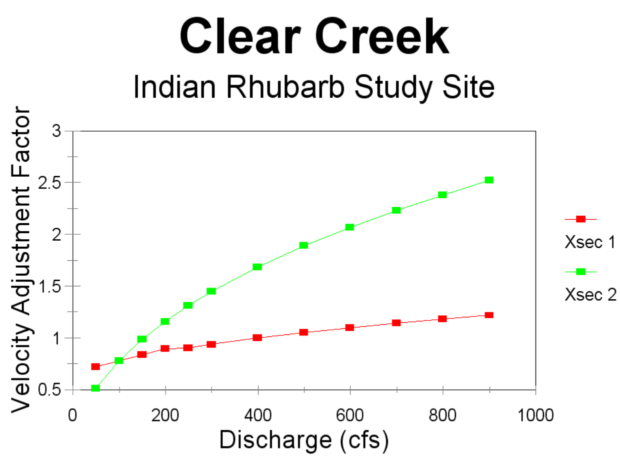
NEED Camp

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
50	0.34	0.73
100	0.53	0.84
150	0.68	0.91
200	0.80	0.97
250	0.92	1.00
300	1.02	1.02
400	1.20	1.07
500	1.36	1.10
600	1.50	1.14
700	1.63	1.18
800	1.75	1.21
900	1.85	1.24



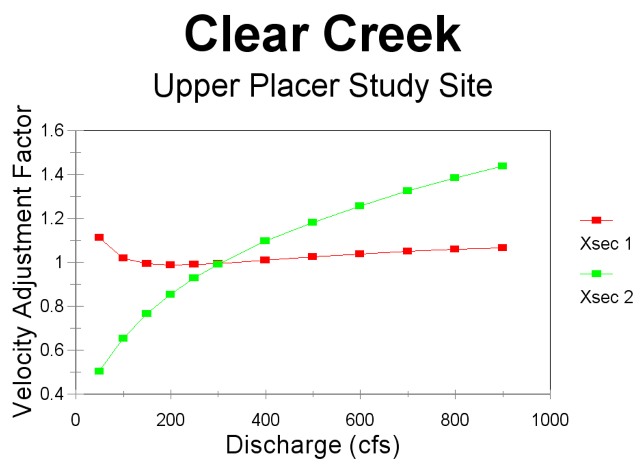
Indian Rhubarb

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
50	0.72	0.51
100	0.78	0.78
150	0.84	0.99
200	0.89	1.16
250	0.90	1.32
300	0.94	1.45
400	1.00	1.69
500	1.05	1.89
600	1.10	2.07
700	1.14	2.23
800	1.18	2.38
900	1.22	2.52



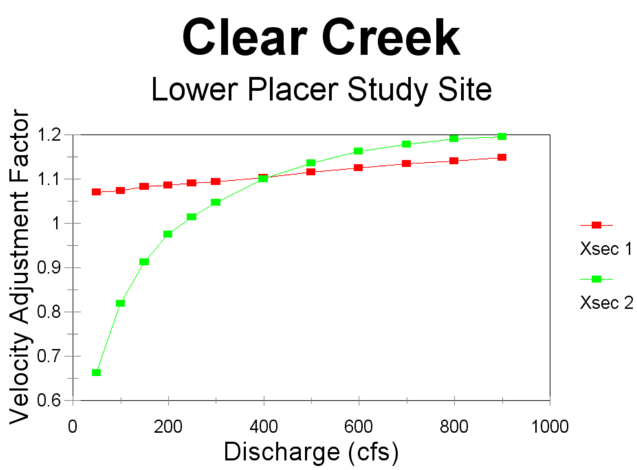
Upper Placer

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	1.11	0.50
100	1.02	0.65
150	0.99	0.76
200	0.99	0.85
250	0.99	0.93
300	1.00	0.99
400	1.01	1.10
500	1.03	1.18
600	1.04	1.26
700	1.05	1.32
800	1.06	1.38
900	1.07	1.44



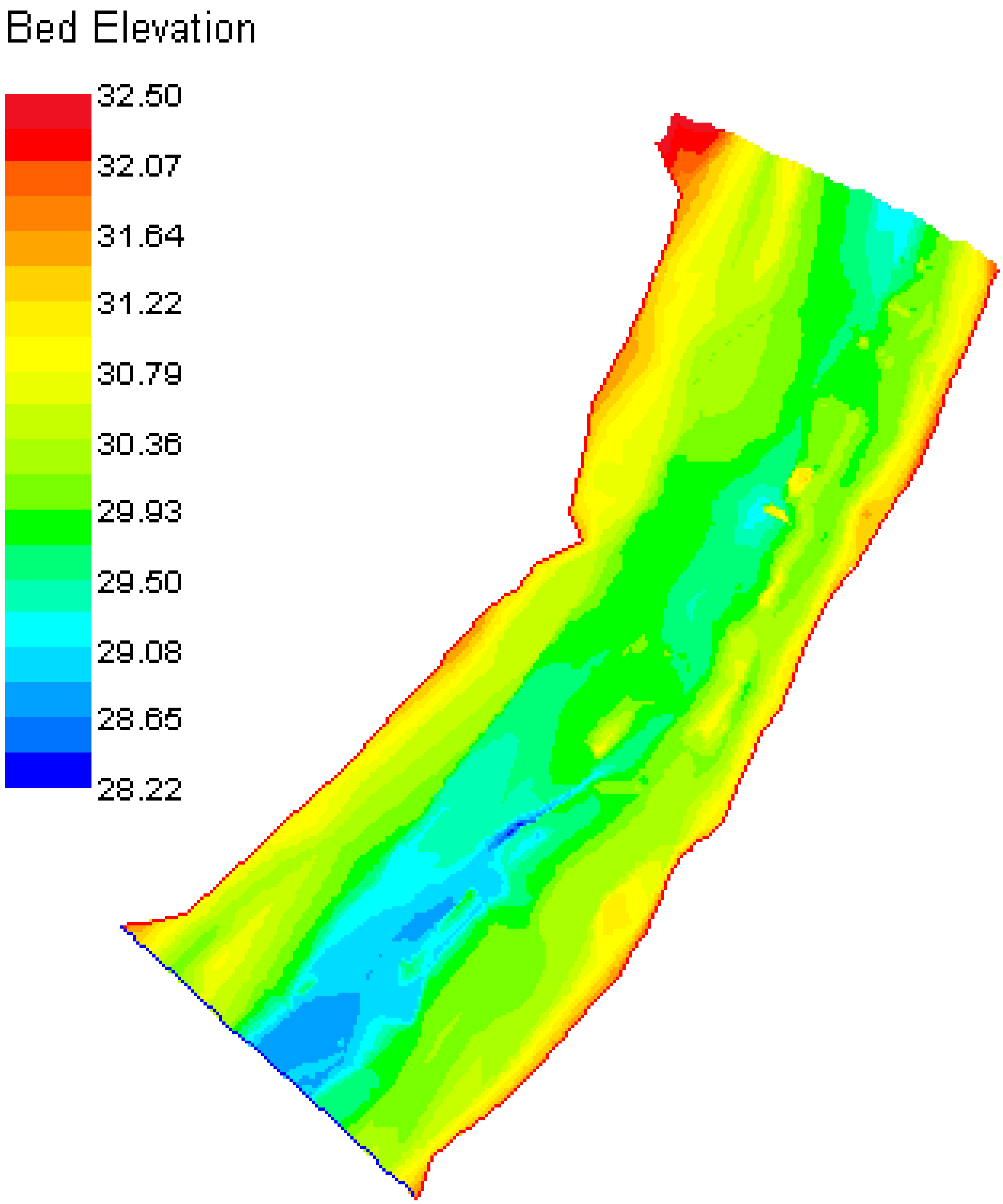
Lower Placer

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	1.07	0.66
100	1.07	0.82
150	1.08	0.91
200	1.09	0.97
250	1.09	1.01
300	1.09	1.05
400	1.10	1.10
500	1.12	1.14
600	1.13	1.16
700	1.13	1.18
800	1.14	1.19
900	1.15	1.20



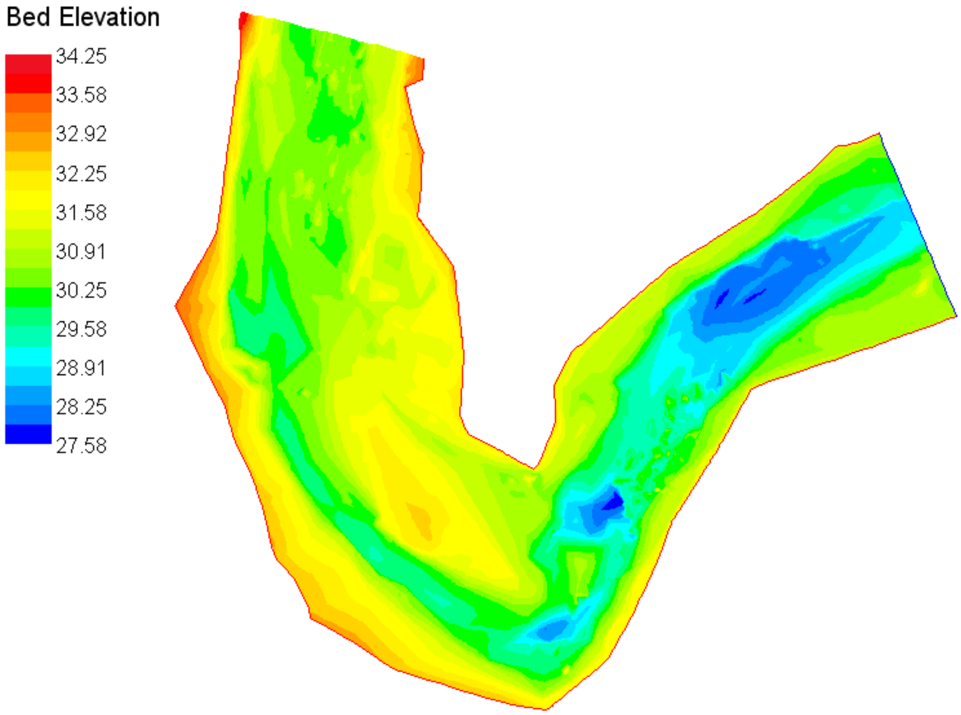
APPENDIX C
BED TOPOGRAPHY OF STUDY SITES

Spawn Area 4 Study Site



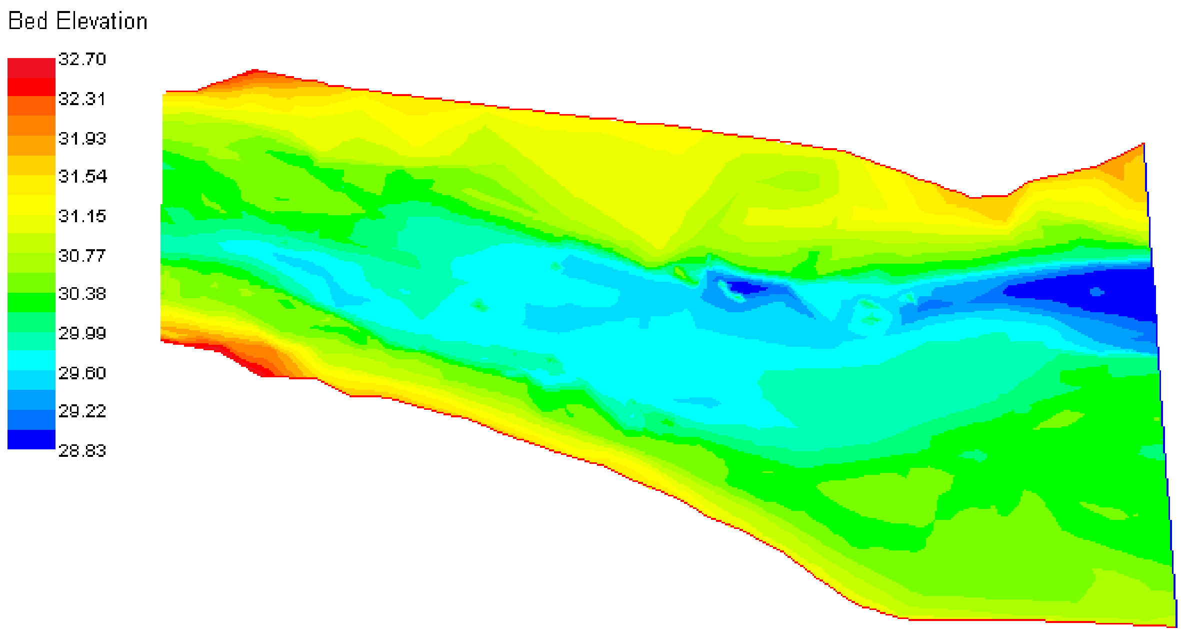
Units of Bed Elevation are meters.

Peltier Study Site



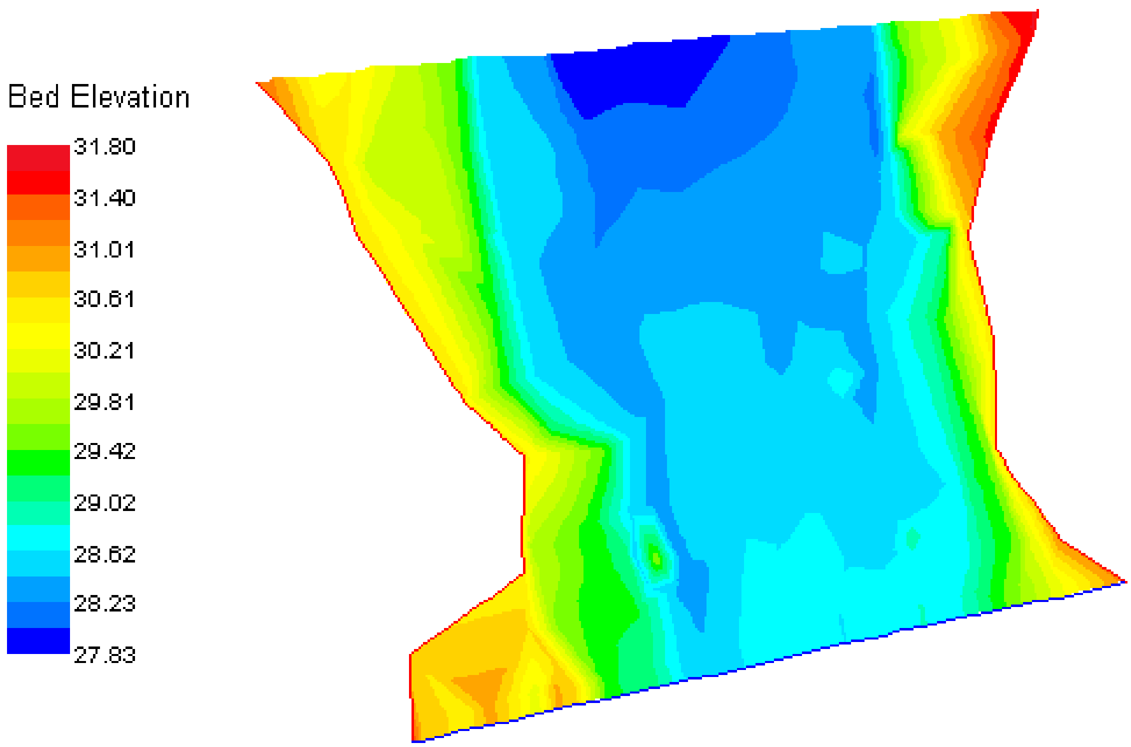
Units of Bed Elevation are meters.

NEED Camp Study Site



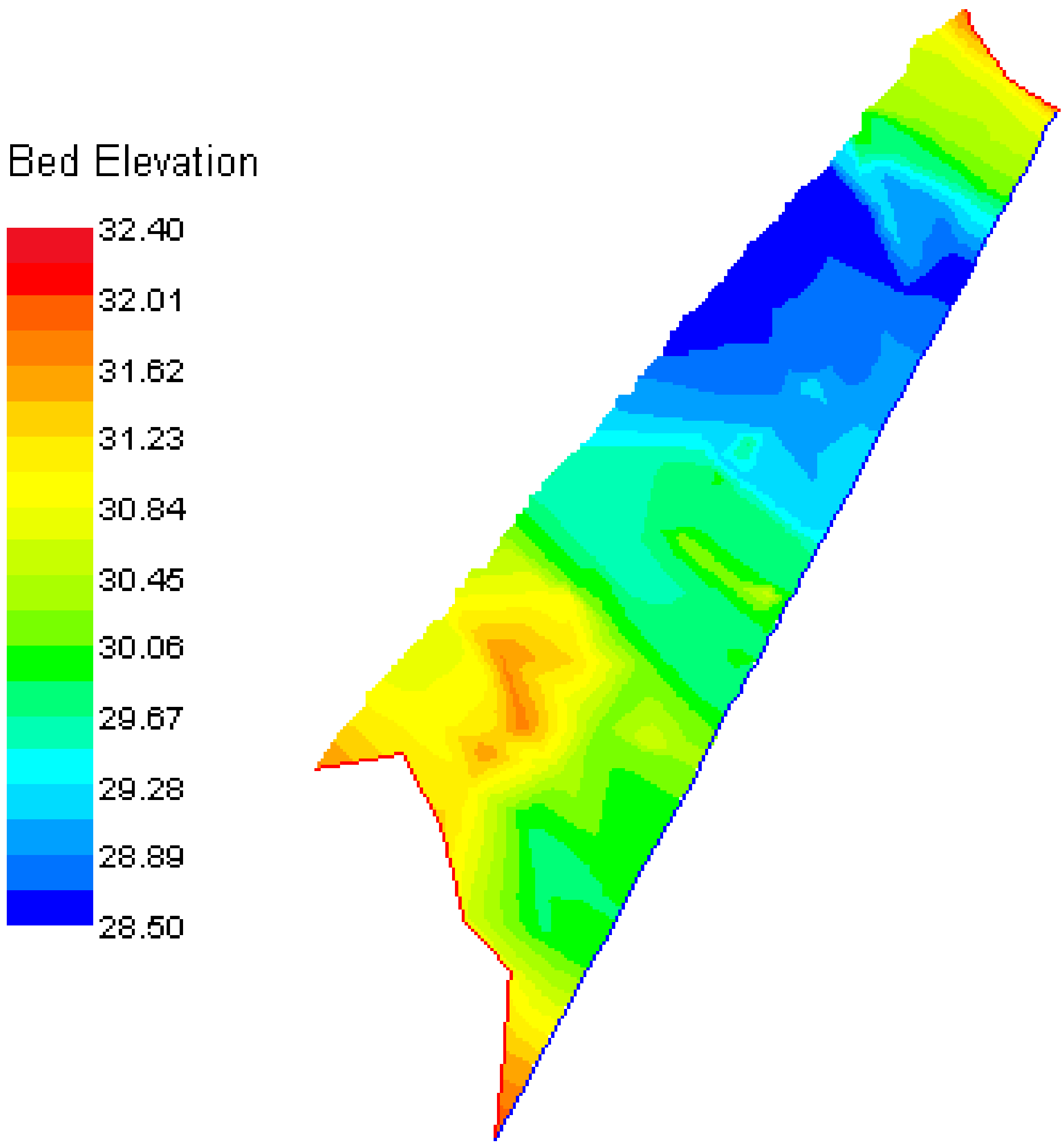
Units of Bed Elevation are meters.

Indian Rhubarb Study Site



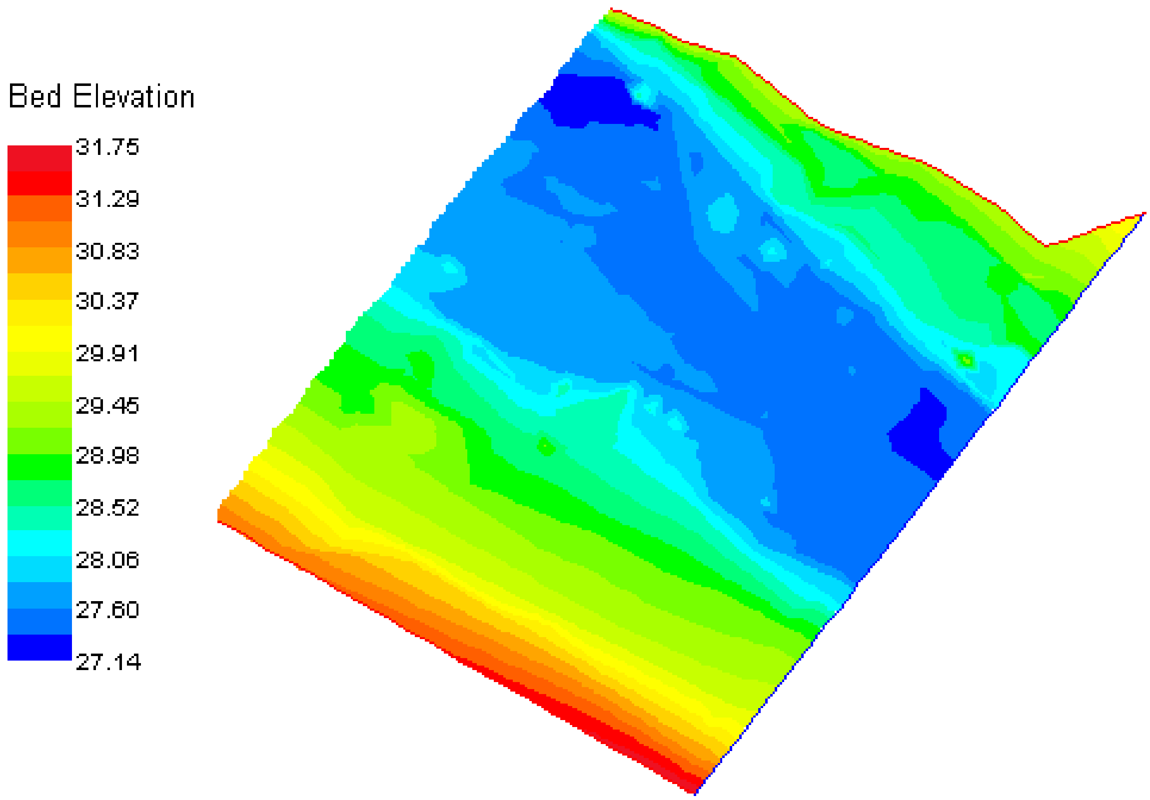
Units of Bed Elevation are meters.

Upper Placer Study Site



Units of Bed Elevation are meters.

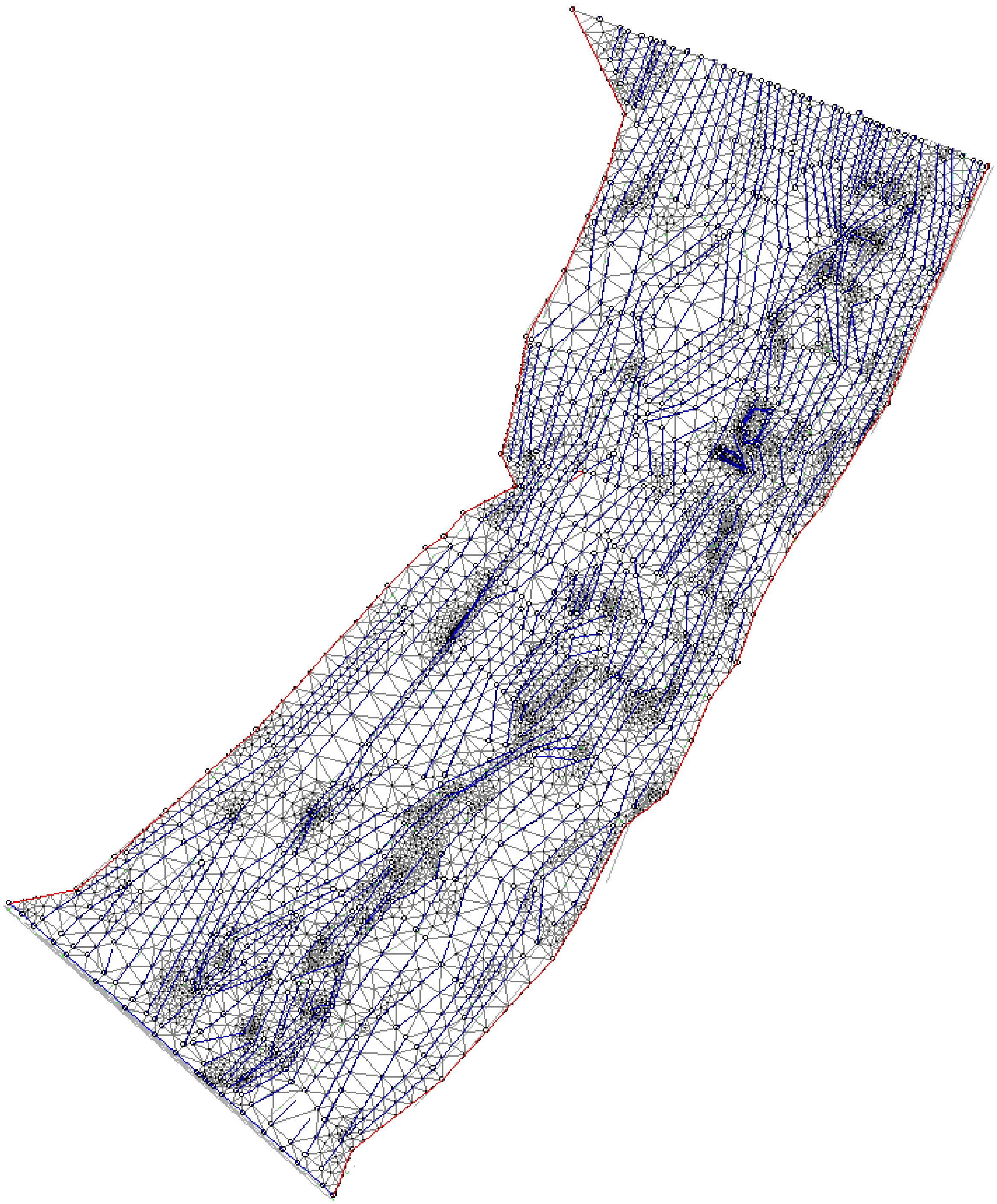
Lower Placer Study Site



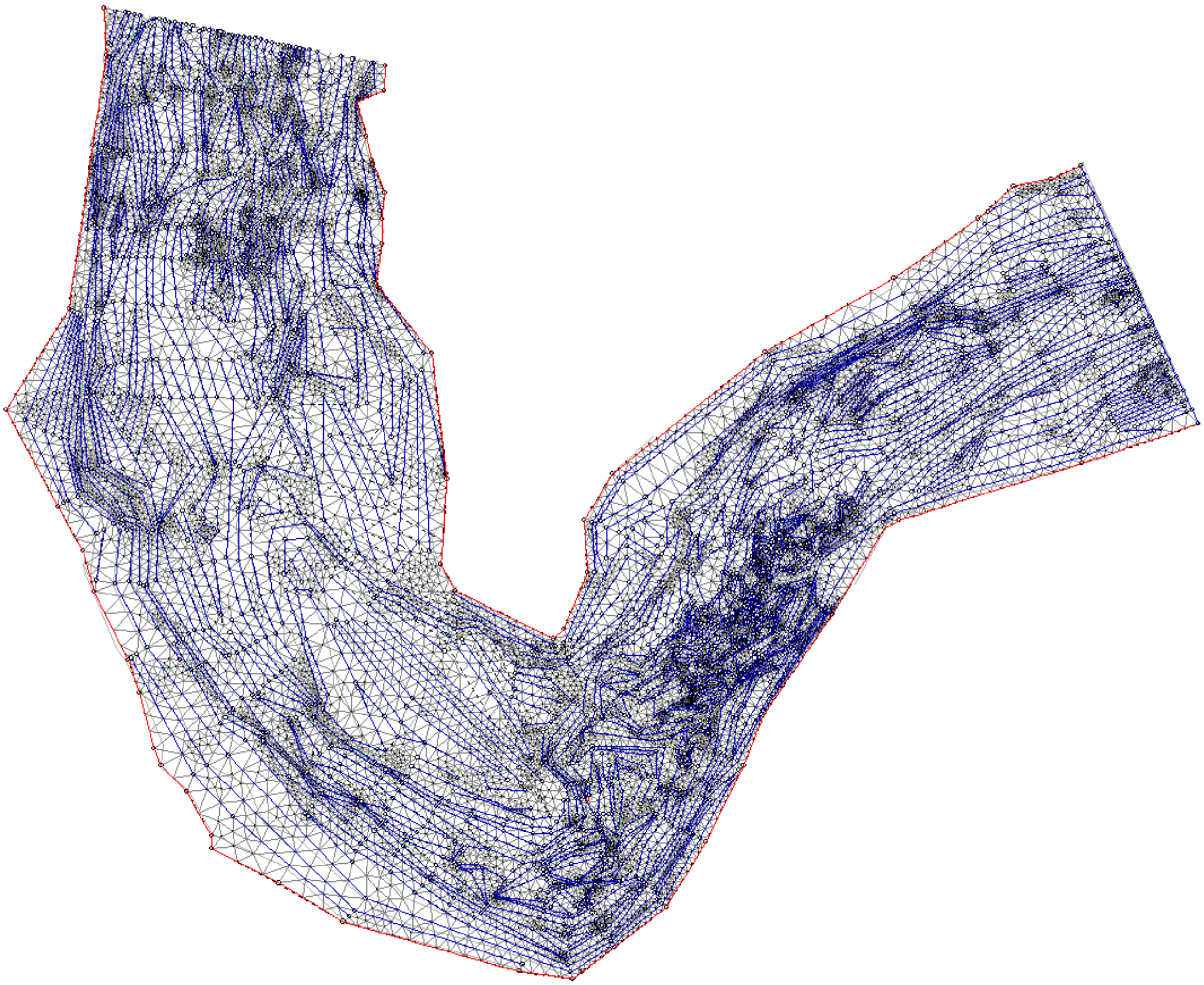
Units of Bed Elevation are meters.

APPENDIX D
COMPUTATIONAL MESHES OF STUDY SITES

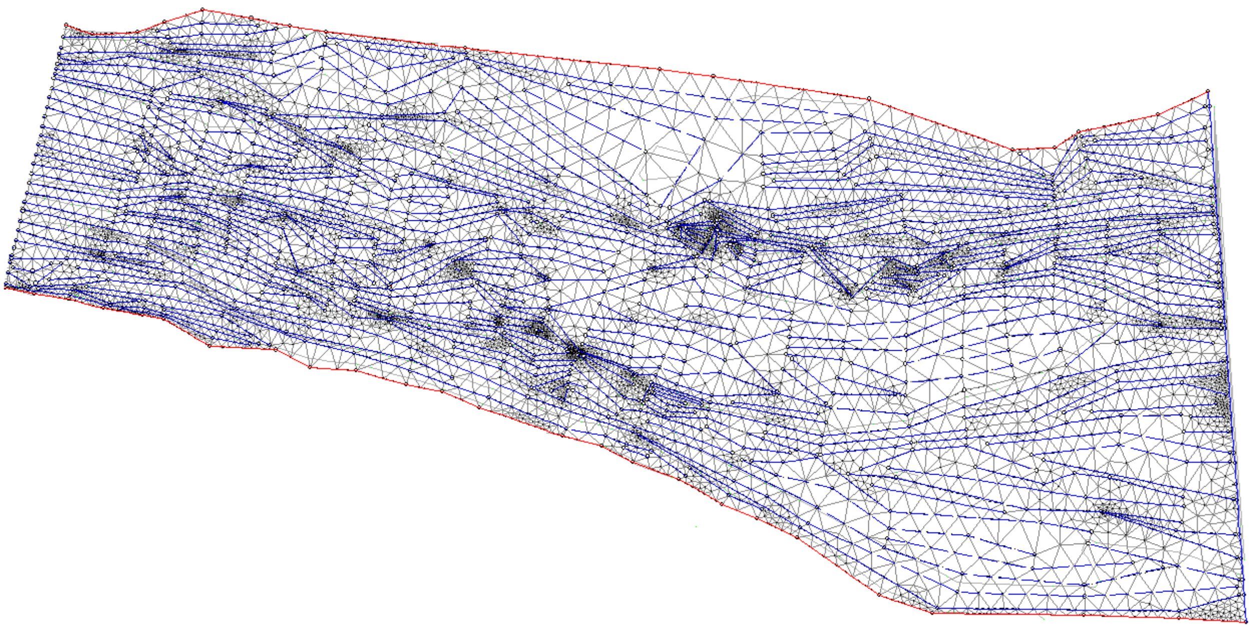
Spawn Area 4 Study Site



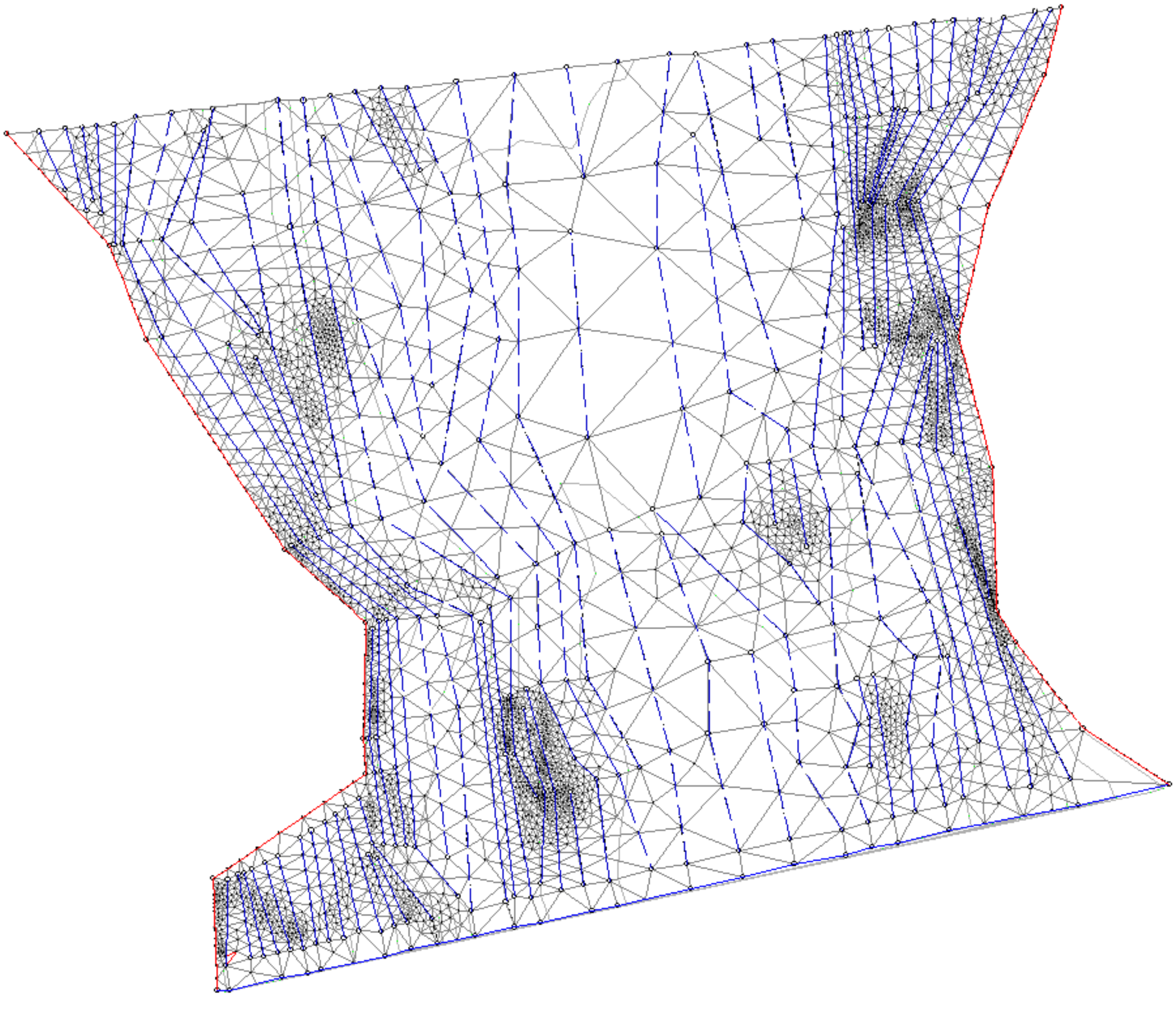
Peltier Study Site



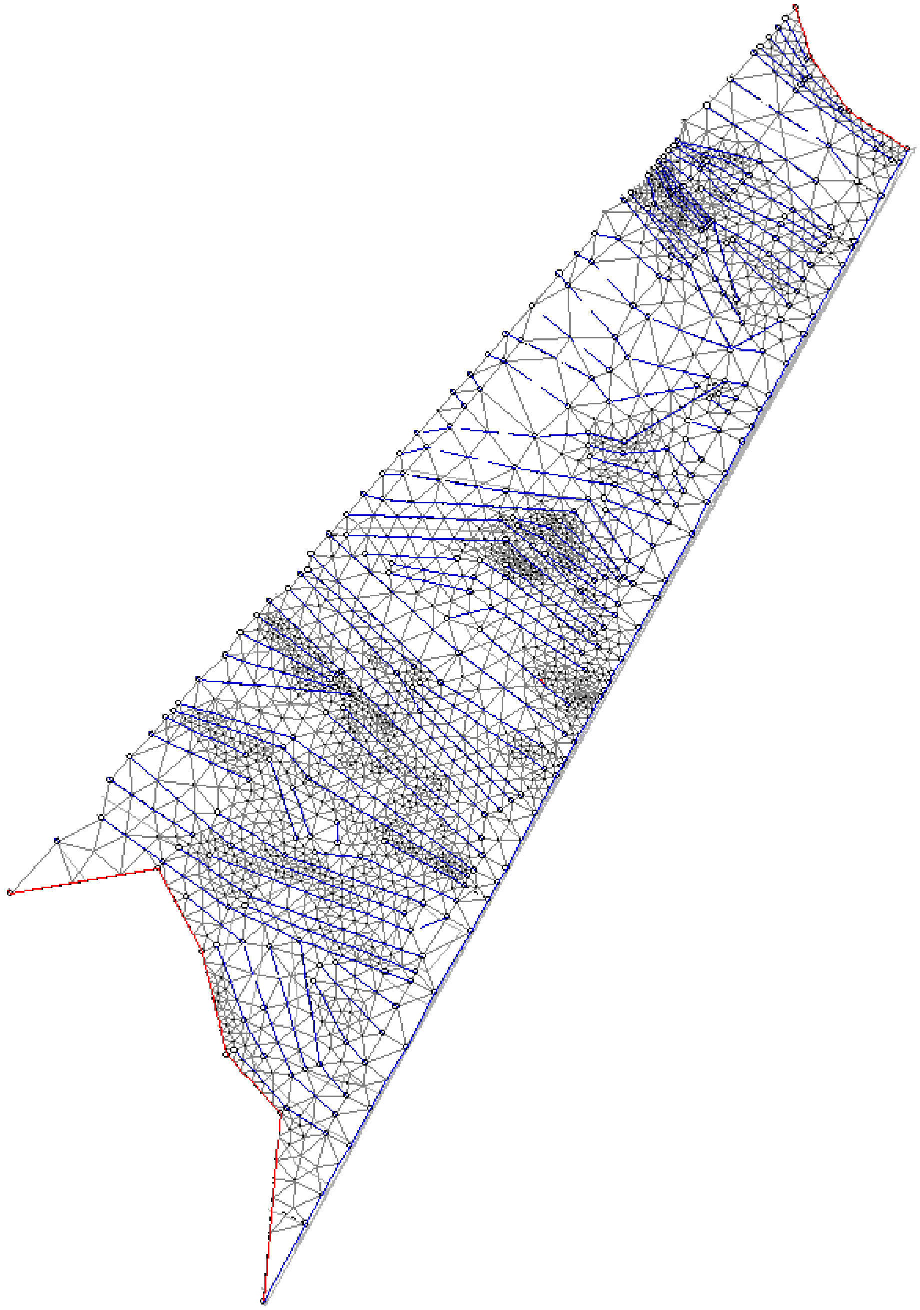
NEED Camp Study Site



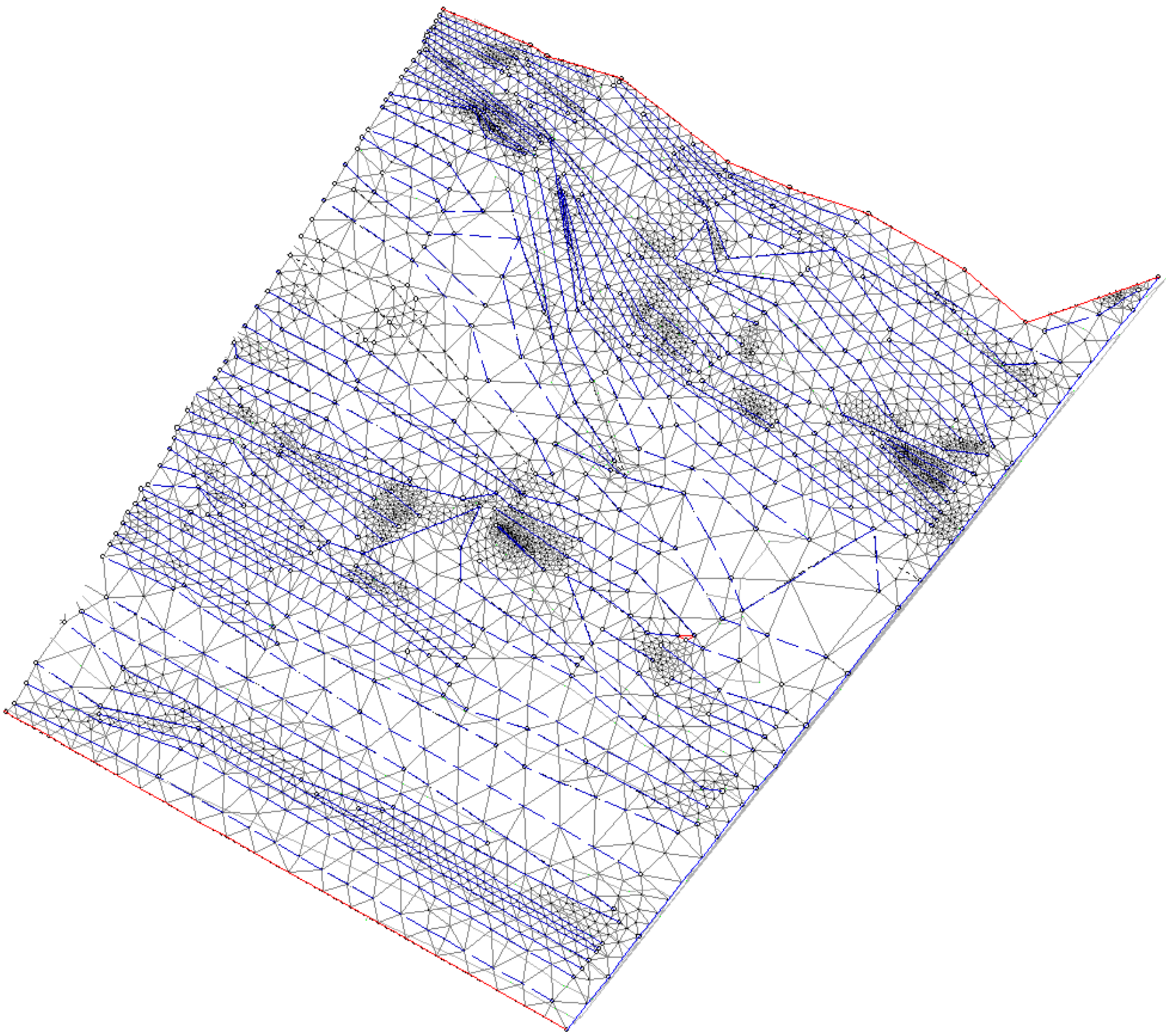
Indian Rhubarb Study Site



Upper Placer Study Site



Lower Placer Study Site



APPENDIX E
2-D WSEL CALIBRATION

Calibration Statistics

Site Name	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Spawn Area 4	90%	6193	0.30	0.70%	< .000001	2.13
Peltier	92%	21827	0.30	0.08%	< .000001	2.82
NEED Camp	94%	8006	0.30	0.12%	.000001	1.32
Indian Rhubarb	95%	4008	0.31	0.12%	< .000001	1.52
Upper Placer	95%	2805	0.31	0.12%	< .000001	0.90
Lower Placer	93%	4671	0.31	0.04%	< .000001	1.59

Spawn Area 4

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2	1.60	0.04	0.04	0.08

Peltier

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	3.0	0.25	0.01	0.28

NEED Camp

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	0.9	0.01	0.03	0.07

Indian Rhubarb

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	0.3	0.04	0.01	0.06

Upper Placer

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	1	0.097	0.04	0.15

Lower Placer

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	0.3	0.02	0.03	0.07

APPENDIX F
VELOCITY VALIDATION STATISTICS

Measured Velocities less than 3 ft/s

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

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Spawn Area 4	75	0.49	0.46	2.40
Peltier	86	0.77	0.30	6.88
NEED Camp	77	0.53	0.51	2.04
Indian Rhubarb	84	0.29	0.22	0.87
Upper Placer	74	0.51	0.56	2.19
Lower Placer	46	0.86	0.60	2.12

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

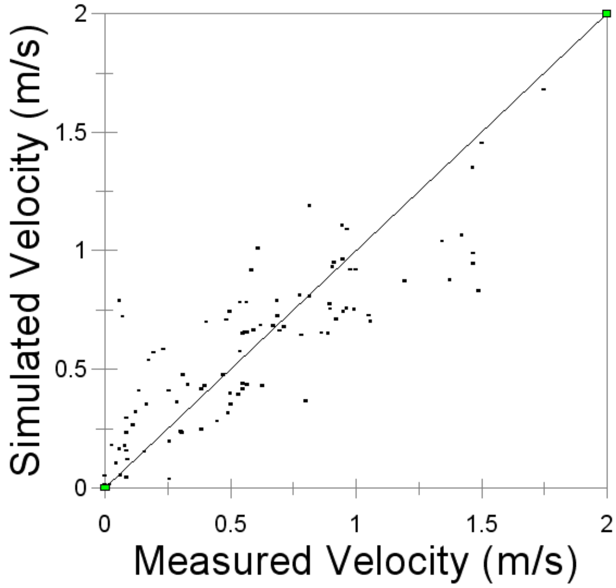
Measured Velocities greater than 3 ft/s

Percent Difference (measured vs. pred. velocities)

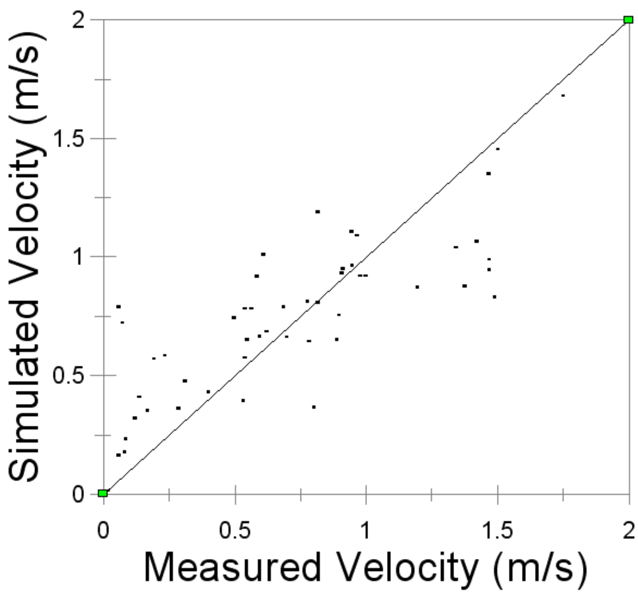
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Spawn Area 4	21	21%	12%	44%
Peltier	14	43%	26%	92%
NEED Camp	15	22%	12%	42%
Indian Rhubarb	12	20%	9%	35%
Upper Placer	20	36%	28%	100%
Lower Placer	47	19%	16%	67%

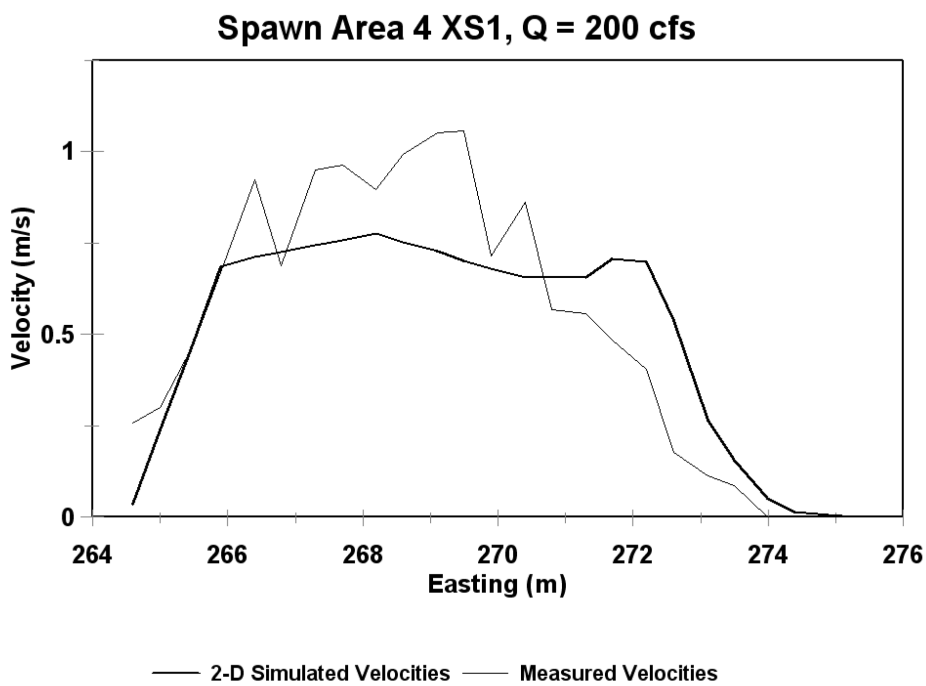
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

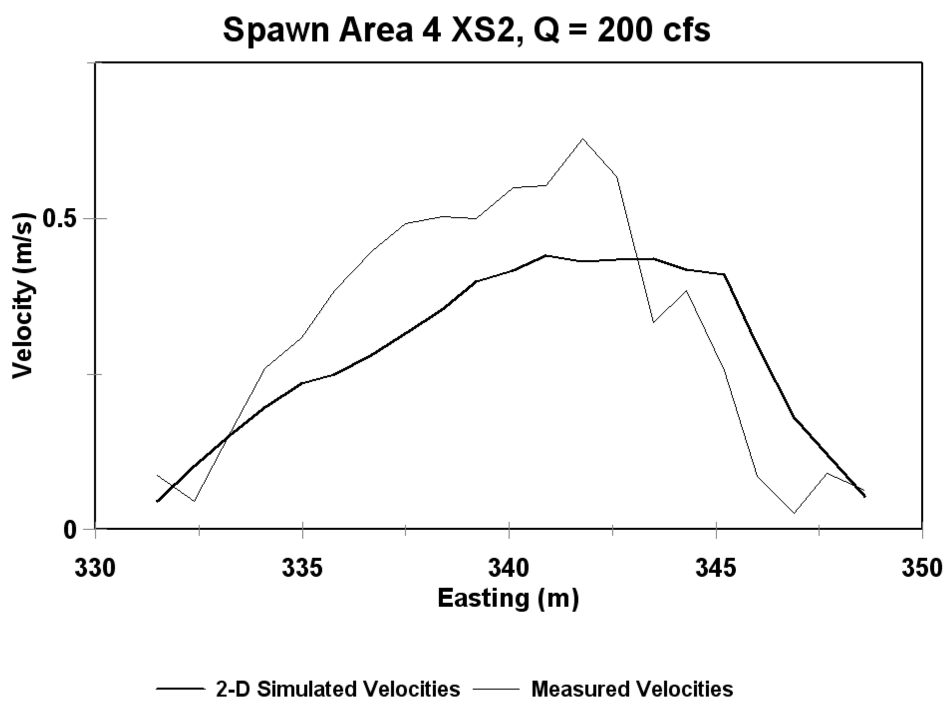
Spawn Area 4
All Validation Velocities



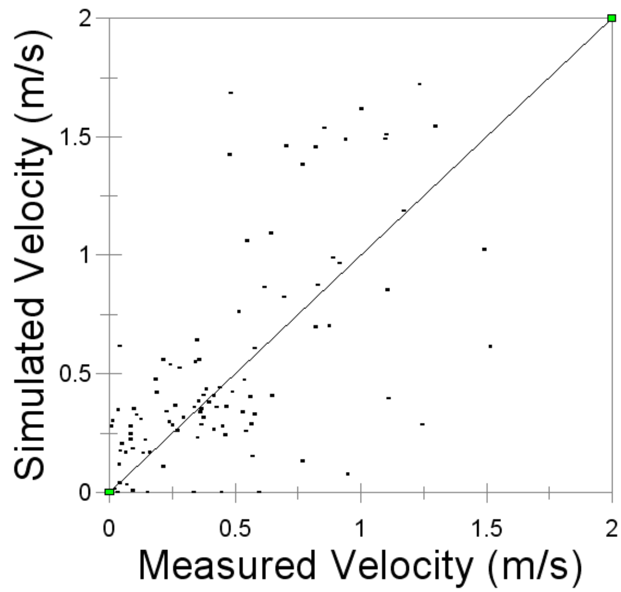
Spawn Area 4
Between Transect Velocities



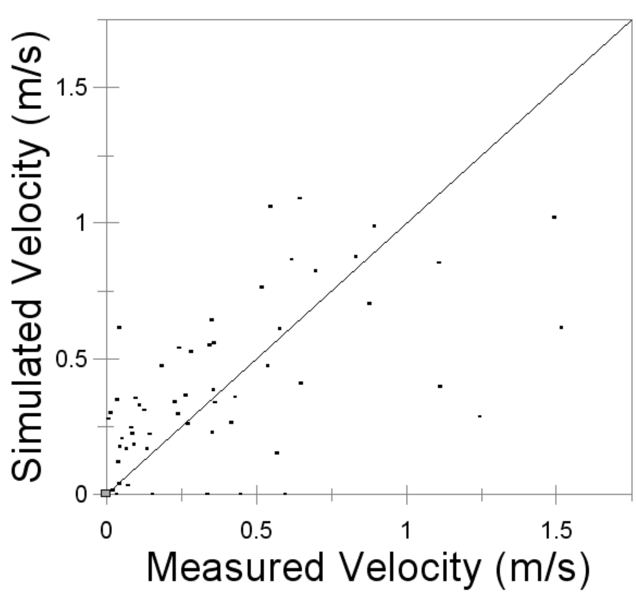

Spawn Area 4 XS1, Q = 200 cfs
Velocity (m/s)
1
0.5
0
264
266
268
270
272
274
276
Easting (m)
2-D Simulated Velocities
Measured Velocities

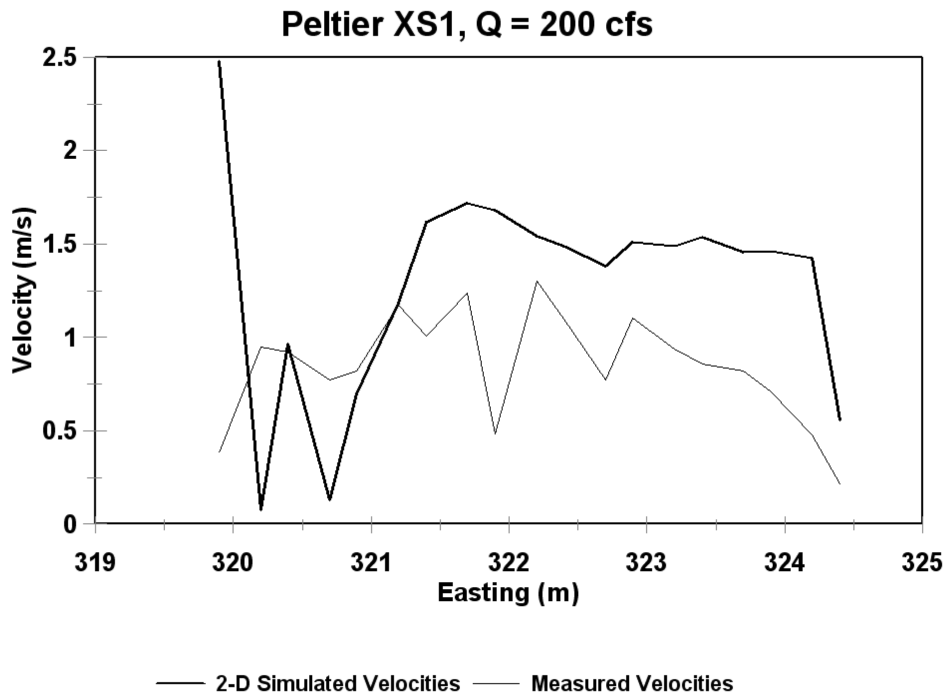

Spawn Area 4 XS2, Q = 200 cfs
Velocity (m/s)
0.5
0
330
335
340
345
350
Easting (m)
2-D Simulated Velocities
Measured Velocities

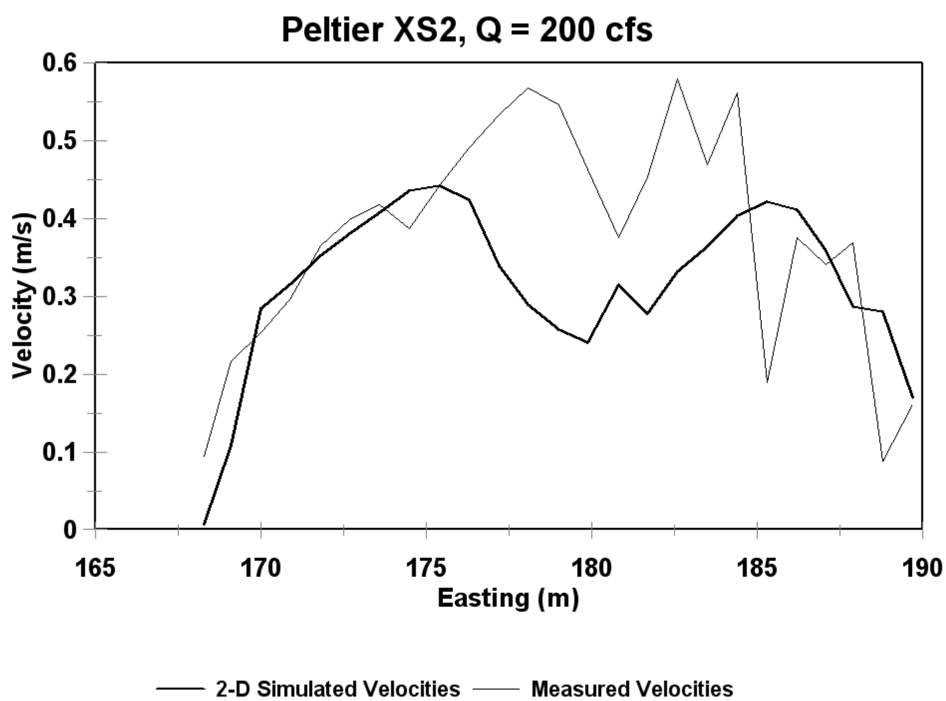
Peltier
All Validation Velocities



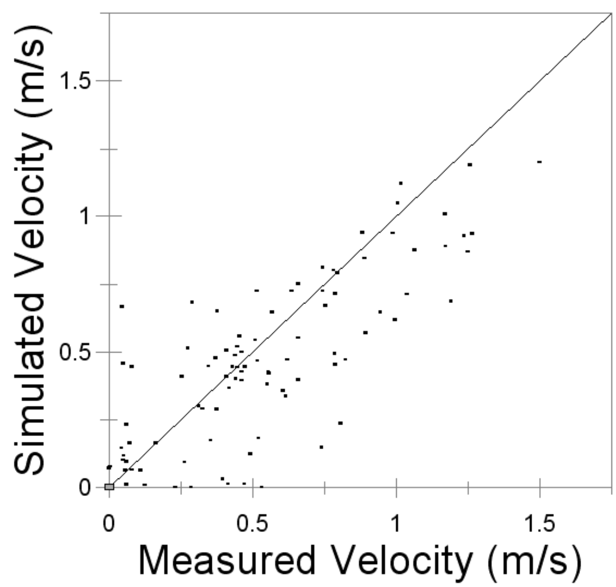
Peltier
Between Transect Velocities



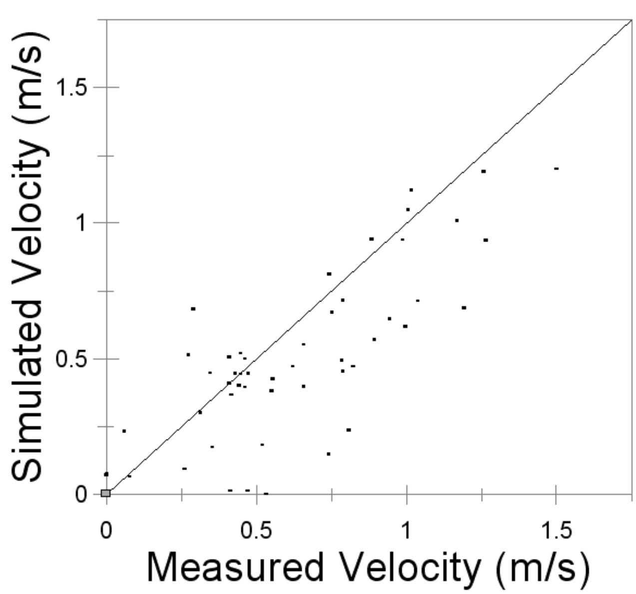

Peltier XS1, Q = 200 cfs
Velocity (m/s)
2.5
2
1.5
1
0.5
0
319
320
321
322
323
324
325
Easting (m)
2-D Simulated Velocities
Measured Velocities

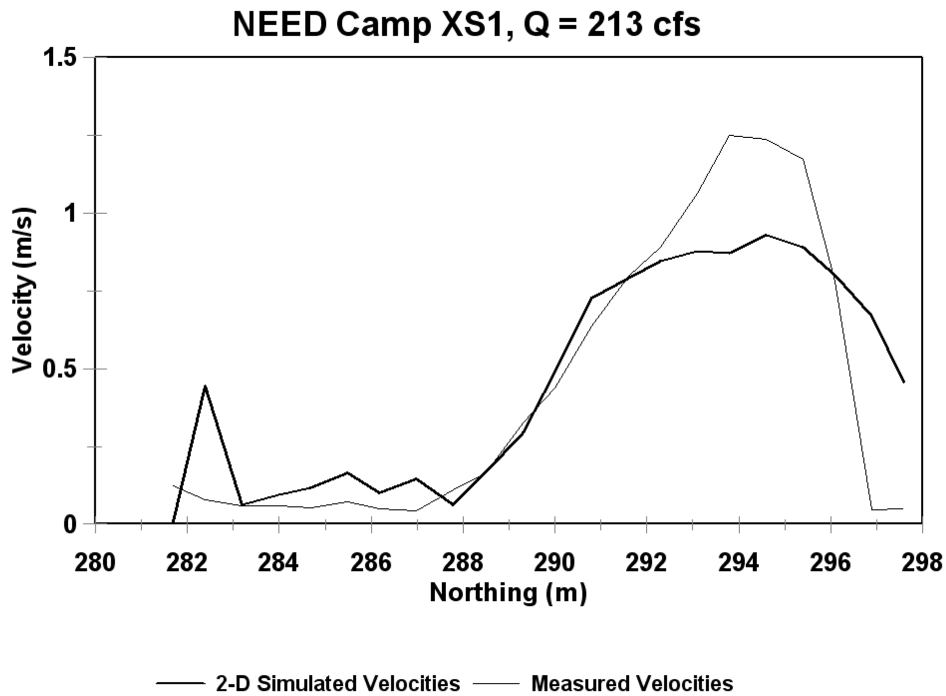

Peltier XS2, Q = 200 cfs
Velocity (m/s)
0.6
0.5
0.4
0.3
0.2
0.1
0
165
170
175
180
185
190
Easting (m)
2-D Simulated Velocities
Measured Velocities

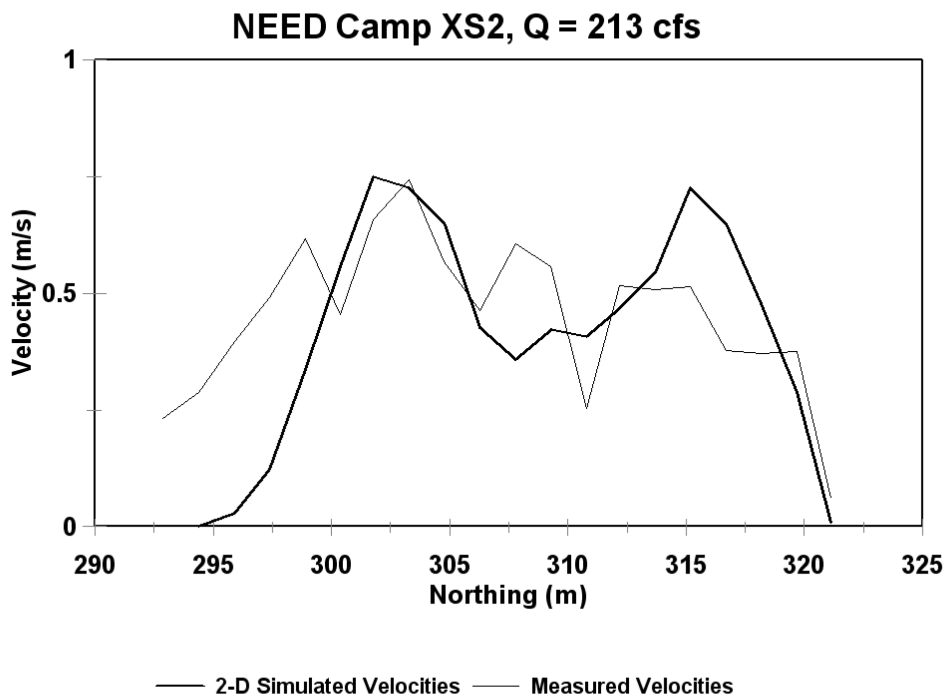
NEED Camp
All Validation Velocities

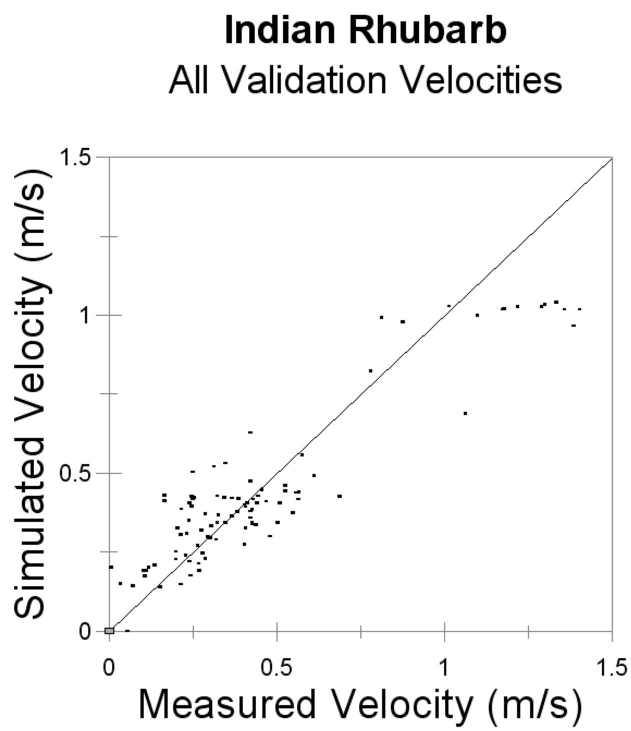


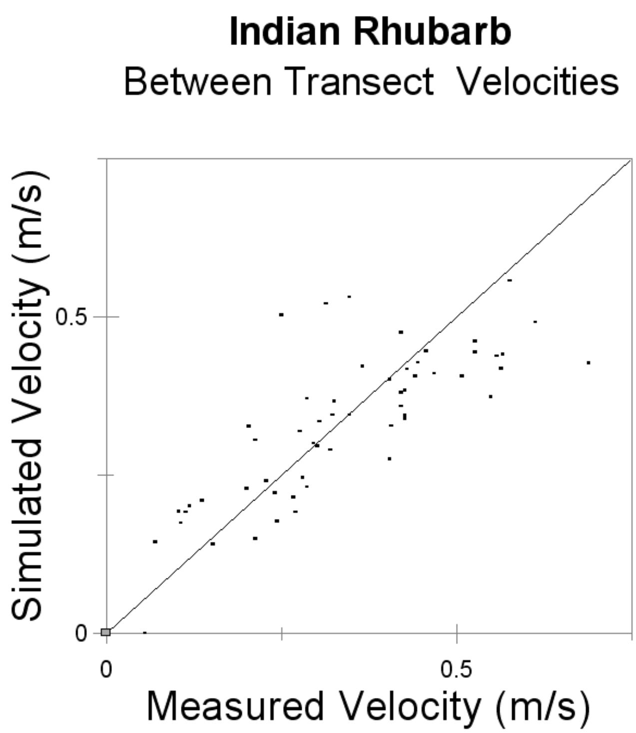
NEED Camp
Between Transect Velocities



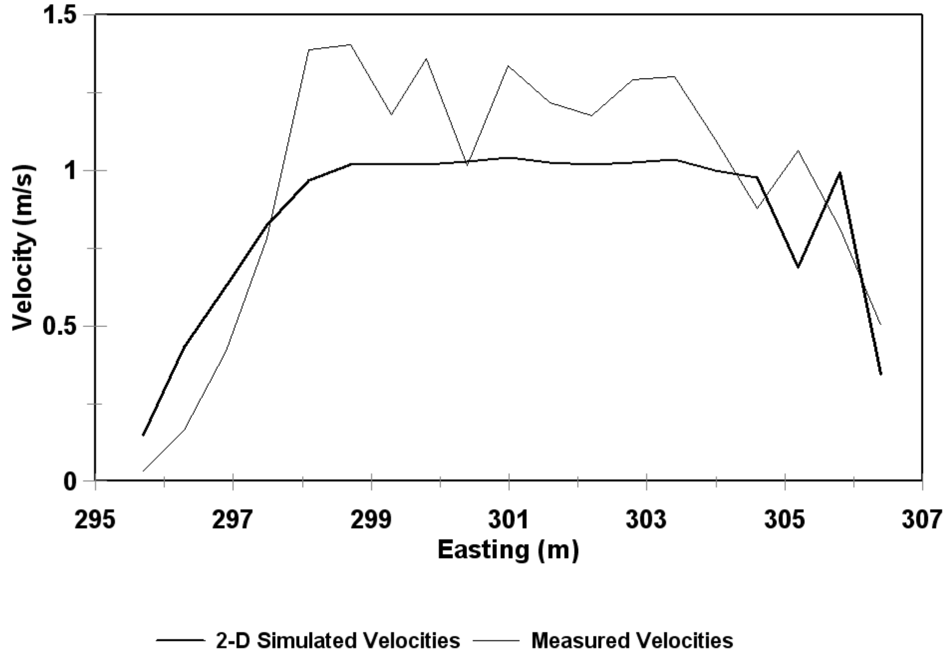

NEED Camp XS1, Q = 213 cfs
Velocity (m/s)
Northing (m)
1.5
1
0.5
0
280
282
284
286
288
290
292
294
296
298
2-D Simulated Velocities
Measured Velocities


NEED Camp XS2, Q = 213 cfs
Velocity (m/s)
Northing (m)
1
0.5
0
290
295
300
305
310
315
320
325
2-D Simulated Velocities
Measured Velocities

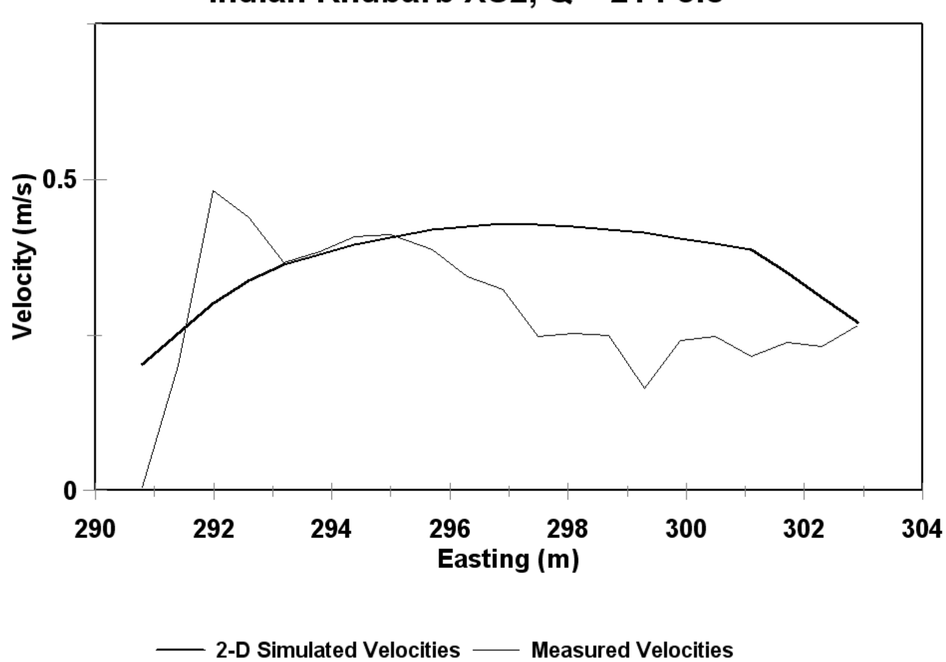

Indian Rhubarb
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
1.5
1
0.5
0
0
0.5
1
1.5

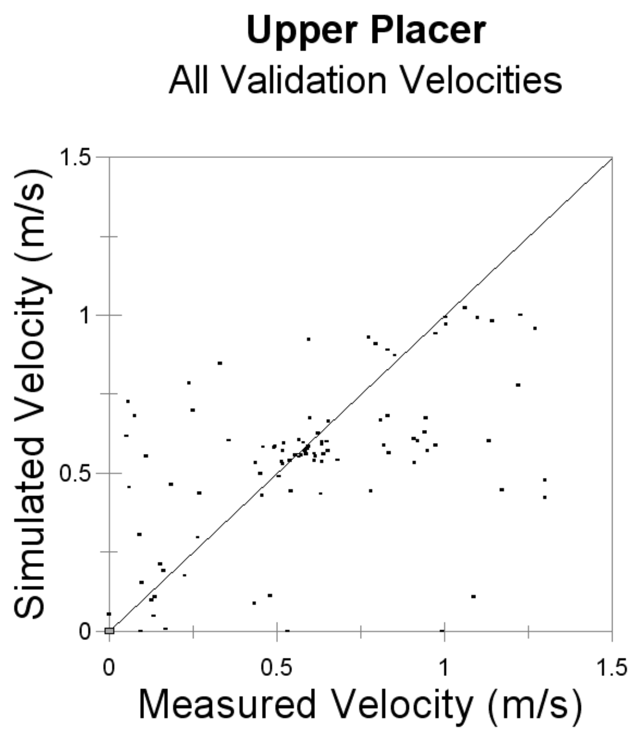

Indian Rhubarb
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.5
0
0
0.5

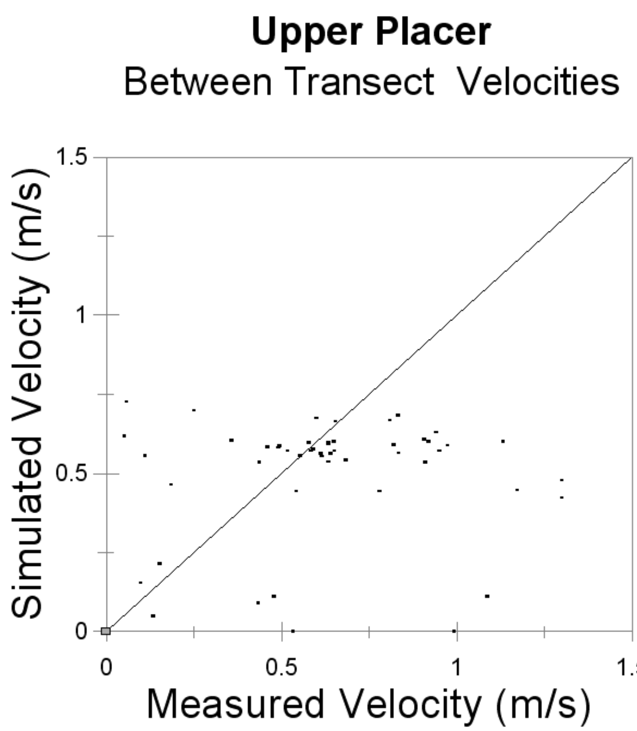
Indian Rhubarb XS1, Q = 214 cfs

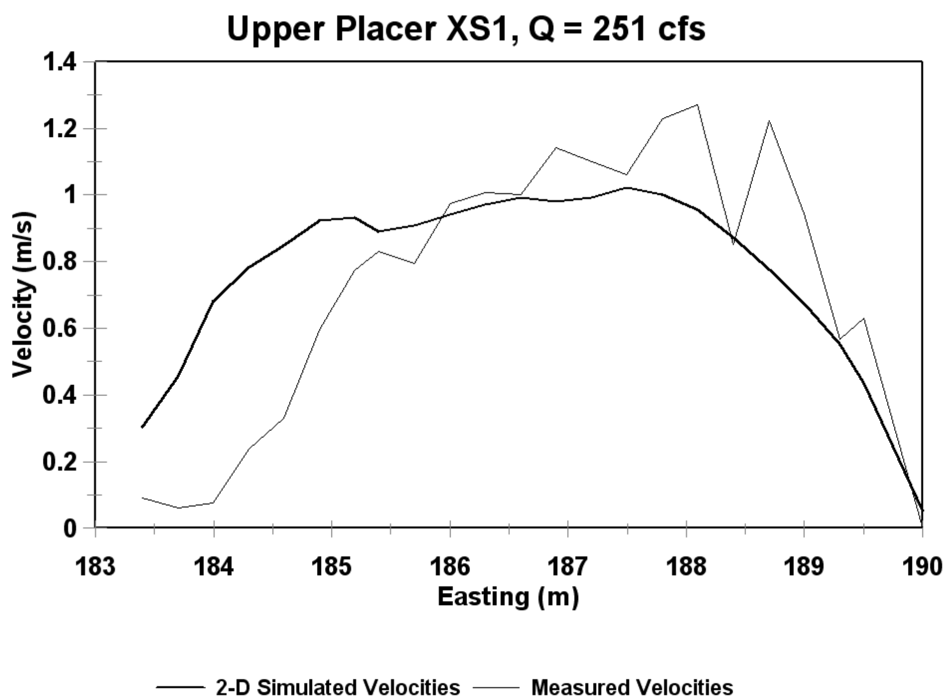


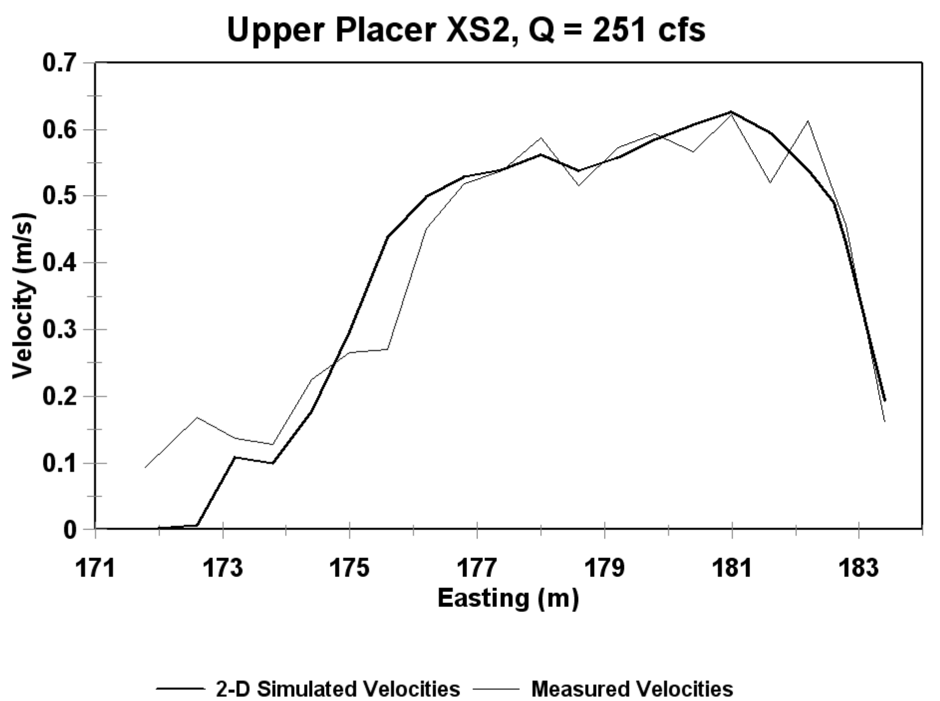
Indian Rhubarb XS2, Q = 214 cfs

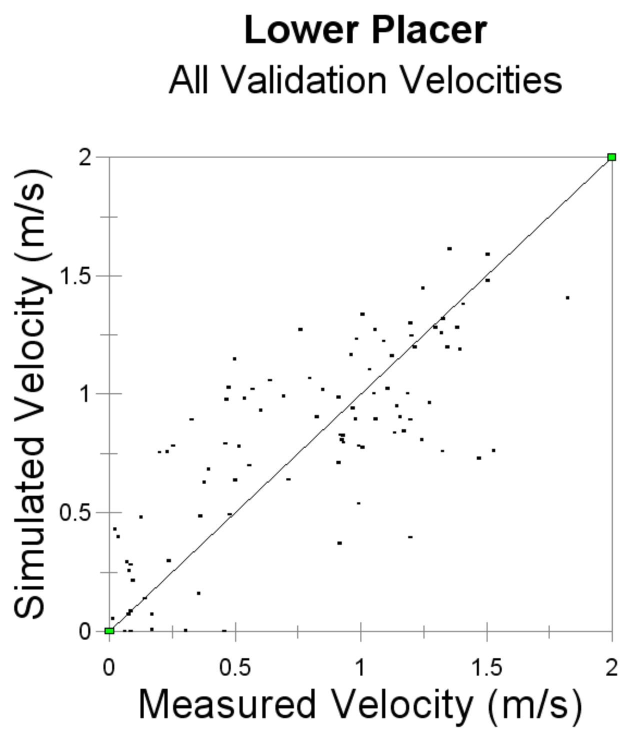


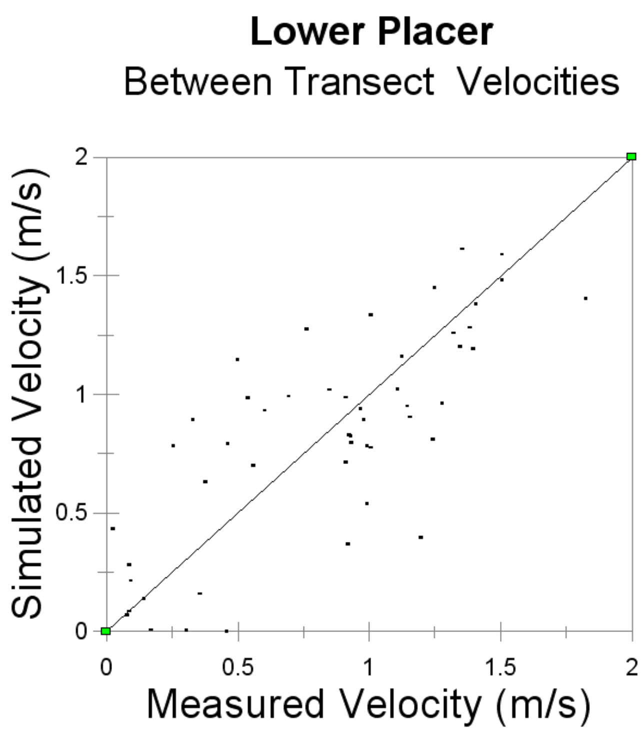

Upper Placer
All Validation Velocities
1.5
1
0.5
0
Simulated Velocity (m/s)
0
0.5
1
1.5
Measured Velocity (m/s)

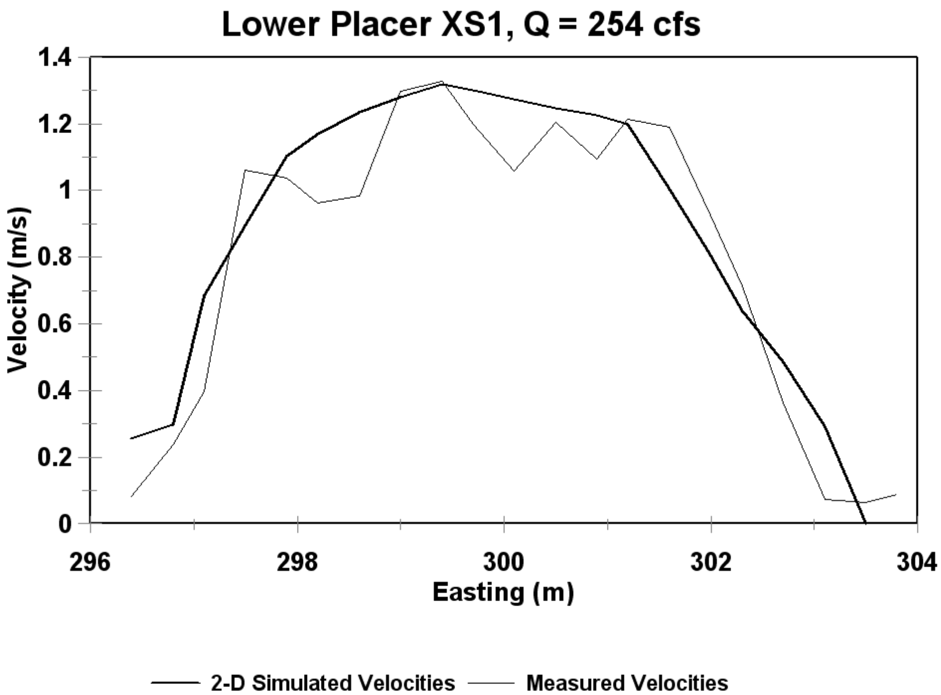

Upper Placer
Between Transect Velocities
1.5
1
0.5
0
Simulated Velocity (m/s)
0
0.5
1
1.5
Measured Velocity (m/s)

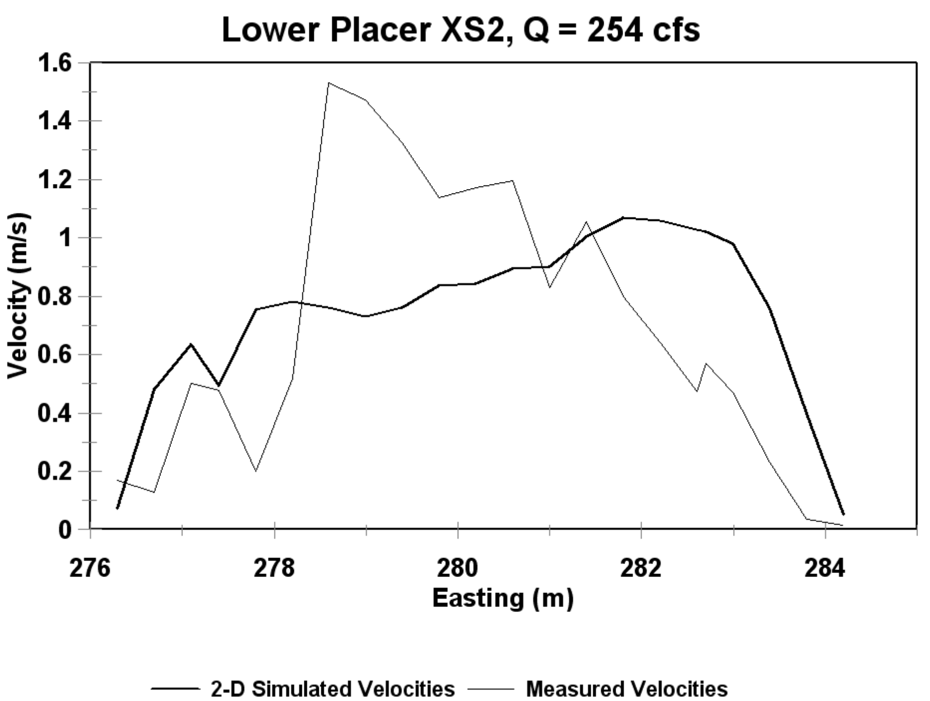

Upper Placer XS1, Q = 251 cfs
Velocity (m/s)
Easting (m)
2-D Simulated Velocities
Measured Velocities


Upper Placer XS2, Q = 251 cfs
Velocity (m/s)
Easting (m)
2-D Simulated Velocities
Measured Velocities


Lower Placer
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0
0.5
1
1.5
2


Lower Placer
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0
0.5
1
1.5
2


Lower Placer XS1, Q = 254 cfs
Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
296
298
300
302
304
Easting (m)
2-D Simulated Velocities
Measured Velocities


Lower Placer XS2, Q = 254 cfs
Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
276
278
280
282
284
Easting (m)
2-D Simulated Velocities
Measured Velocities

APPENDIX G
SIMULATION STATISTICS

Spawn Area 4

Flow (cfs)	Net Q	Sol	Max F
50	0.71%	< .000001	2.62
75	0.47%	< .000001	4.43
100	0.35%	< .000001	3.45
125	0.28%	< .000001	2.43
150	0.47%	< .000001	2.53
175	0.20%	< .000001	2.24
200	0.35%	< .000001	3.30
225	0.47%	< .000001	2.94
250	0.71%	< .000001	2.68
275	0.90%	< .000001	2.38
300	0.94%	< .000001	2.52
350	0.91%	< .000001	1.63
400	0.79%	< .000001	2.79
450	0.55%	< .000001	2.36
500	0.42%	< .000001	1.76
550	0.45%	< .000001	7.98
600	0.53%	.000002	3.76
650	0.54%	< .000001	3.55
700	0.61%	< .000001	3.25
750	0.66%	< .000001	2.50
800	0.66%	< .000001	2.22
850	0.71%	< .000001	2.10
900	0.71%	< .000001	2.13

Peltier

Flow (cfs)	Net Q	Sol Δ	Max F
50	7.86%	< .000001	3.24
75	4.29%	.000001	1.45
100	2.50%	< .000001	1.10
125	2.29%	.000002	1.36
150	2.14%	.000001	2.71
175	2.40%	< .000001	4.16
200	3.51%	< .000001	2.68
225	5.00%	< .000001	2.31
250	0.28%	< .000001	1.57
275	6.67%	< .000001	3.47
300	1.06%	< .000001	2.19
350	0.51%	< .000001	6.30
400	0.35%	< .000001	4.57
450	0.24%	< .000001	4.35
500	0.21%	< .000001	5.67
550	0.13%	.000005	3.40
600	0.24%	< .000001	2.91
650	0.27%	< .000001	2.56
700	0.20%	< .000001	3.09
750	0.24%	< .000001	3.71
800	0.18%	< .000001	3.75
850	0.08%	< .000001	3.86
900	0.08%	< .000001	2.82

NEED Camp

Flow (cfs)	Net Q	Sol Δ	Max F
50	2.12%	< .000001	1.06
75	2.35%	.000001	1.73
100	1.41%	.000003	1.40
125	0.85%	.000003	1.12
150	0.47%	< .000001	1.38
175	0.61%	.000003	5.97
200	0.53%	< .000001	3.81
225	0.47%	< .000001	2.35
250	0.28%	< .000001	1.82
275	0.26%	< .000001	1.51
300	0.24%	< .000001	2.01
350	0.20%	.000002	1.55
400	0.18%	.000001	4.10
450	0.16%	.000001	2.84
500	0.21%	< .000001	2.36
550	0.39%	< .000001	5.04
600	0.41%	< .000001	3.04
650	0.43%	.000001	2.32
700	0.61%	< .000001	1.89
750	0.71%	< .000001	1.68
800	0.35%	.000001	1.50
850	0.17%	.000001	1.39
900	0.12%	.000001	1.32

Indian Rhubarb

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.00%	< .000001	0.50
75	0.47%	< .000001	0.43
100	0.35%	< .000001	0.42
125	0.28%	< .000001	0.43
150	0.47%	< .000001	0.49
175	0.40%	< .000001	0.54
200	0.35%	< .000001	0.67
225	0.31%	< .000001	0.89
250	0.14%	< .000001	1.04
275	0.13%	< .000001	0.99
300	0.12%	< .000001	1.38
350	0.10%	< .000001	1.54
400	0.09%	< .000001	2.27
450	0.08%	< .000001	2.44
500	0.07%	< .000001	1.80
550	0.13%	< .000001	1.60
600	0.12%	< .000001	1.53
650	0.11%	< .000001	1.43
700	0.10%	< .000001	1.36
750	0.05%	< .000001	1.35
800	0.04%	< .000001	1.34
850	0.17%	< .000001	1.32
900	0.12%	< .000001	1.52

Upper Placer

Flow (cfs)	Net Q	Sol Δ	Max F
50	2.83%	< .000001	0.90
75	1.88%	< .000001	0.98
100	1.77%	< .000001	1.66
125	1.41%	< .000001	0.89
150	0.71%	< .000001	0.97
175	0.20%	< .000001	1.16
200	0.18%	< .000001	1.56
225	0.16%	< .000001	1.14
250	0.14%	< .000001	1.13
275	0.13%	< .000001	1.30
300	0.35%	< .000001	1.60
350	0.50%	< .000001	1.80
400	0.53%	< .000001	1.00
450	0.47%	< .000001	0.82
500	0.21%	< .000001	0.80
550	0.13%	< .000001	0.67
600	0.12%	< .000001	0.69
650	0.16%	< .000001	0.63
700	0.15%	< .000001	0.66
750	0.14%	< .000001	0.79
800	0.13%	< .000001	1.03
850	0.12%	< .000001	1.05
900	0.12%	< .000001	0.94

Lower Placer

Flow (cfs)	Net Q	Sol Δ	Max F
50	2.83%	< .000001	1.30
75	0.94%	< .000001	1.34
100	0.71%	< .000001	1.43
125	0.57%	< .000001	1.35
150	0.47%	< .000001	1.72
175	0.40%	< .000001	1.69
200	0.35%	< .000001	1.53
225	0.31%	< .000001	1.40
250	0.14%	.000006	1.33
275	0.13%	< .000001	1.63
300	0.12%	.000008	3.09
350	0.20%	< .000001	2.26
400	0.18%	< .000001	1.91
450	0.16%	.000003	1.88
500	0.07%	< .000001	1.93
550	0.19%	< .000001	1.97
600	0.24%	< .000001	2.44
650	0.27%	< .000001	2.17
700	0.30%	< .000001	1.87
750	0.28%	< .000001	1.52
800	0.26%	< .000001	1.43
850	0.04%	< .000001	1.37
900	0.04%	< .000001	1.59

APPENDIX H
HABITAT SUITABILITY CRITERIA

SPRING-RUN CHINOOK SALMON SPAWNING HSC

Water Depth (ft)	SI Value
0.0	0
0.7	0
0.8	0.08
0.9	0.11
1.0	0.15
1.1	0.18
1.2	0.22
1.4	0.28
1.7	0.34
1.8	0.35
1.9	0.36
2.2	0.36
2.3	0.35
2.4	0.35
2.5	0.34
2.6	0.33
2.7	0.33
2.8	0.32
2.9	0.32
3.0	0.31
3.4	0.31
3.5	0.32
3.6	0.32
3.8	0.34
4.2	0.42
4.5	0.51
4.6	0.55
4.7	0.58
4.8	0.62
4.9	0.67
5.4	0.87
5.6	0.93
5.9	0.99
6.0	1
6.2	1
6.3	0.99
6.4	0.97
6.5	0.94
6.6	0.90
6.7	0.84
6.8	0.76
6.9	0.67
7.0	0.56
7.1	0
100	0

Water Velocity (ft/s)	SI Value
0.00	0
0.69	0
0.70	0.06
0.80	0.08
0.90	0.10
1.00	0.13
1.10	0.17
1.20	0.21
1.30	0.25
1.40	0.30
1.50	0.36
1.60	0.41
1.70	0.48
1.80	0.54
1.90	0.60
2.00	0.66
2.10	0.72
2.20	0.77
2.30	0.82
2.40	0.87
2.50	0.91
2.60	0.94
2.70	0.97
2.80	0.98
2.90	1
3.00	1
3.10	1
3.20	0.99
3.30	0.97
3.40	0.95
3.50	0.92
3.60	0.88
3.70	0.83
3.80	0.79
3.90	0.73
4.00	0.67
4.10	0.61
4.20	0.55
4.30	0.49
4.40	0.43
4.41	0
100	0

Substrate Composition	SI Value
0	0
0.1	0
1	0
1.2	0.19
1.3	0.64
2.3	0.82
2.4	1
3.4	0.56
3.5	0.12
4.6	0.01
6.8	0
10	0
100	0

STEELHEAD/RAINBOW TROUT SPAWNING HSC

Water Depth (ft)	SI Value
0.00	0
0.3	0
0.4	0.16
0.5	0.26
0.6	0.38
0.7	0.51
0.8	0.64
0.9	0.75
1.0	0.85
1.1	0.92
1.2	0.96
1.3	0.99
1.4	1
1.5	1
28.6	0
100	0

Water Velocity (ft/s)	SI Value
0.00	0
0.60	0
0.61	0.08
0.70	0.14
0.80	0.25
0.90	0.38
1.00	0.53
1.10	0.66
1.20	0.78
1.30	0.87
1.40	0.94
1.50	0.98
1.60	1.00
1.70	1.00
1.80	0.99
1.90	0.97
2.00	0.95
2.10	0.93
2.20	0.90
2.30	0.87
2.40	0.85
2.50	0.82
2.60	0.80
2.70	0.78
2.80	0.76
2.90	0.73
3.00	0.70
3.10	0.66
3.20	0.61
3.30	0.56
3.40	0.49
3.50	0.41
3.60	0.33
3.70	0.25
3.80	0.17
3.89	0.11
3.90	0
100	0

Substrate Composition	SI Value
0	0
0.1	0
1	0.38
1.2	1.00
1.3	0.44
2.3	0.26
2.4	0.07
3.4	0.06
3.5	0.04
4.6	0.01
6.8	0
10	0
100	0

APPENDIX I
HABITAT MODELING RESULTS

Spring-run Chinook salmon spawning WUA (ft^2) in Upper Alluvial Segment

Flow	Spawn Area 4	Peltier	NEED Camp	Total
50	130	268	363	1698
75	238	531	670	3208
100	341	840	961	4777
125	440	1124	1209	6185
150	540	1411	1421	7519
175	660	1730	1616	8934
200	759	1985	1783	10095
225	845	2240	1921	11163
250	919	2486	2064	12195
275	985	2702	2212	13155
300	1047	2927	2338	14075
350	1162	3283	2584	15674
400	1249	3580	2824	17066
450	1269	3847	3027	18160
500	1240	4130	3130	18956
550	1216	4316	3198	19467
600	1199	4524	3264	20039
650	1171	4752	3278	20517
700	1132	4930	3264	20797
750	1083	5113	3180	20909
800	994	5346	3129	21118
850	930	5559	2998	21158
900	901	5826	2884	21432

Spring-run Chinook salmon spawning WUA (ft^2) in Canyon Segment

Flow	Indian Rhubarb	Upper Placer	Lower Placer	Total
50	2.6	6.6	2.3	39
75	15	10	7.1	111
100	28	14	19	209
125	41	17	35	319
150	55	19	50	429
175	74	21	66	552
200	90	22	76	644
225	109	22	85	742
250	129	22	89	825
275	155	22	89	912
300	184	22	87	1003
350	245	21	84	1202
400	309	20	78	1397
450	369	20	72	1584
500	429	21	66	1770
550	473	22	62	1912
600	502	24	56	1995
650	522	27	52	2064
700	525	30	45	2058
750	512	32	43	2015
800	487	33	40	1921
850	454	35	34	1795
900	398	36	27	1580

Steelhead/rainbow trout spawning WUA (ft^2) in Upper Alluvial Segment

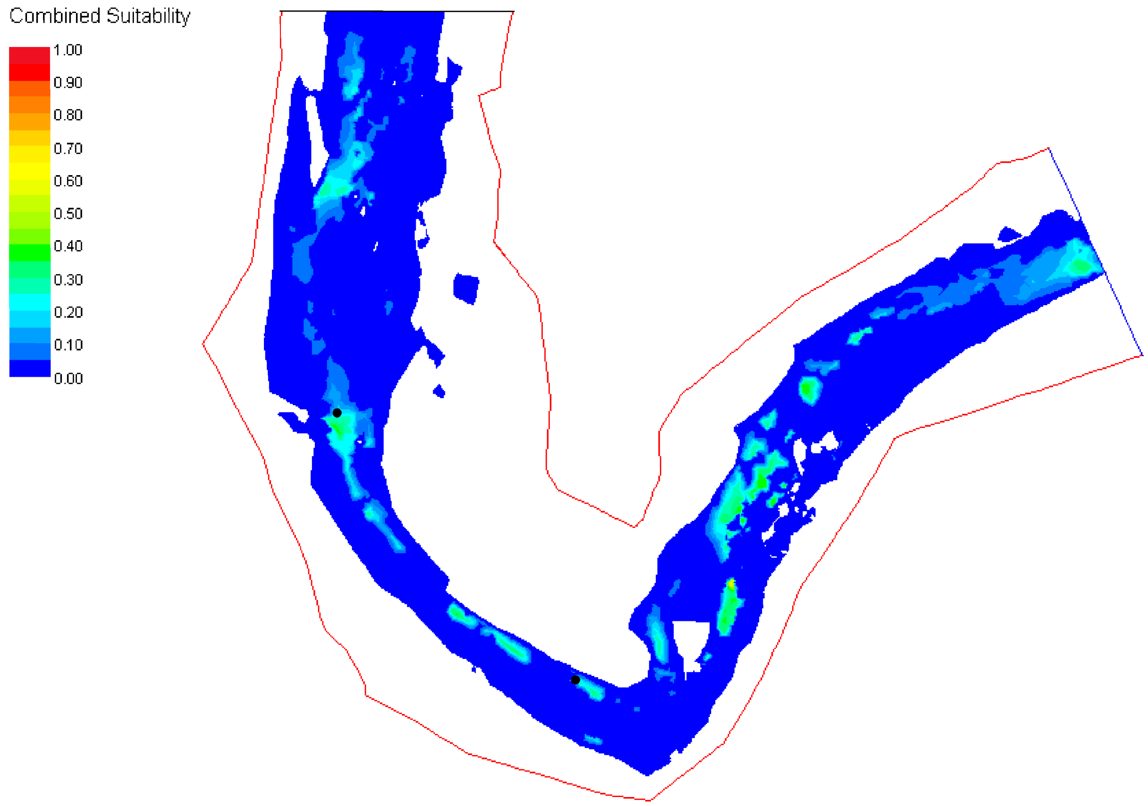
Flow	Spawn Area 4	Peltier	NEED Camp	Total
50	218	742	1310	12276
75	313	1320	1870	18951
100	392	1850	2395	25084
125	491	2241	2845	30175
150	640	2601	3151	34579
175	771	2955	3412	38615
200	849	3178	3548	40980
225	903	3376	3602	42634
250	941	3530	3635	43851
275	955	3655	3657	44725
300	971	3781	3639	45390
350	1045	3832	3549	45582
400	1006	3833	3435	44758
450	952	3832	3321	43845
500	873	3880	3125	42622
550	793	3905	2954	41396
600	714	3933	2771	40133
650	643	3980	2586	39001
700	567	4034	2401	37880
750	497	4137	2191	36925
800	431	4224	2005	36032
850	386	4312	1804	35177
900	346	4420	1609	34486

Steelhead/rainbow trout spawning WUA (ft^2) in Canyon Segment

Flow	Indian Rhubarb	Upper Placer	Lower Placer	Total
50	6.7	4.7	25	651
75	31	6.4	45	1469
100	62	7.9	65	2432
125	90	8.2	90	3394
150	112	8.1	105	4047
175	131	7.6	112	4501
200	139	7.3	111	4636
225	144	7.0	110	4708
250	145	6.6	109	4691
275	145	7.2	106	4642
300	143	8.0	100	4512
350	136	8.7	92	4253
400	128	8.7	87	4028
450	119	28	85	4171
500	111	61	81	4557
550	103	78	95	4964
600	94	88	104	5148
650	85	95	105	5119
700	76	94	92	4724
750	64	89	80	4195
800	51	82	67	3590
850	39	76	52	2991
900	30	69	40	2513

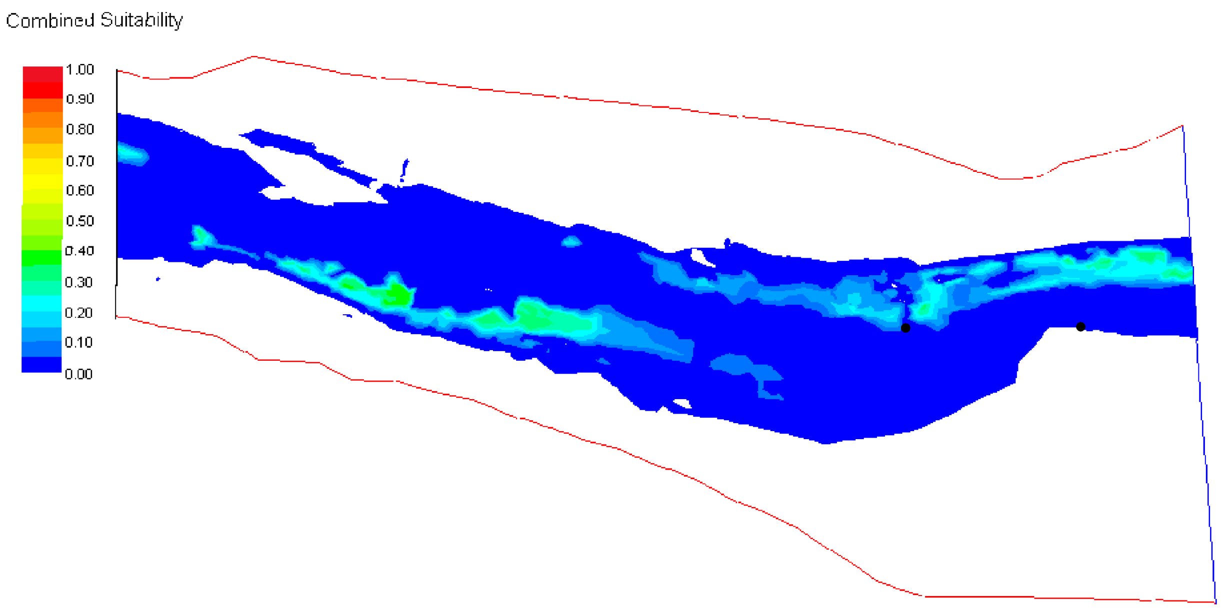
APPENDIX J
RIVER2D COMBINED SUITABILITY OF REDD LOCATIONS

PELTIER STUDY SITE
SPRING-RUN CHINOOK SALMON SPAWNING, FLOW = 161 CFS



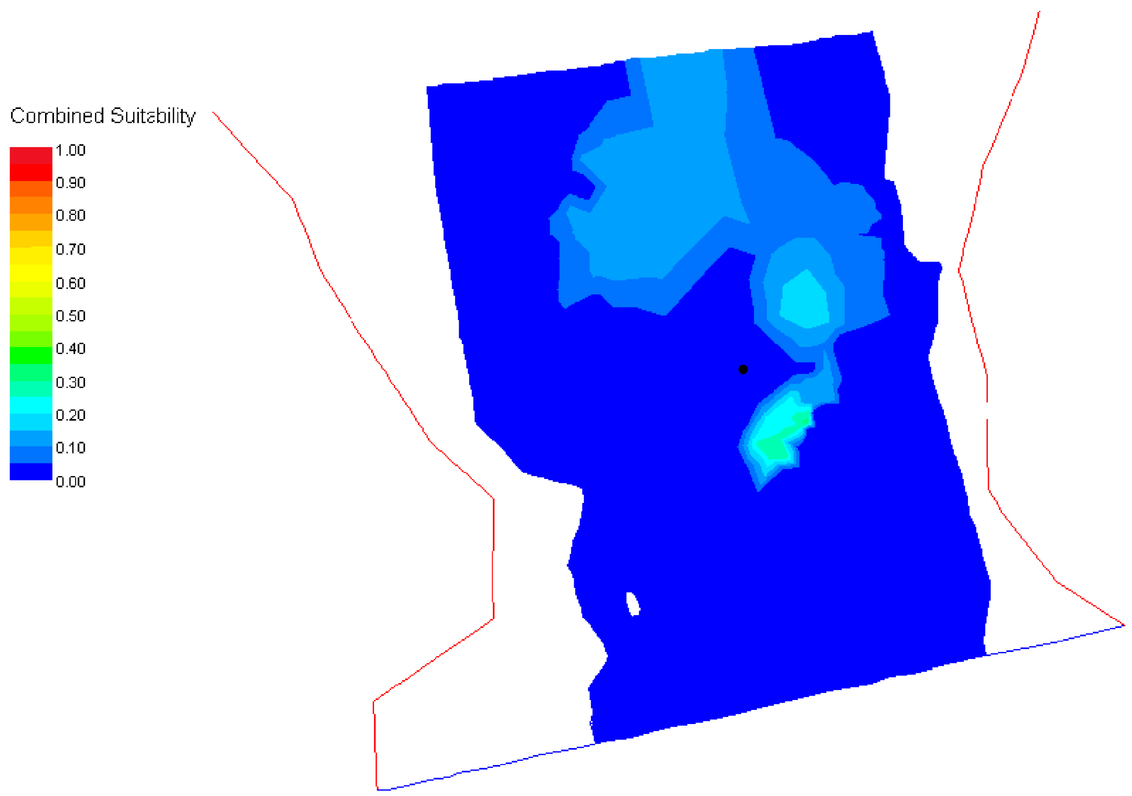
Redd locations: ●

NEED CAMP STUDY SITE
SPRING-RUN CHINOOK SALMON SPAWNING, FLOW = 164 CFS



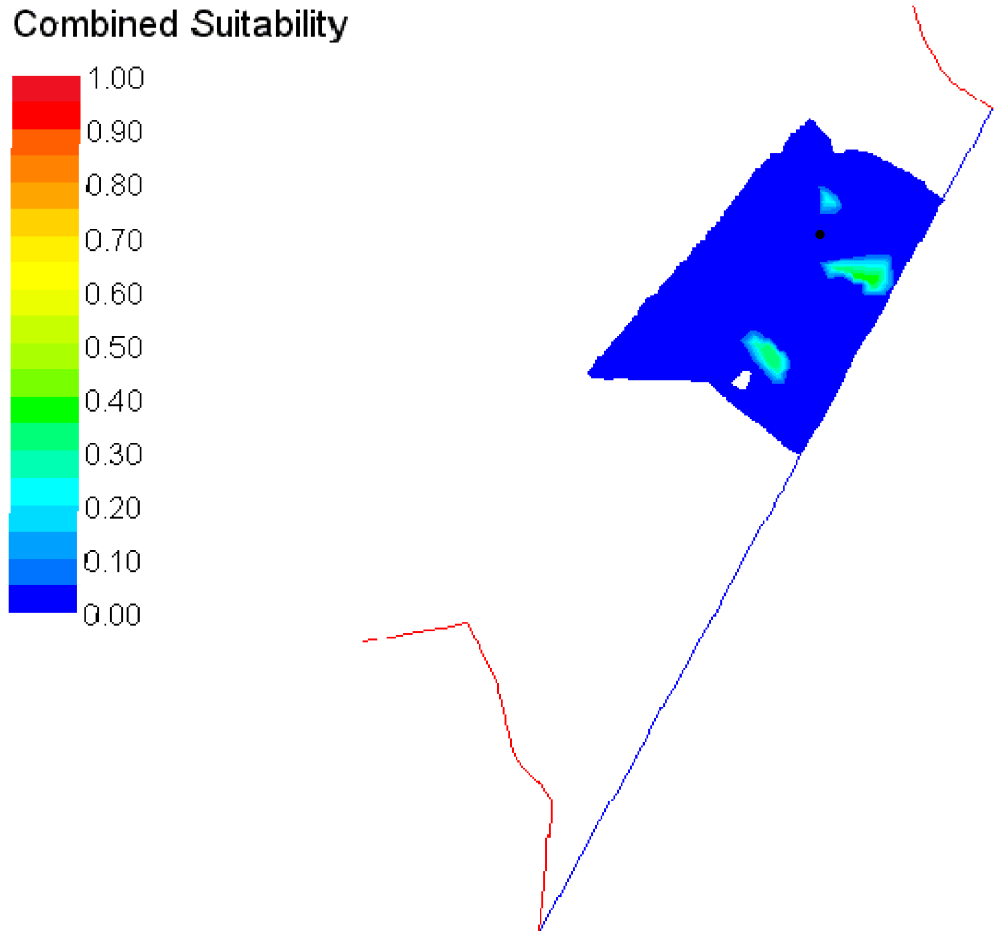
Redd locations: ●

INDIAN RHUBARB STUDY SITE
SPRING-RUN CHINOOK SALMON SPAWNING, FLOW = 166 CFS



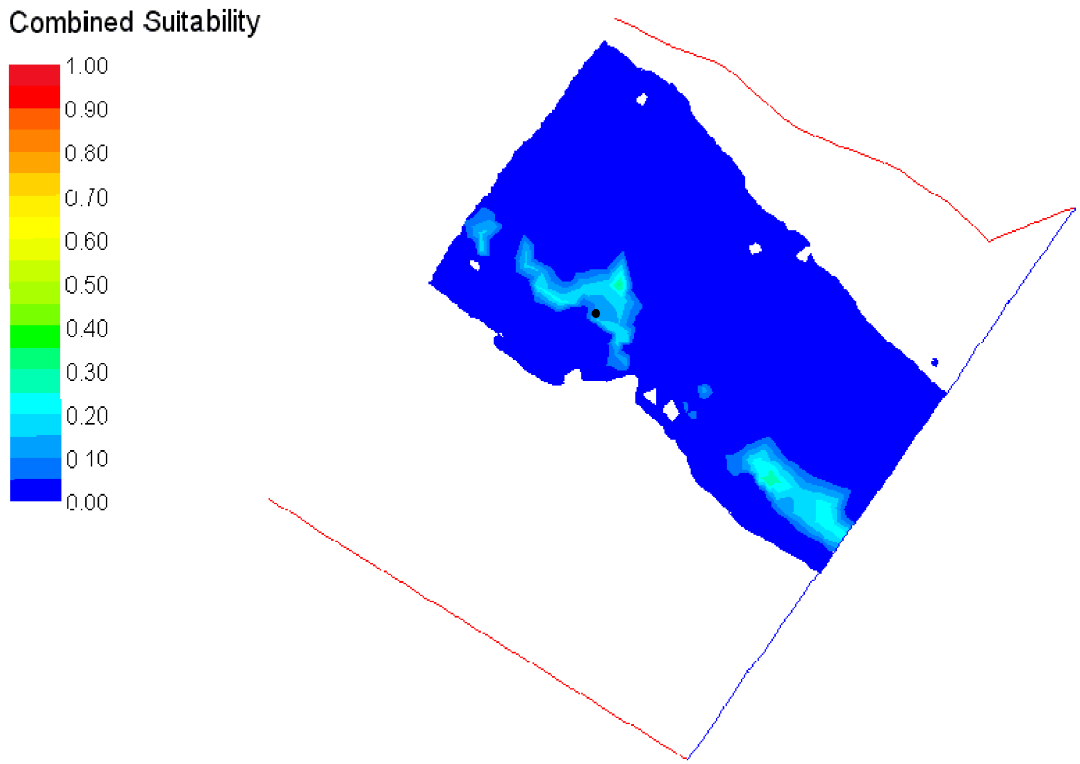
Redd locations: ●

UPPER PLACER STUDY SITE
SPRING-RUN CHINOOK SALMON SPAWNING, FLOW = 172 CFS



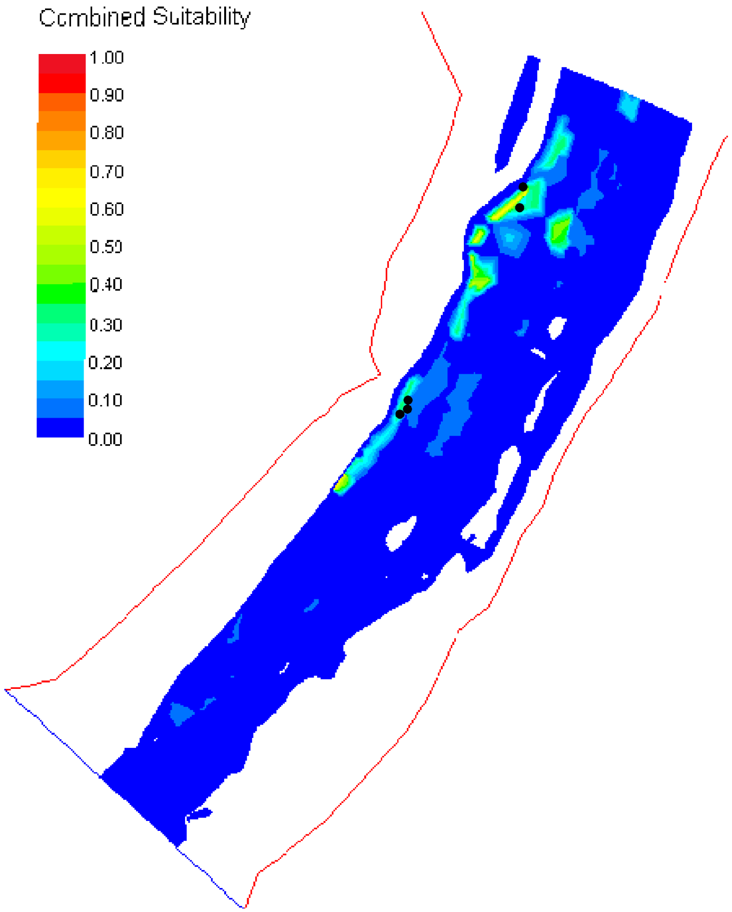
Redd locations: ●

LOWER PLACER STUDY SITE
SPRING-RUN CHINOOK SALMON SPAWNING, FLOW = 172 CFS



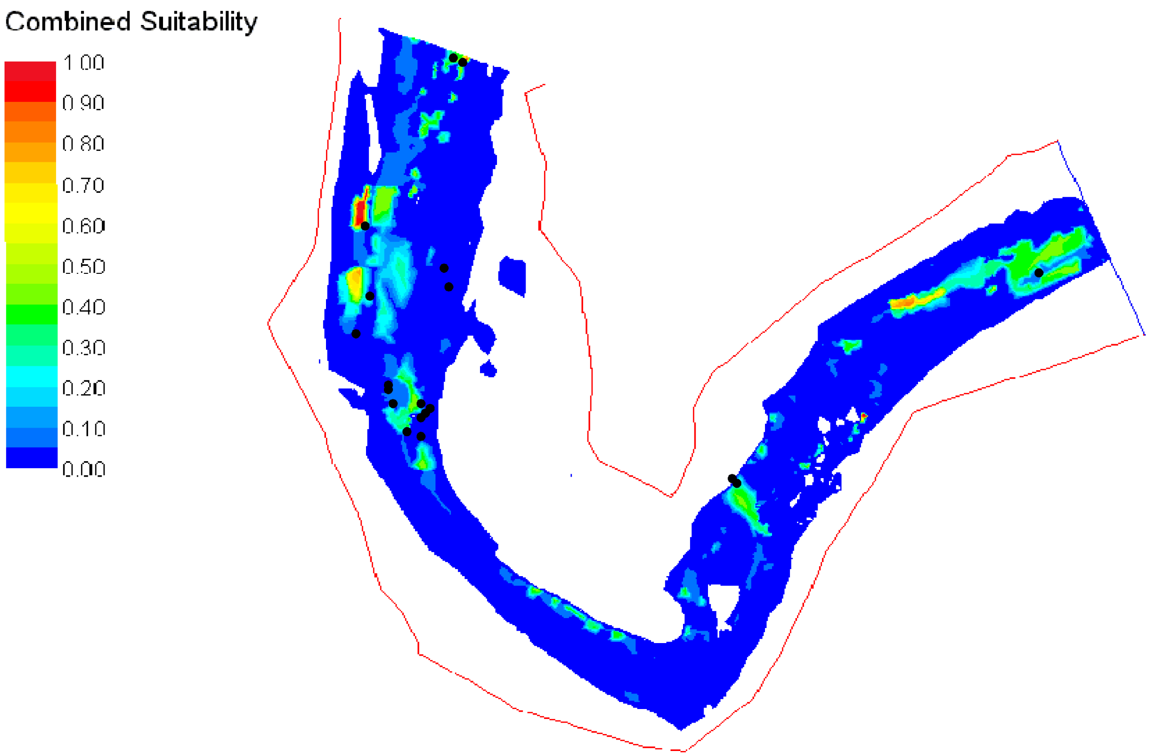
Redd locations: ●

SPAWN AREA 4 STUDY SITE
STEELHEAD SPAWNING, FLOW = 200 CFS



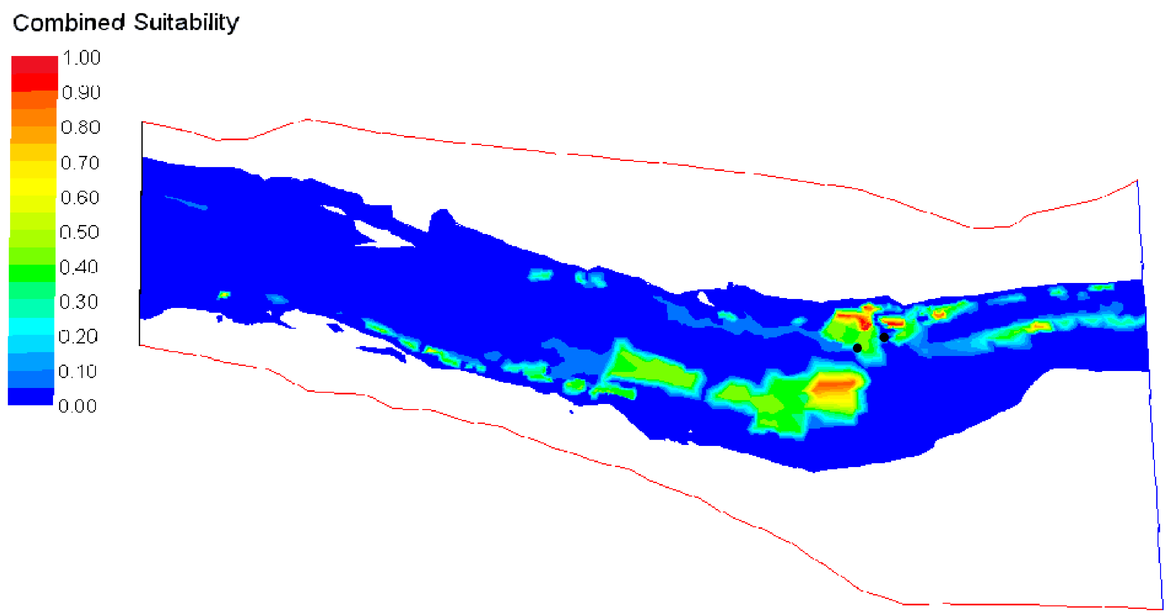
Redd locations: ●

PELTIER STUDY SITE
STEELHEAD SPAWNING, FLOW = 200 CFS



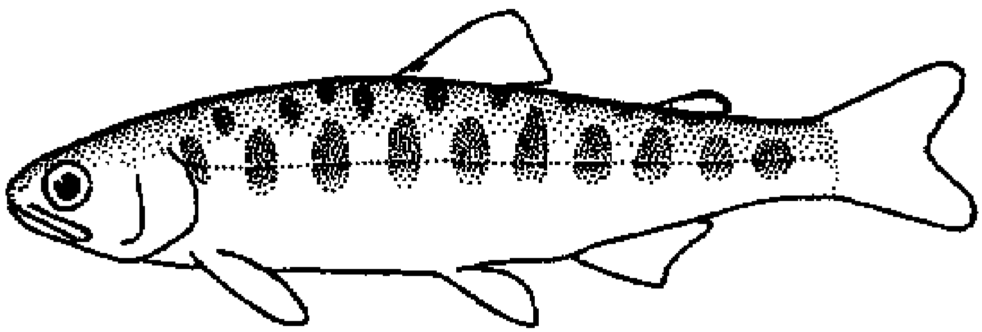
Redd locations: ●

NEED CAMP STUDY SITE
STEELHEAD SPAWNING, FLOW = 262 CFS



Redd locations: ●

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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Prepared by staff of
The Restoration and Monitoring Program

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

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.

ACKNOWLEDGMENTS

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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

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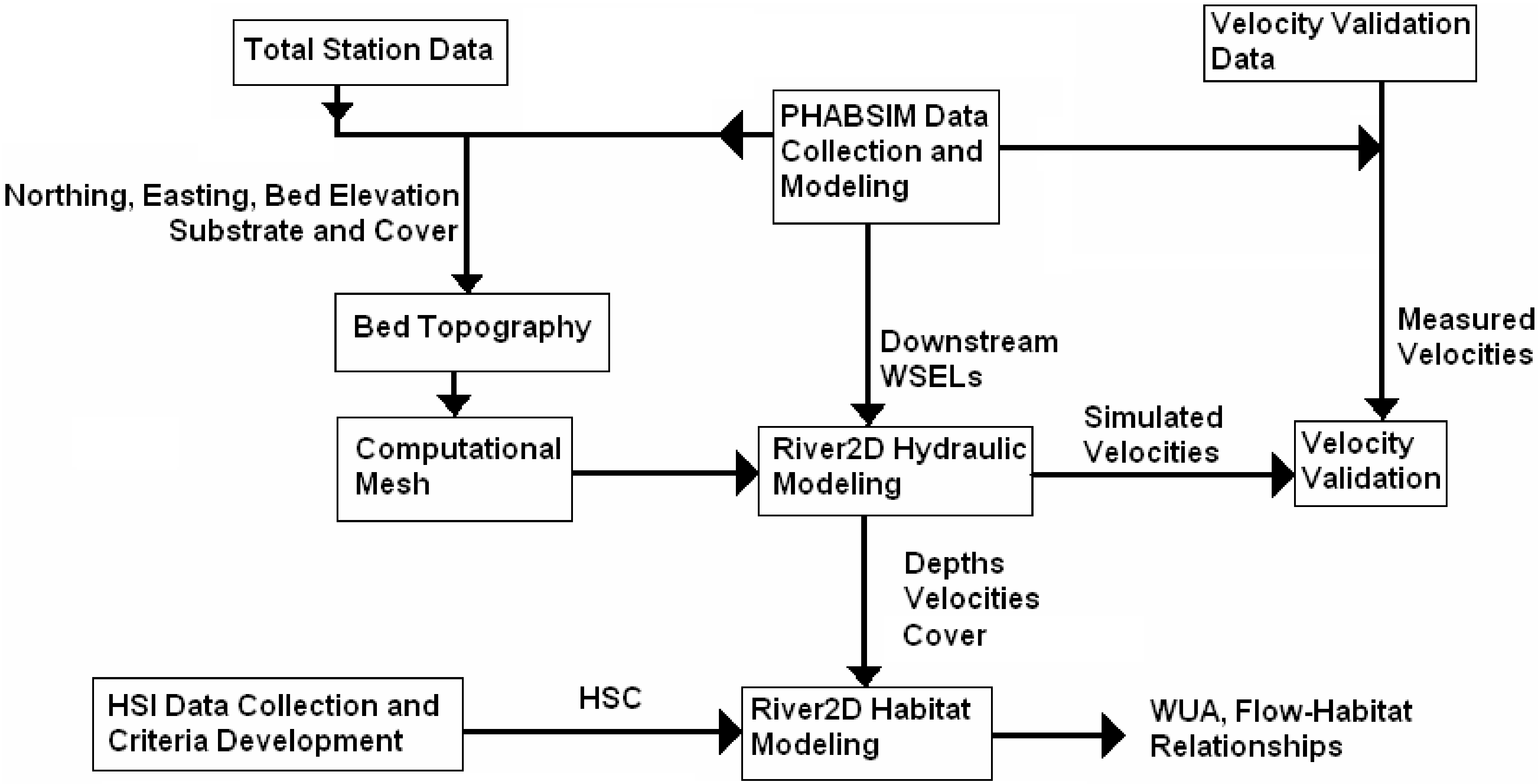
[3] PHABSIM is the collection of one dimensional hydraulic and habitat models which can be used to predict the relationship between physical habitat availability and streamflow over a range of river discharges. PHABSIM was used to develop the stage-discharge relationships at the study site boundaries.

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.

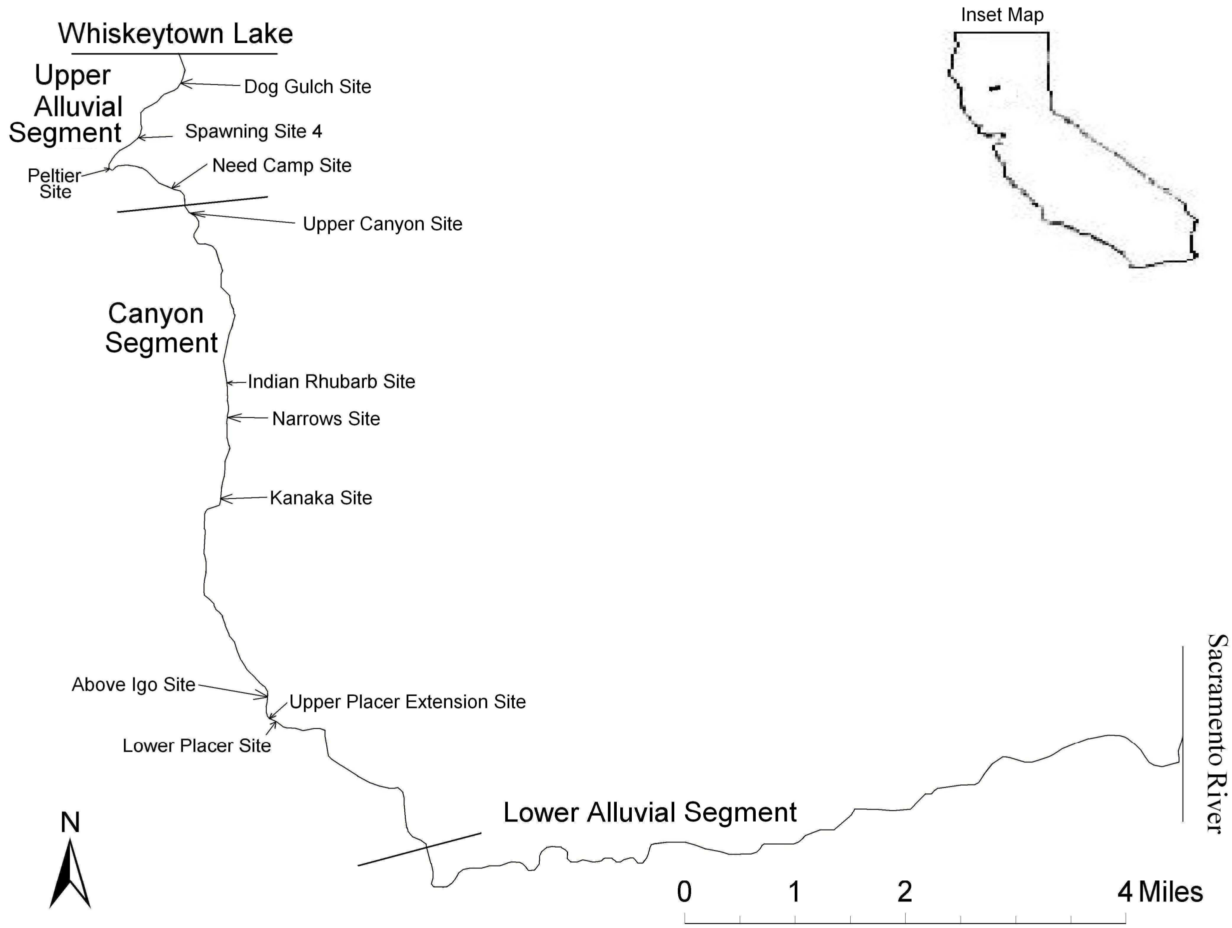
Study Segment Delineation

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

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[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

[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].

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[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

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[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).

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[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).

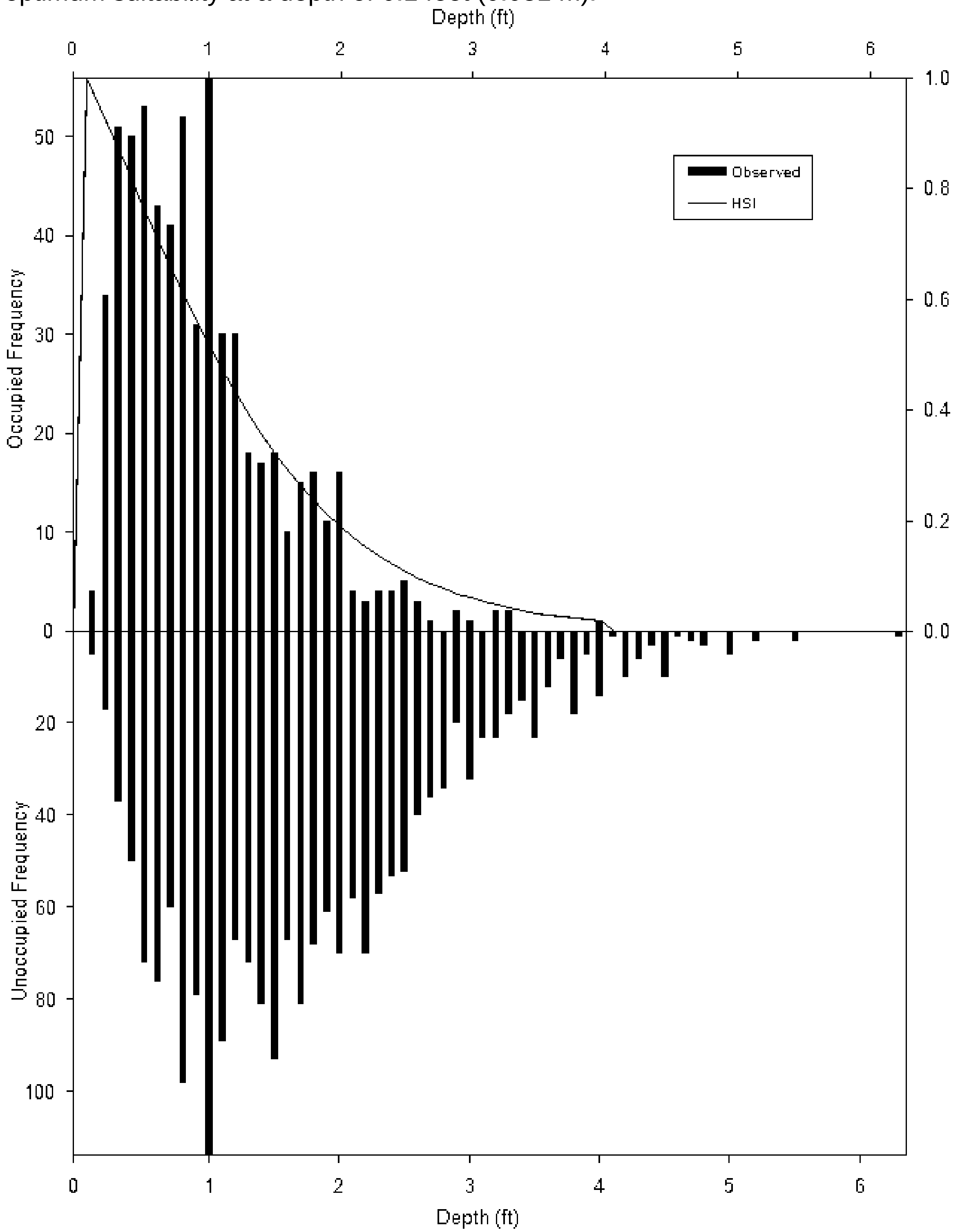


Figure 4. Spring-run Chinook salmon and steelhead/rainbow trout fry rearing velocity HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout fry rearing has a non-zero suitability for velocities of 0 to 3.60 feet/sec (0 to 1.097 m/s) and an optimum suitability at a velocity of zero.

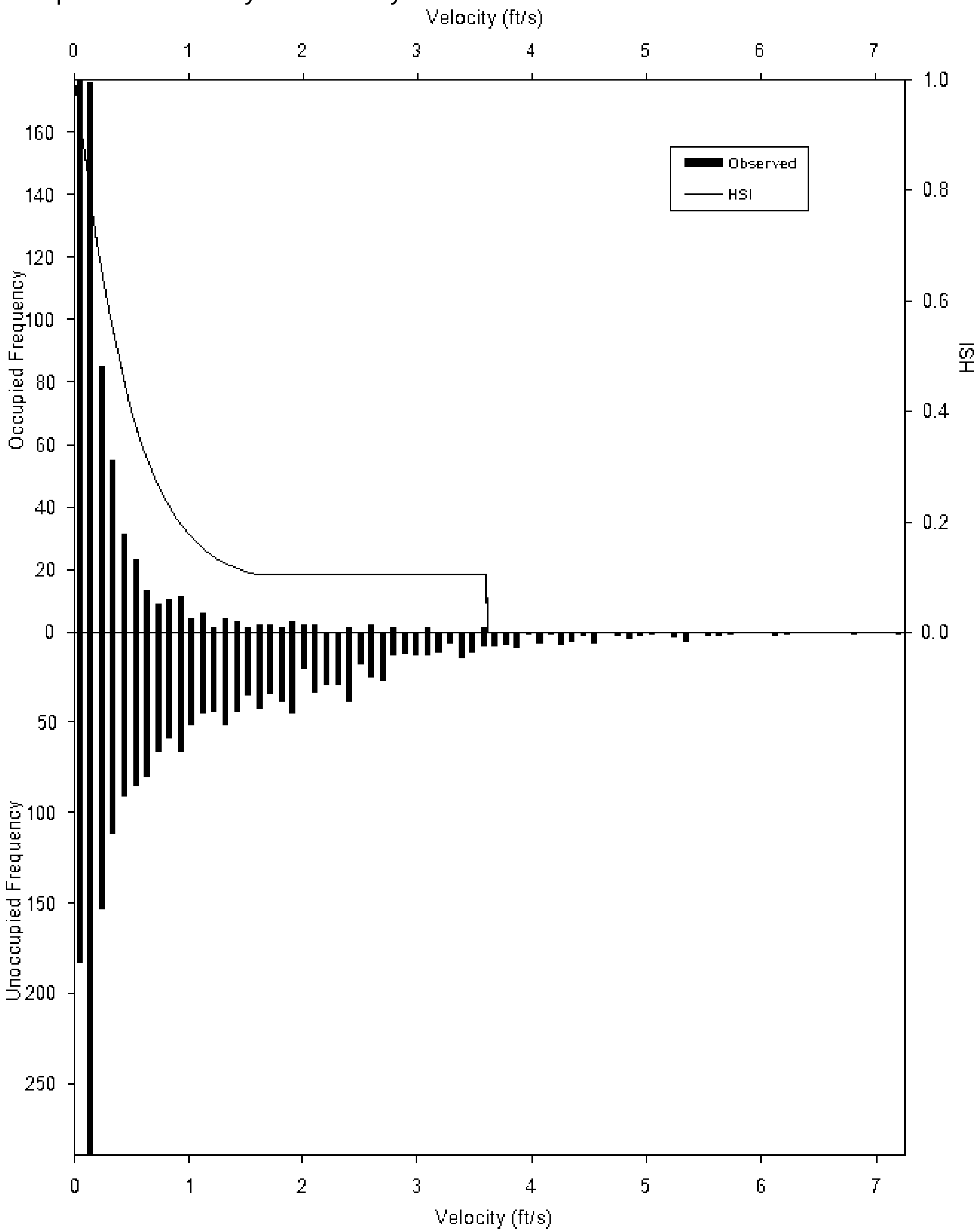


Figure 5. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing depth HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing has a non-zero suitability for depths of 0.3 to 5.5 feet (0.09 to 1.68 m) and an optimum suitability at depths of 2.8 to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

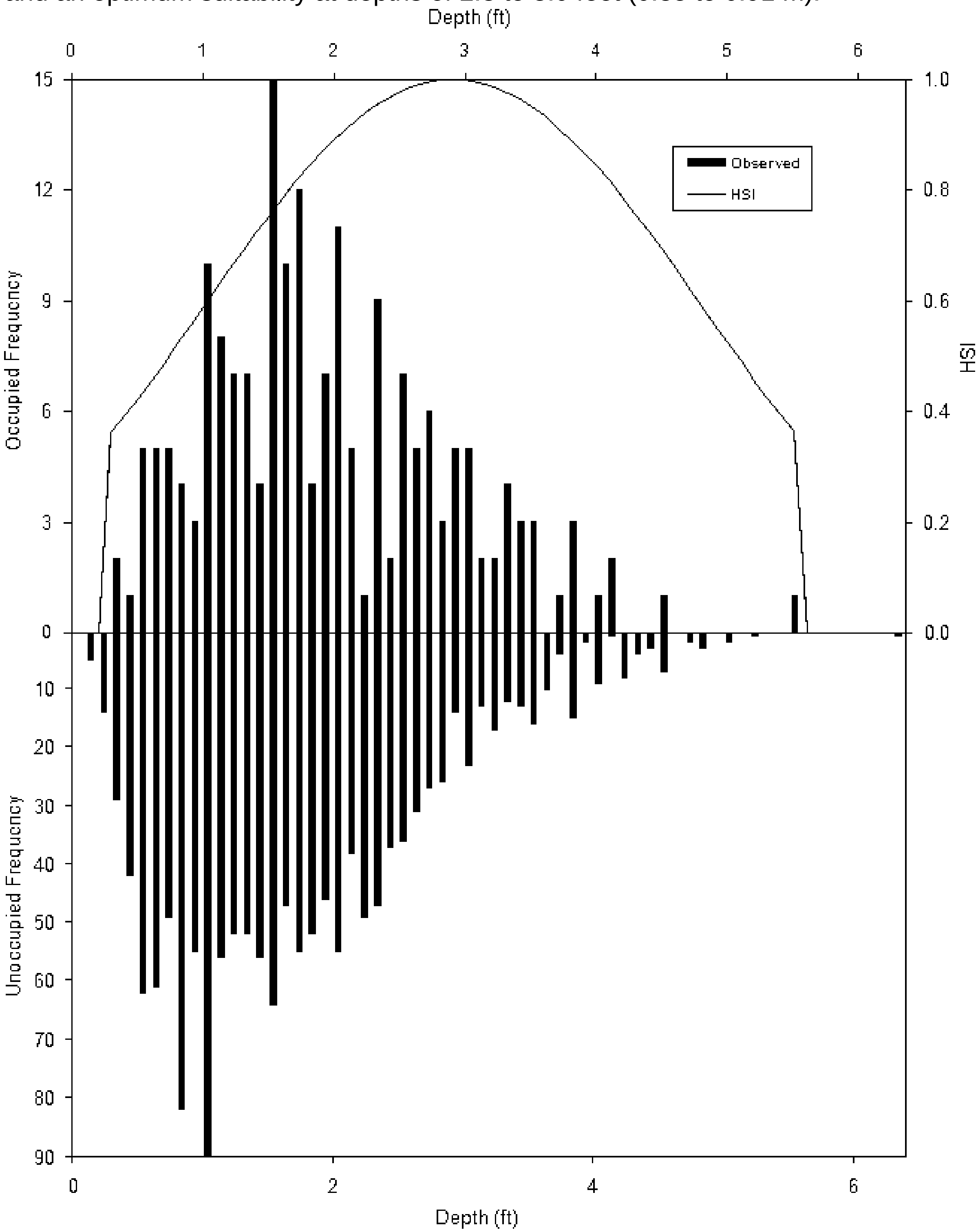


Figure 6. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing velocity HSC. The HSC show that spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing has a non-zero suitability for velocities of 0 to 5.53 feet/sec (0 to 1.685 m/s) and an optimum suitability at velocities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

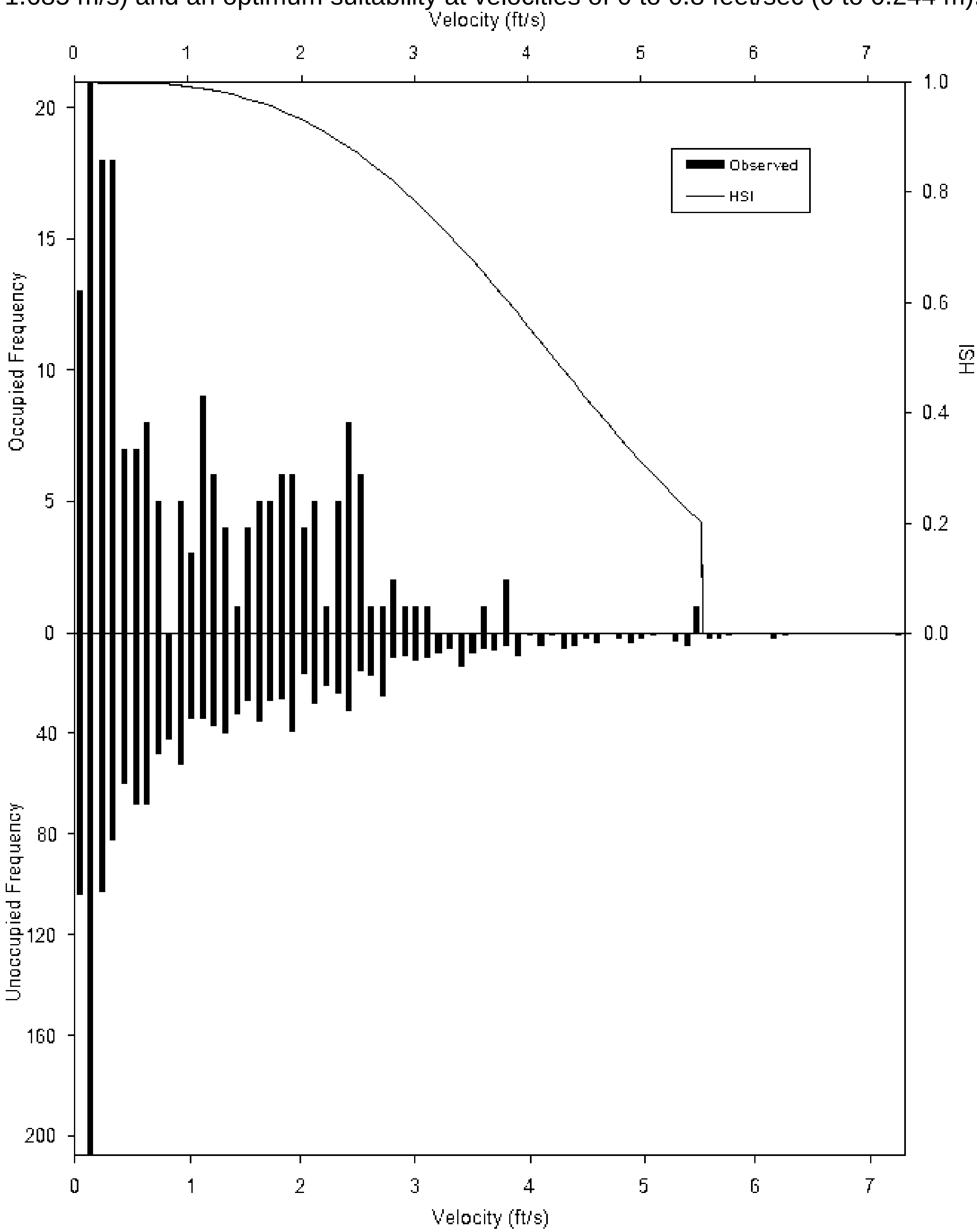


Table 18. Adjacent velocity logistic regression coefficients and R^2 values. The R^2 values are McFadden's Rho-squared values. The coefficients in this table were determined from Equation 2.

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.

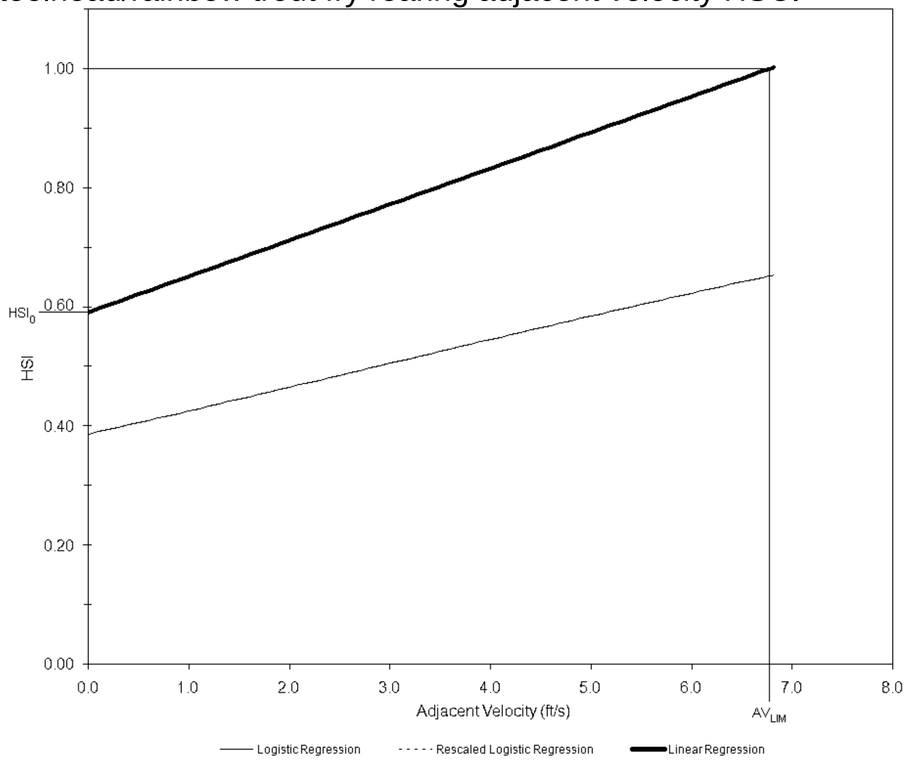


Figure 8. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing adjacent velocity HSC.

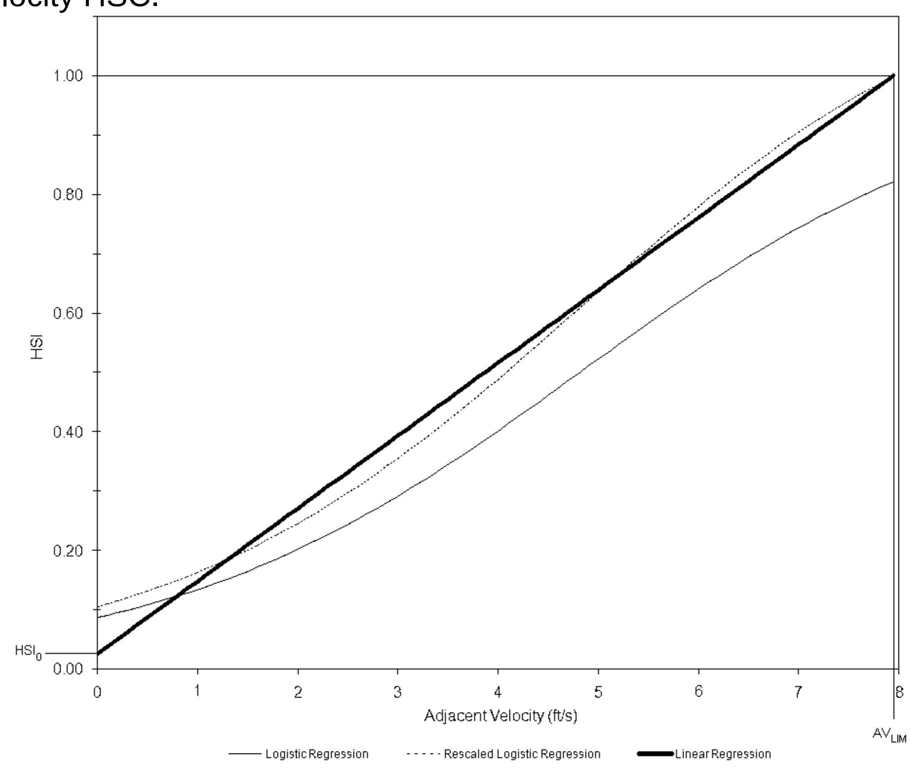


Table 19. Statistical tests of difference between cover codes, using the number of observations where fish were present and absent. An asterisk indicates that presence/absence of fish for those cover codes were significantly different at p = 0.05.

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.

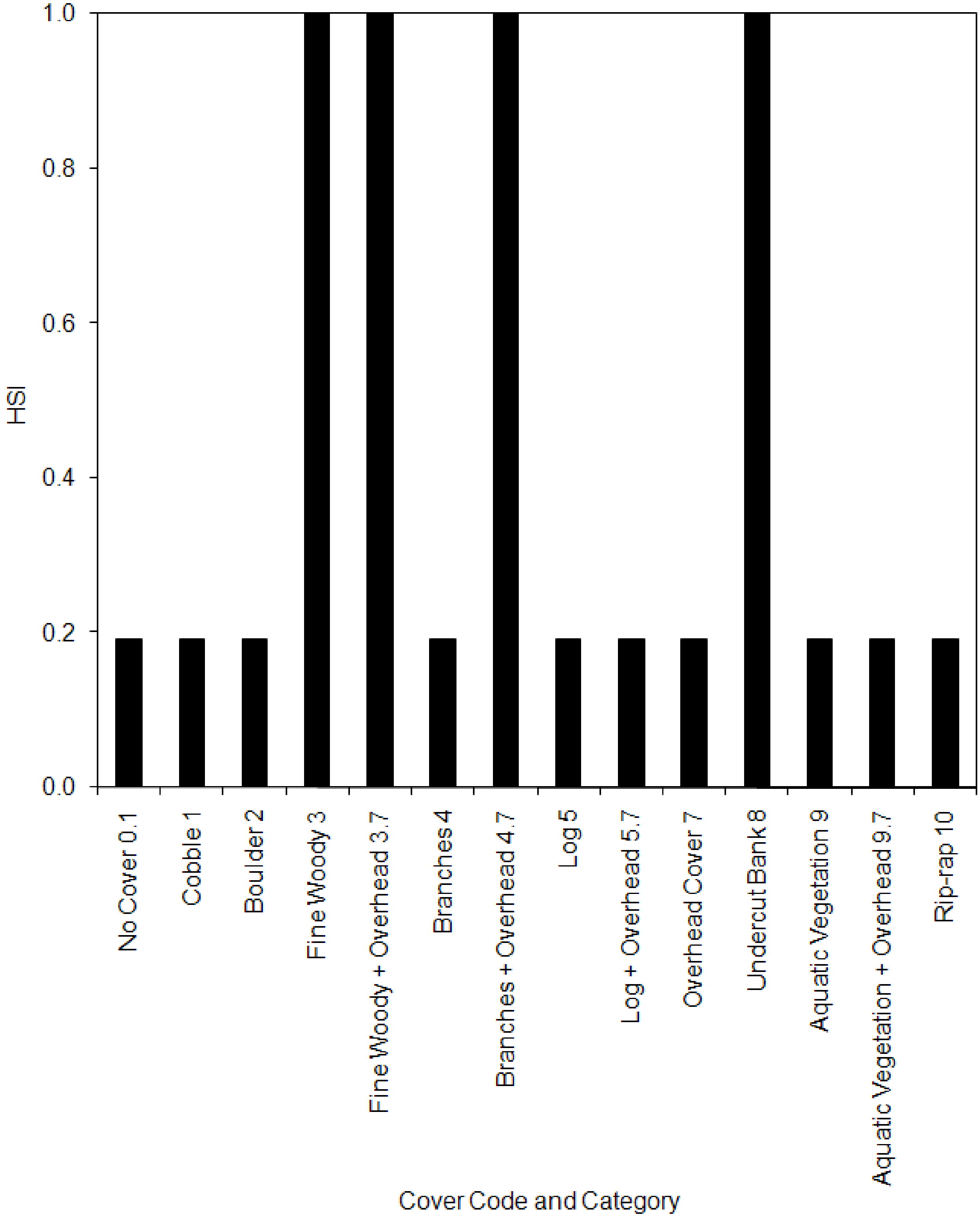


Figure 10. Steelhead/rainbow trout fry rearing cover HSC.

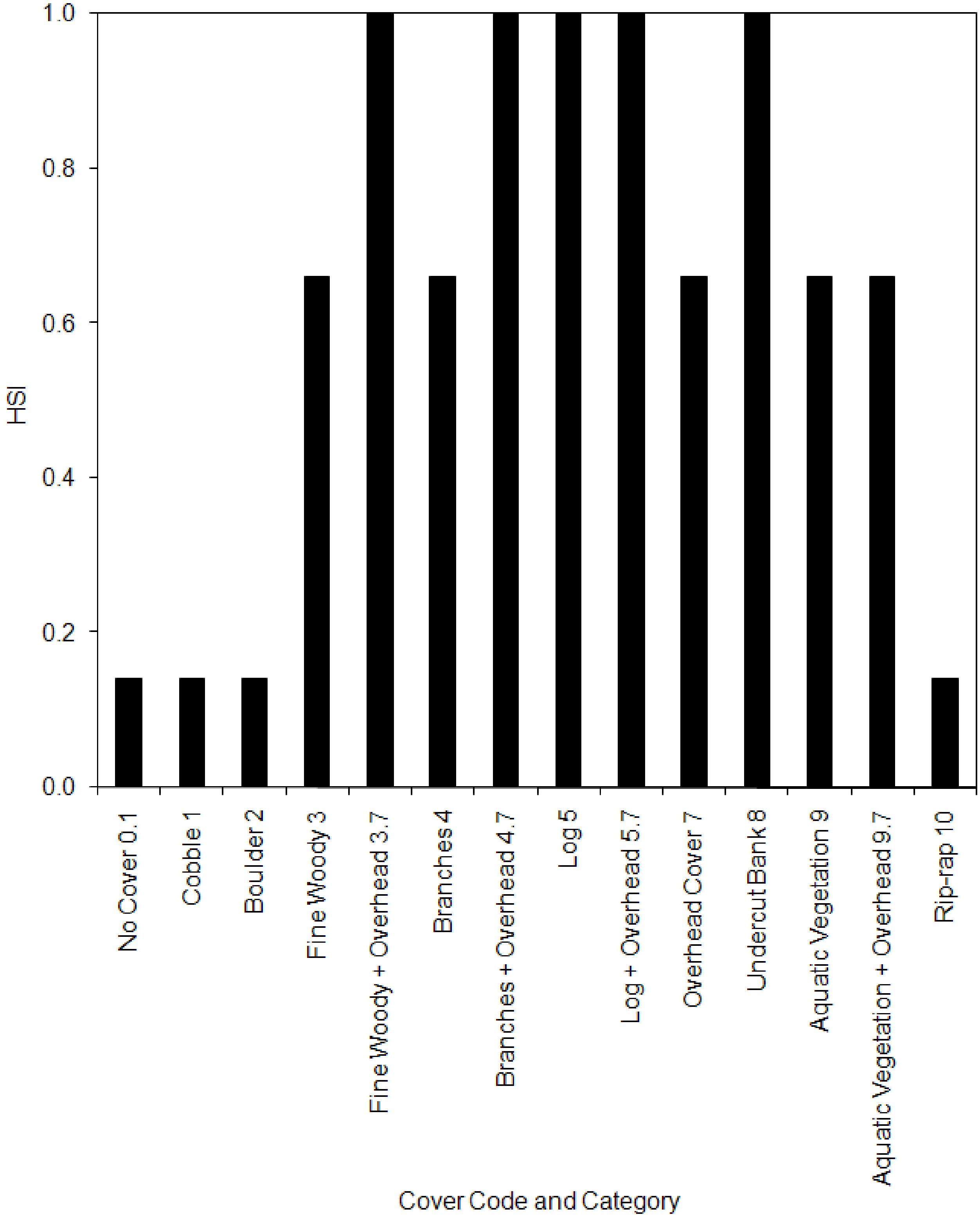


Figure 11. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing cover HSC.

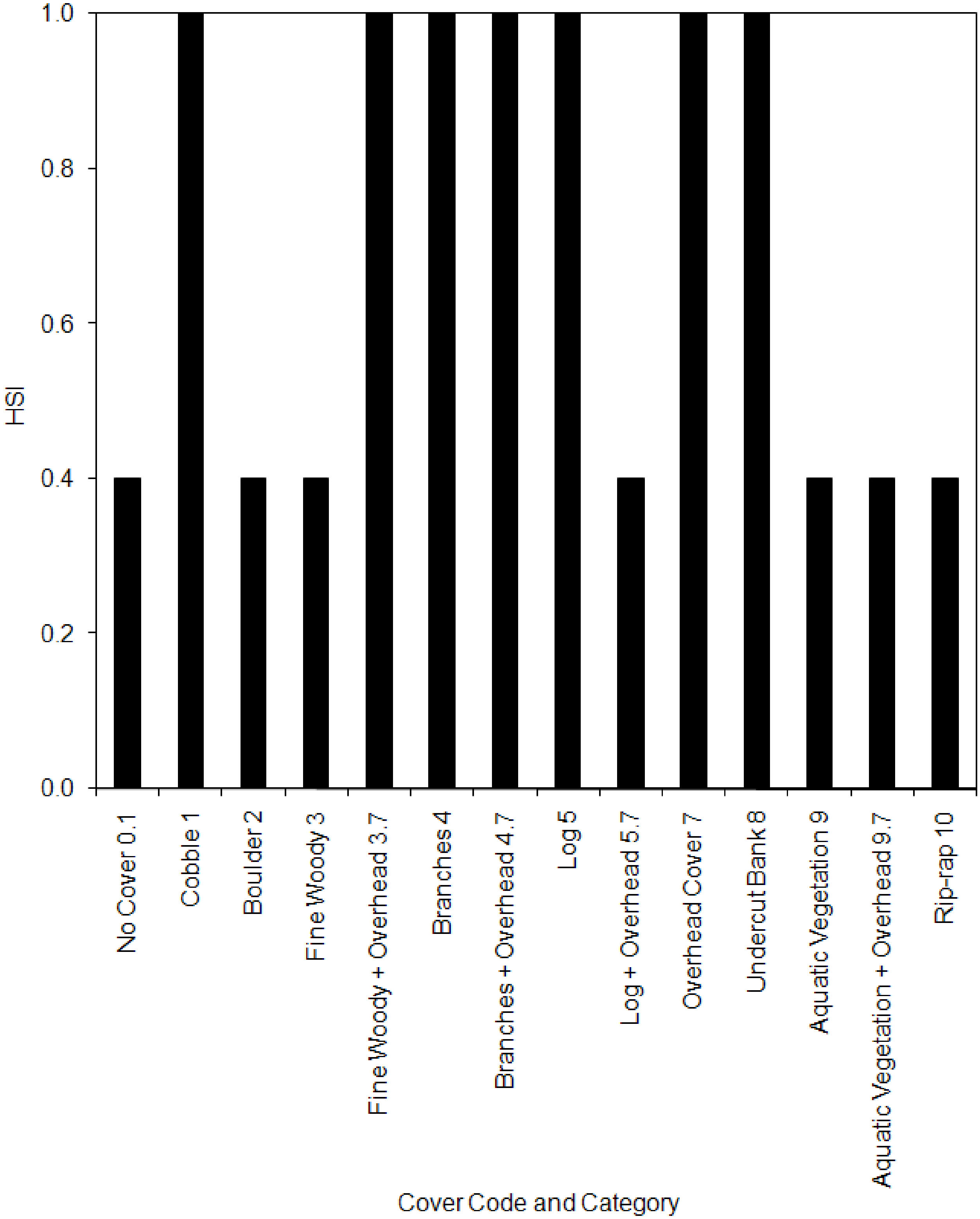


Table 21. Ratio of habitat areas in segment to habitat areas in modeled sites. Entries with an asterisk indicate that the habitat type was not modeled in that reach. Entries with two asterisks indicate that the habitat type was not present in that reach. The ratios were adjusted to account for study 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.

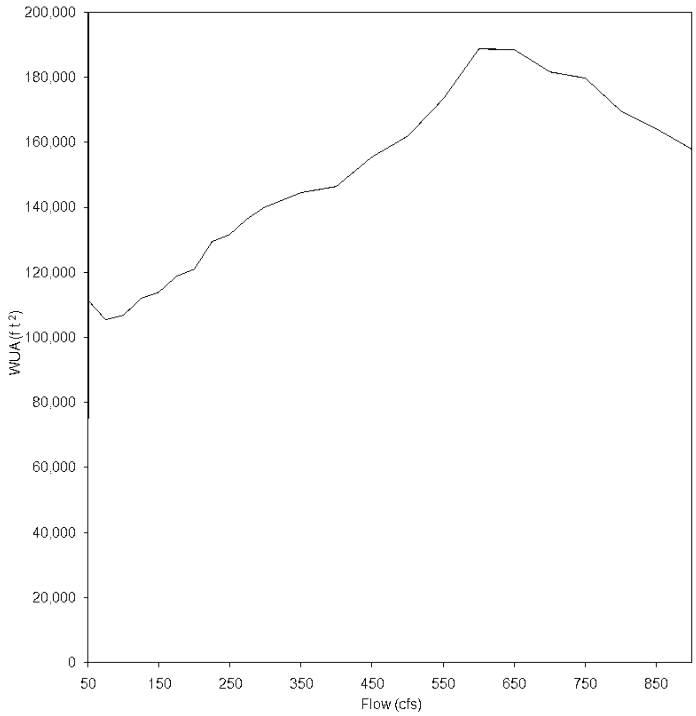


Figure 13. Spring-run Chinook salmon fry rearing flow-habitat relationship in the Canyon Segment. The flow with the predicted maximum spring-run Chinook salmon fry rearing habitat was 900 cfs.

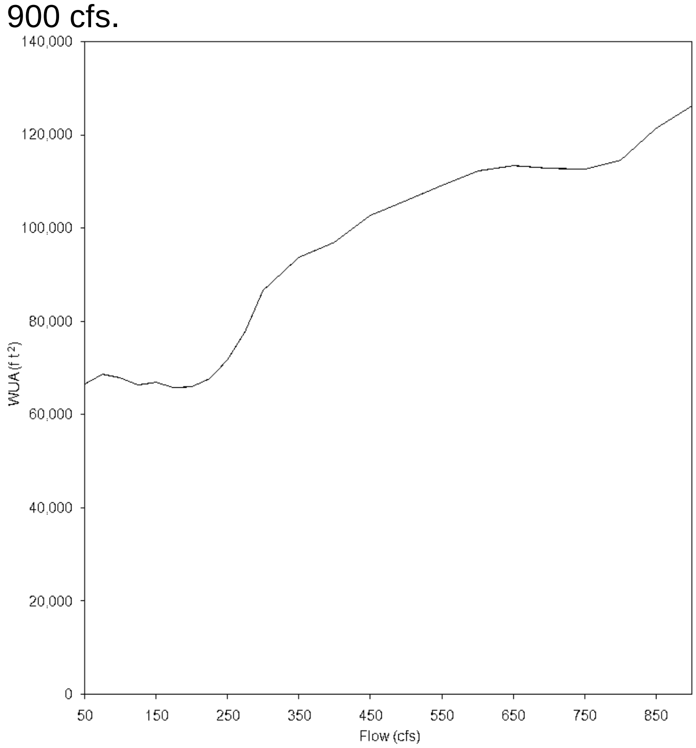


Figure 14. Steelhead/rainbow trout fry rearing flow-habitat relationship in the Upper Alluvial Segment. The flow with the predicted maximum steelhead/rainbow trout fry rearing habitat was 700 cfs.

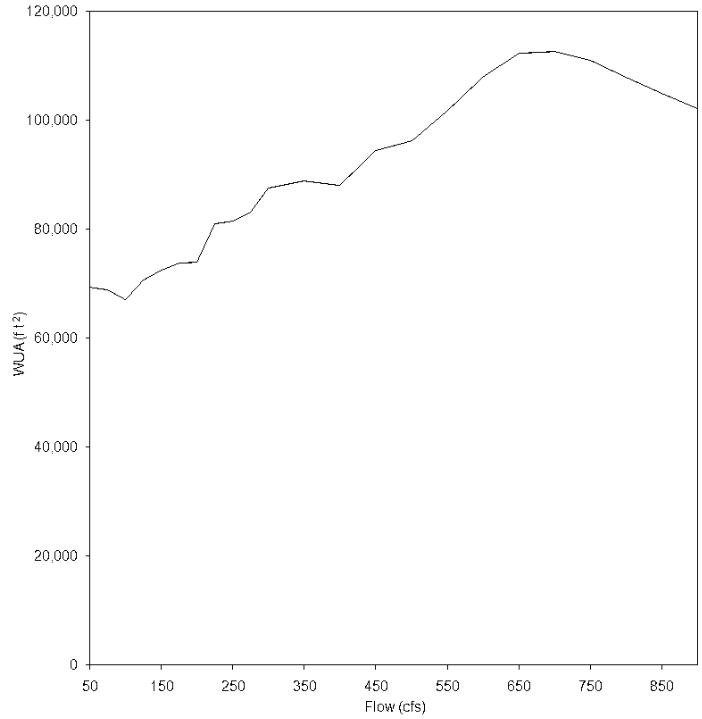


Figure 15. Steelhead/rainbow trout fry rearing flow-habitat relationship in the Canyon Segment. The flow with the predicted maximum steelhead/rainbow trout fry rearing habitat was 900 cfs.

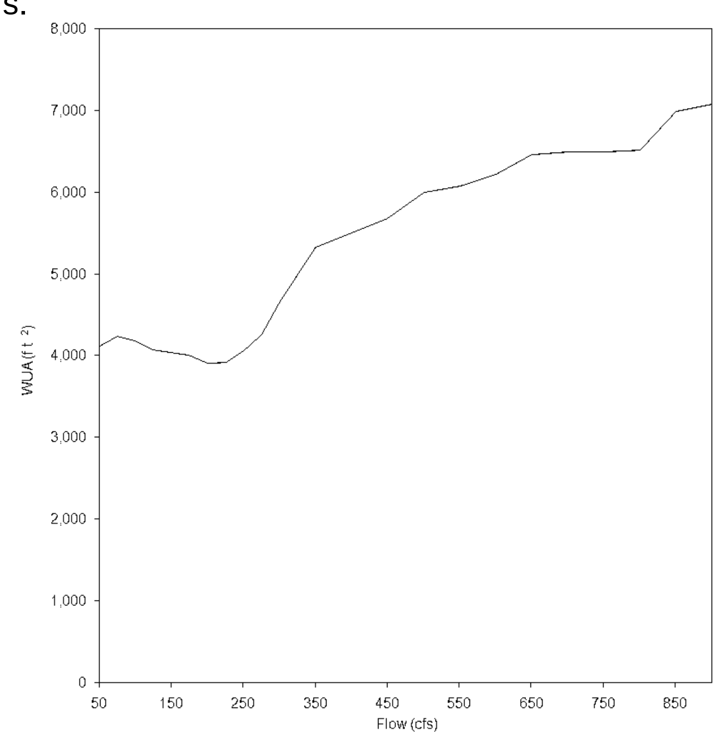


Figure 16. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing flow-habitat relationship in the Upper Alluvial Segment. The flow with the predicted maximum spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing habitat was 900 cfs.

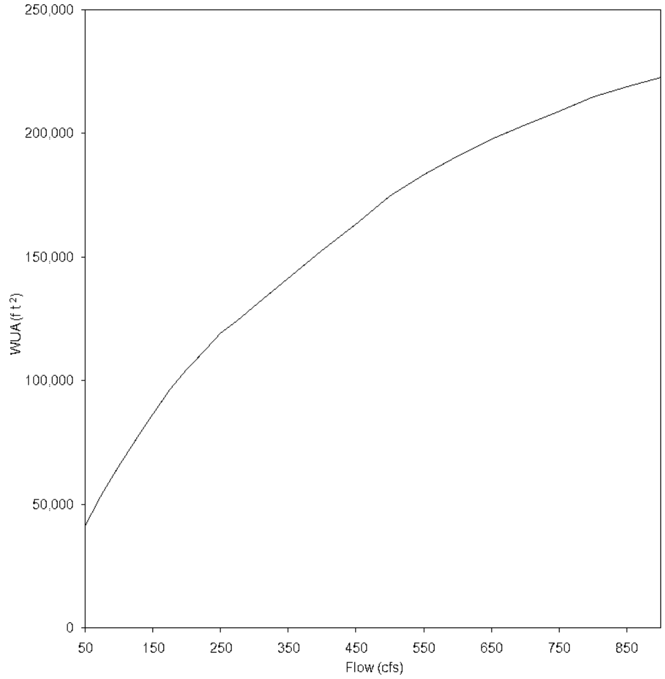
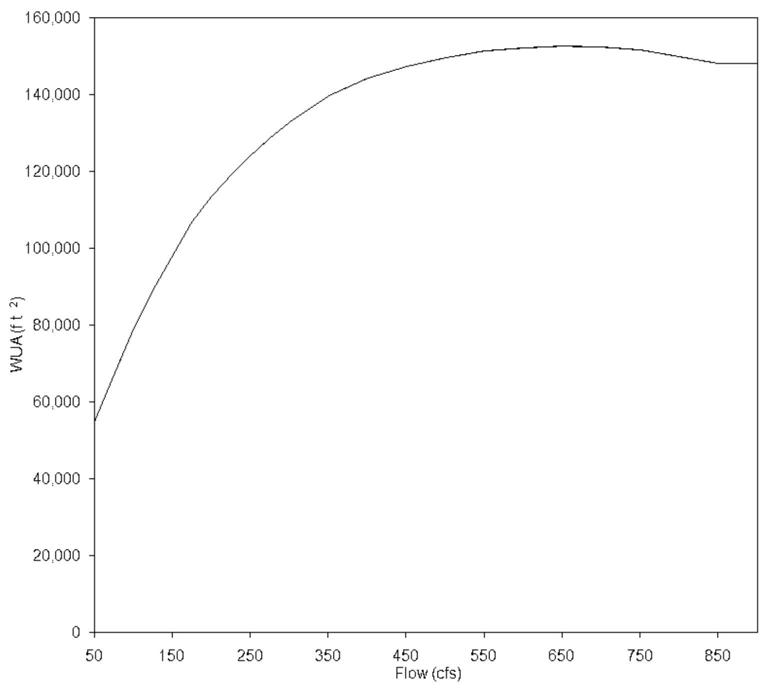


Figure 17. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing flow-habitat relationship in the Canyon Segment. The flow with the predicted maximum spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing habitat was 650 cfs.



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.

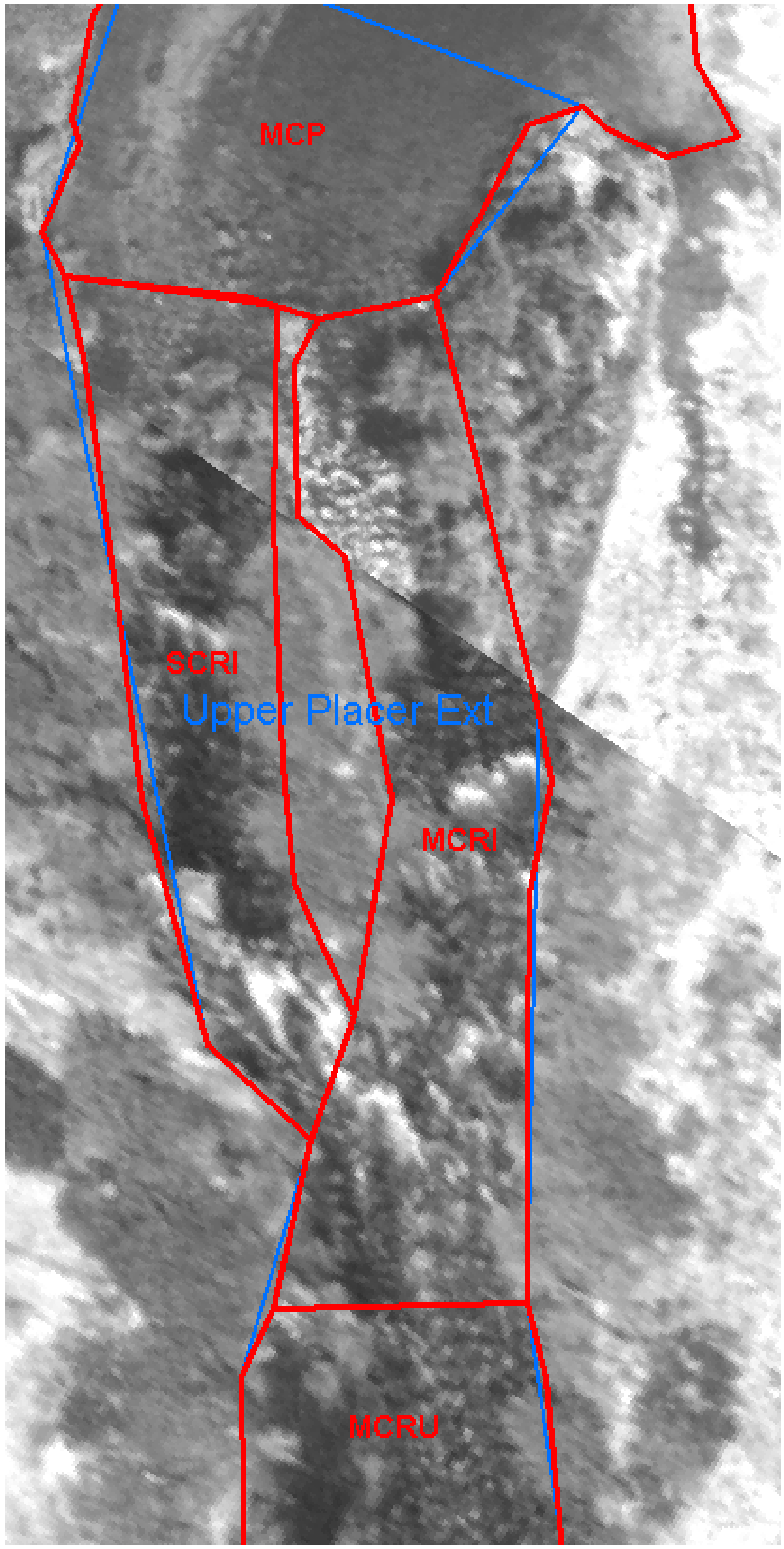
River2D Model Construction

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.

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[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.

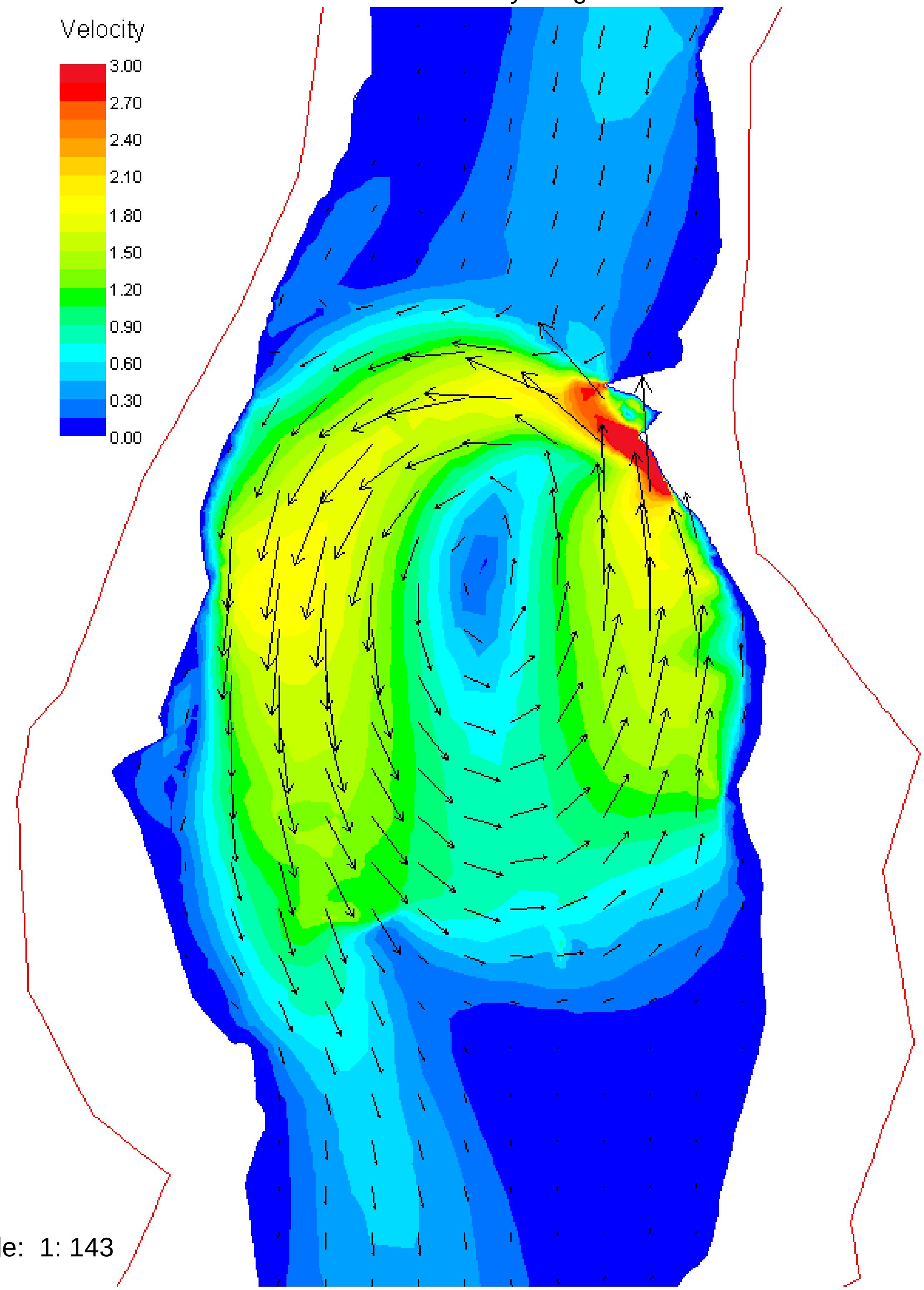
We attribute the overprediction of velocities for the middle portion of the Narrows site to a strong eddy that was produced in the hydraulic model (see Figure 19). The strong simulated upstream velocities on the east side of the channel were countered by the strong downstream velocities on the west side 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.

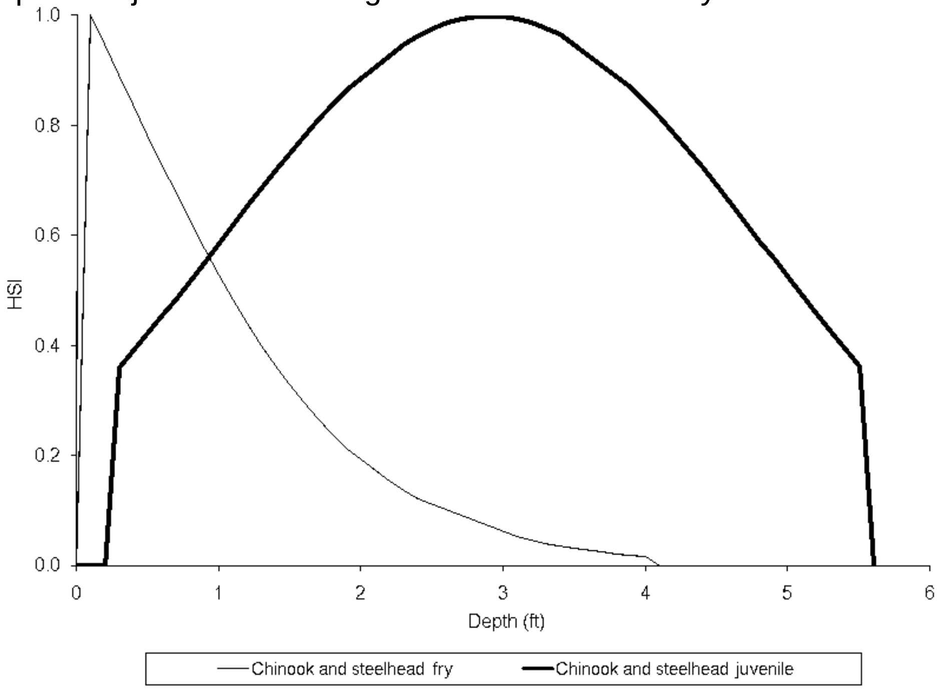


Figure 21. Comparison of velocity HSC from this study. These criteria indicate that there was a slower rate of decline of suitability with increasing velocity for Chinook and steelhead/rainbow trout juveniles than for Chinook salmon and steelhead/ rainbow trout fry.

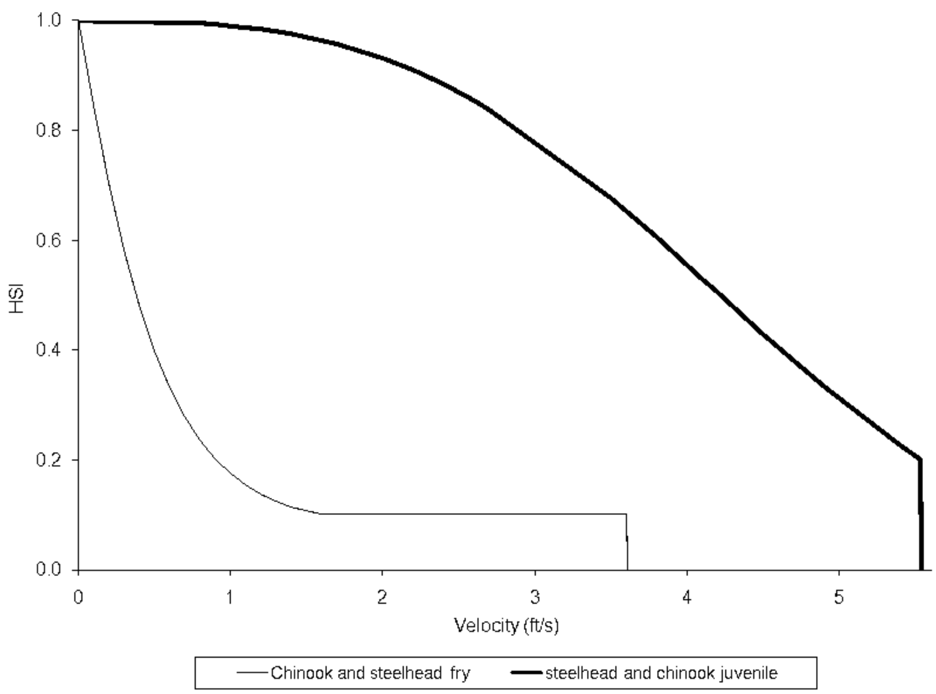


Figure 22. Comparison of cover HSC from this study. These criteria indicate that no cover, cobble and boulder had a lower suitability for fry than juveniles, but that there was a consistent preference for composite cover (instream woody plus overhead).

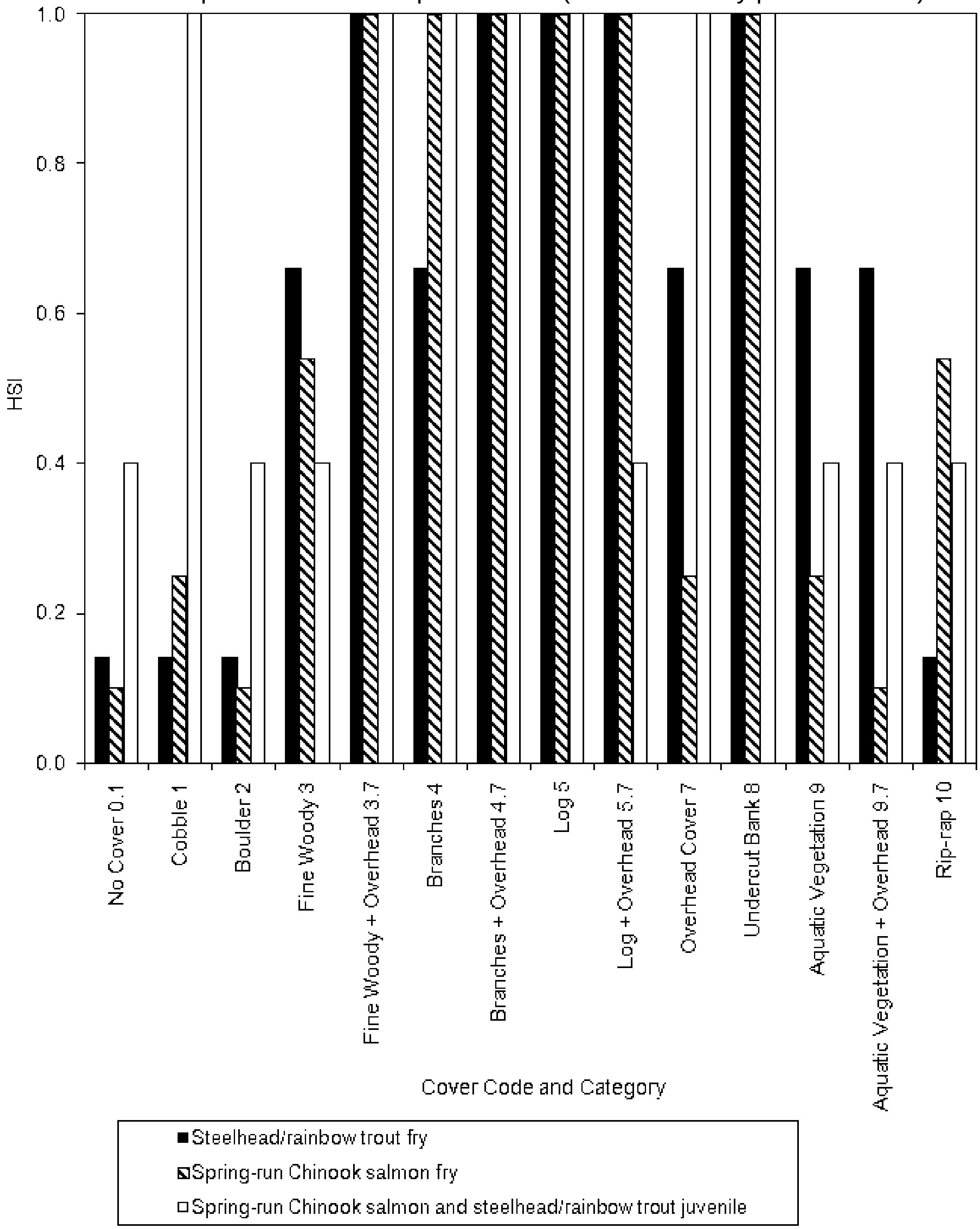
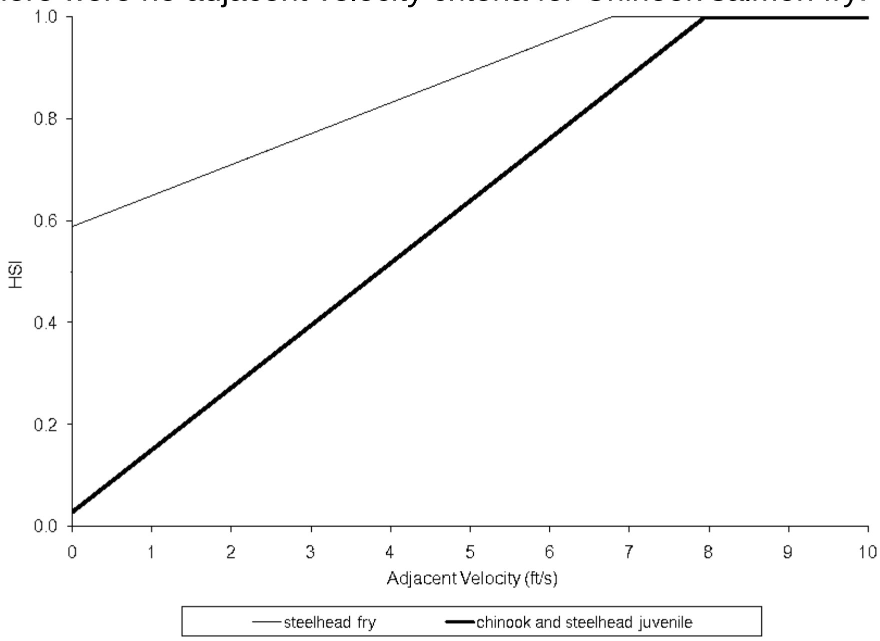


Figure 23. Comparison of adjacent velocity HSC from this study. These criteria indicate that turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas was most important for Chinook salmon and steelhead juveniles. There were no adjacent velocity criteria for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

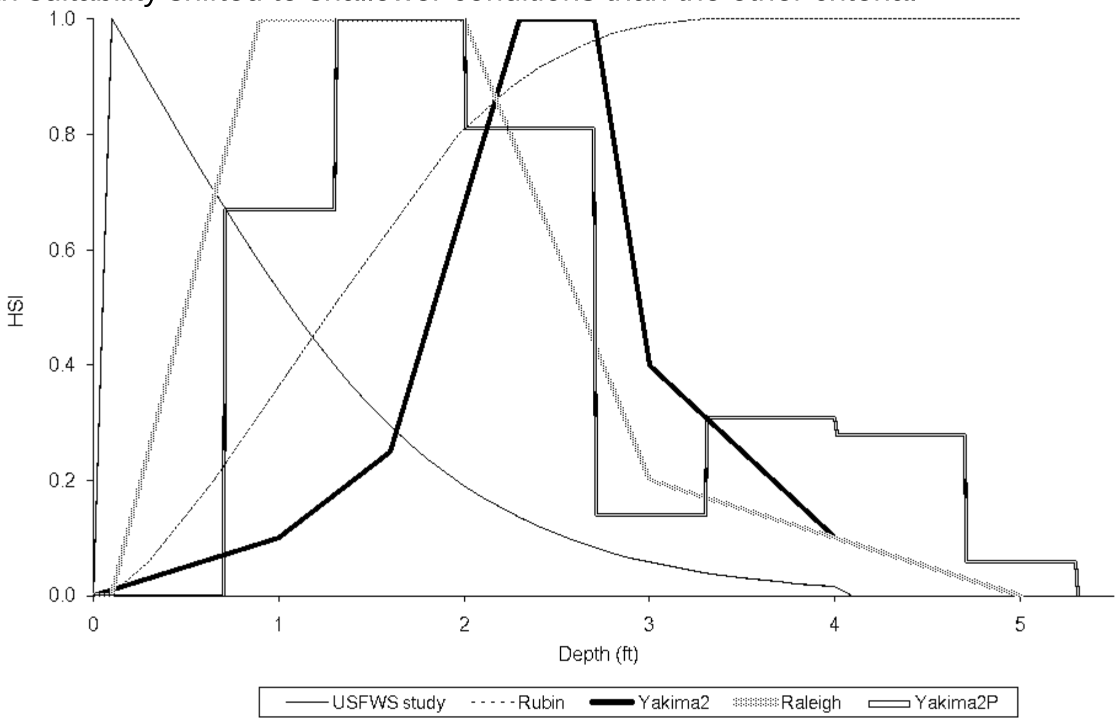


Figure 25. Comparison of spring-run Chinook salmon fry velocity HSC from this study with other spring-run Chinook salmon fry velocity HSC. The criteria from this study show non-zero suitability, albeit at low values, for faster conditions than other criteria.

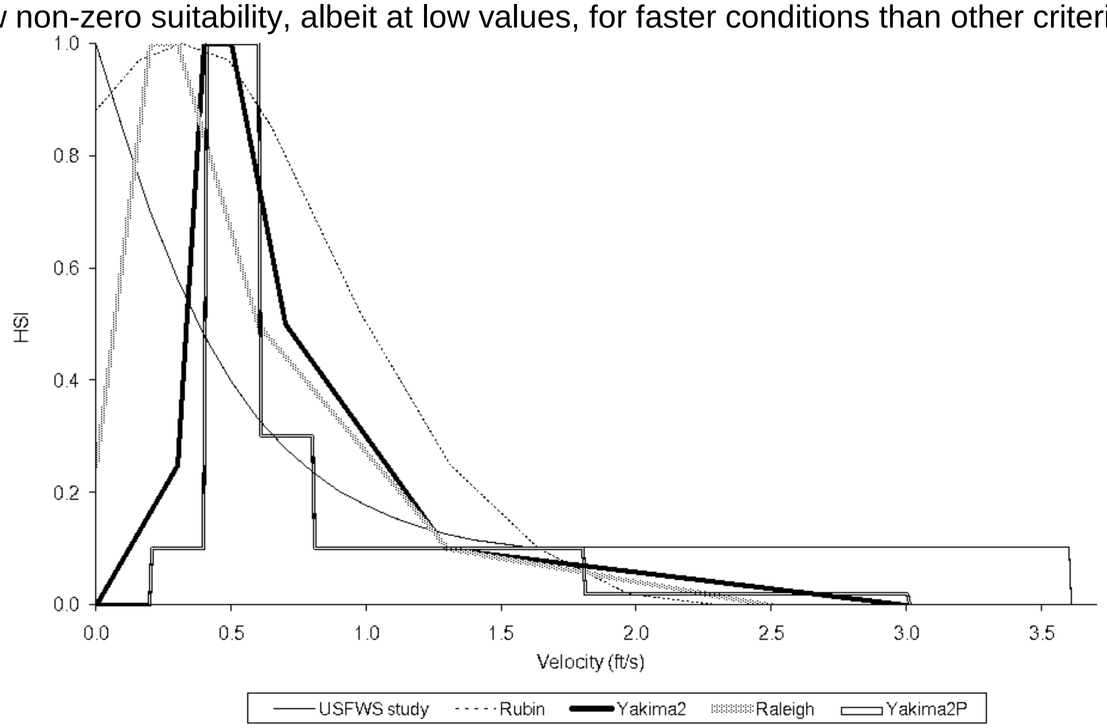


Figure 26. Comparison of spring-run Chinook salmon juvenile depth HSC from this study with other spring-run Chinook salmon juvenile depth HSC. The criteria from this study are similar to the Yakima River criteria, although reaching zero suitability at a shallower depth.

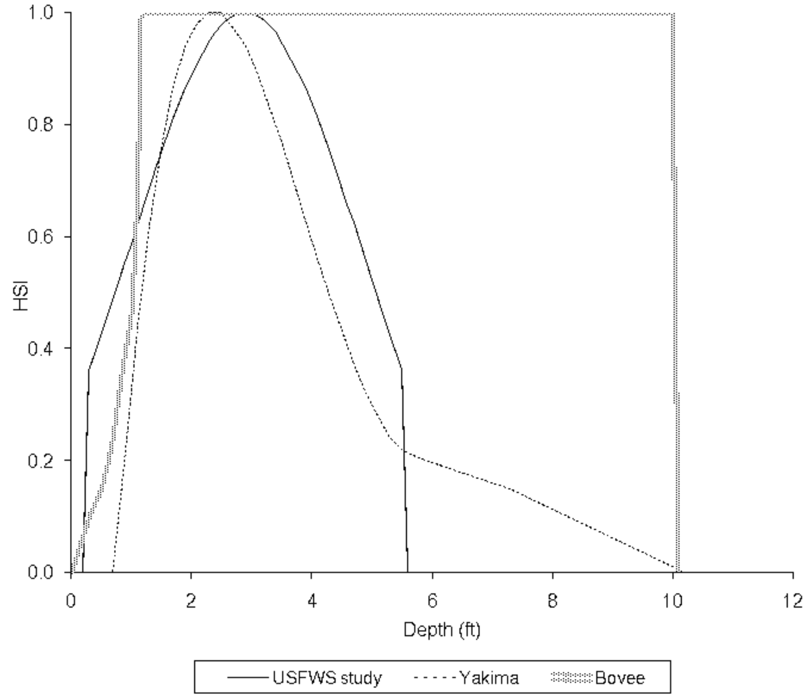


Figure 27. Comparison of spring-run Chinook salmon juvenile velocity HSC from this study with other spring-run Chinook salmon juvenile velocity HSC. The criteria from this study show non-zero suitability for faster conditions than other criteria.

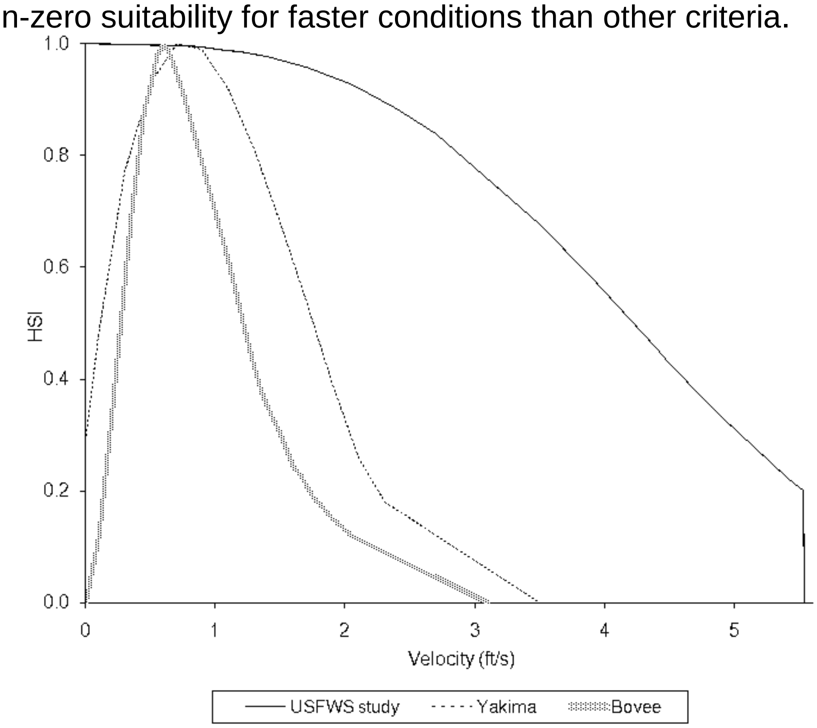


Figure 28. Comparison of steelhead/rainbow trout fry depth HSC from this study with other steelhead fry depth HSC. The criteria from this study show depth suitability shifted to shallower conditions than the other criteria.

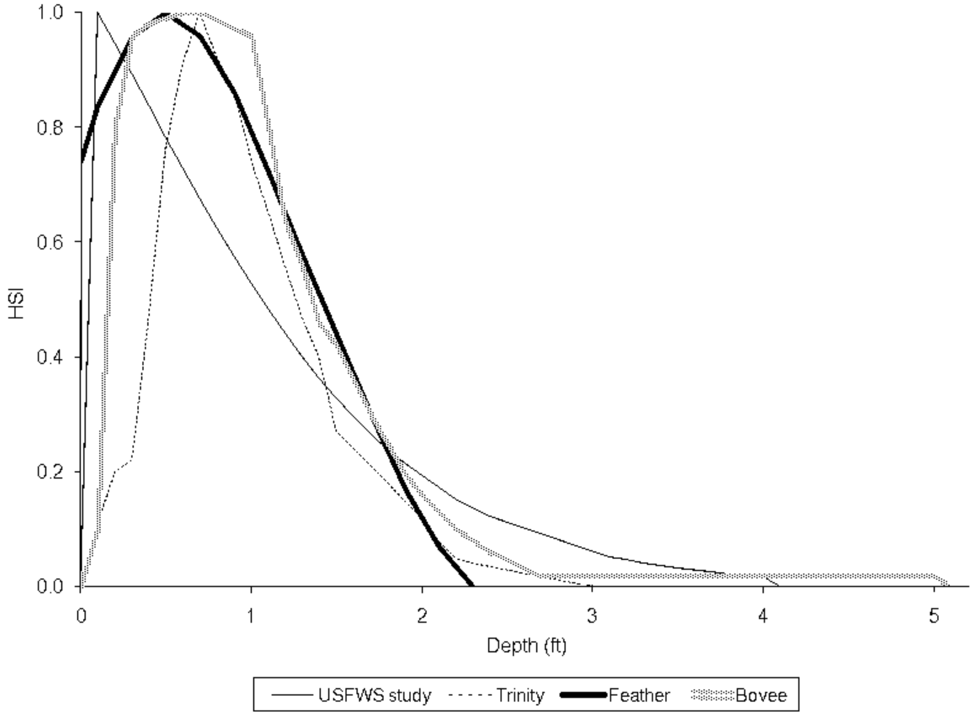


Figure 29. Comparison of steelhead/rainbow trout fry velocity HSC from this study with other steelhead fry velocity HSC. The criteria from this study show non-zero suitability extending to faster conditions than other criteria.

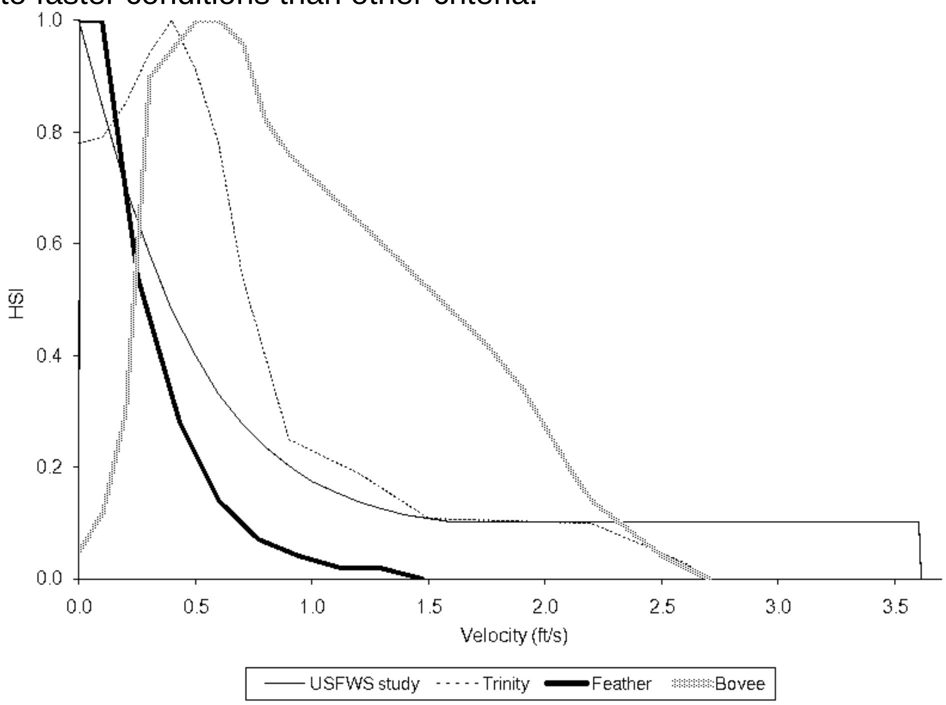


Figure 30. Comparison of steelhead/rainbow trout juvenile depth HSC from this study with other steelhead juvenile depth HSC. The criteria from this study show optimum suitability for deeper conditions than the other criteria.

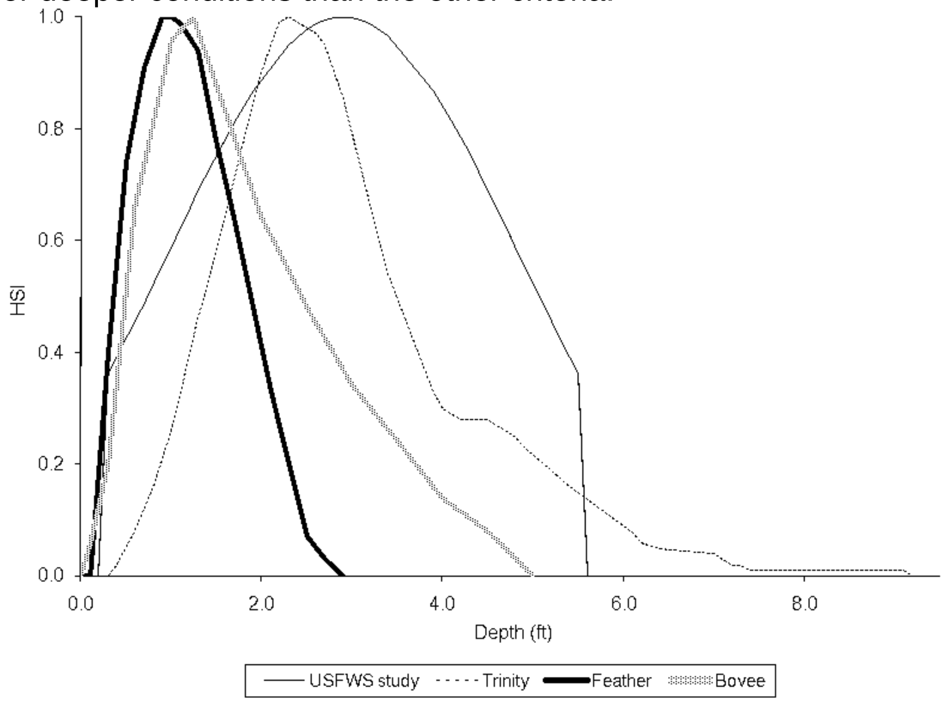


Figure 31. Comparison of steelhead/rainbow trout juvenile velocity HSC from this study with other steelhead juvenile velocity HSC. The criteria from this study show non-zero suitability extending to faster conditions than other criteria.

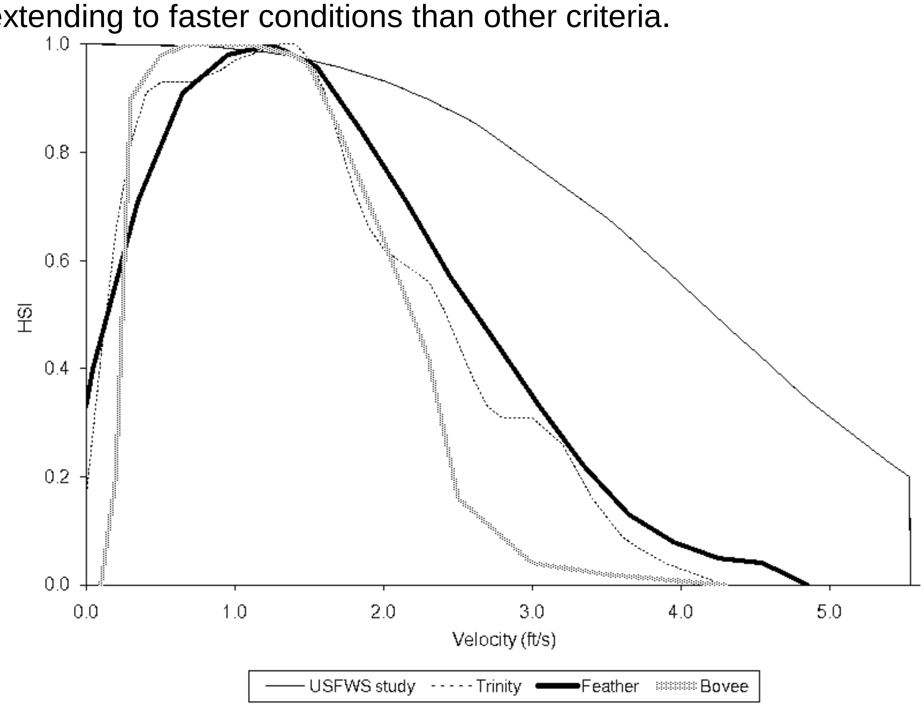
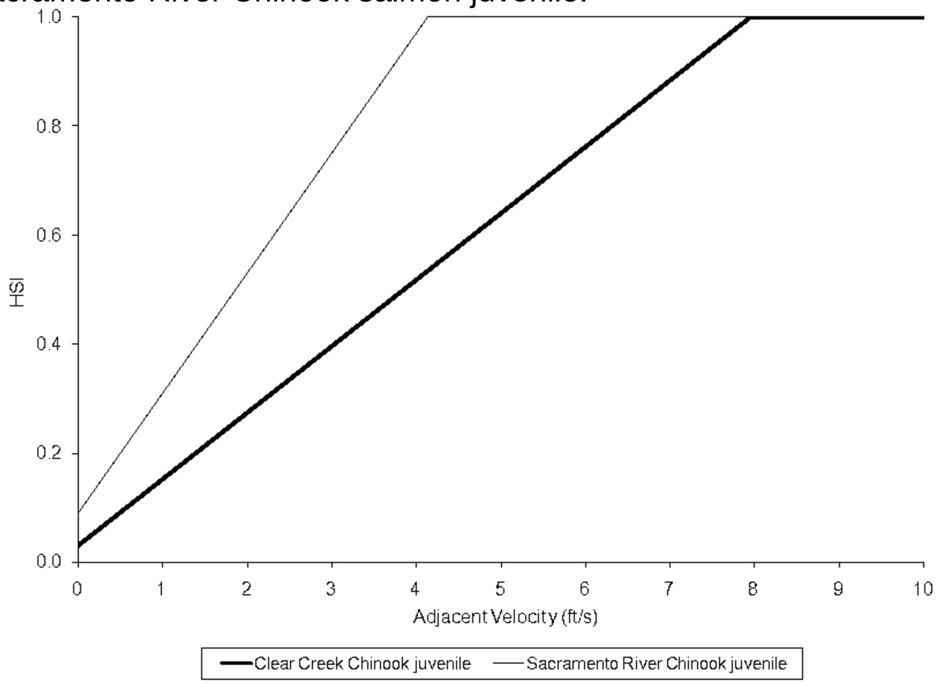


Figure 32. Comparison of spring-run Chinook salmon juvenile adjacent velocity HSC from this study with other Chinook salmon juvenile adjacent velocity HSC. The criteria indicate that turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas was more important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

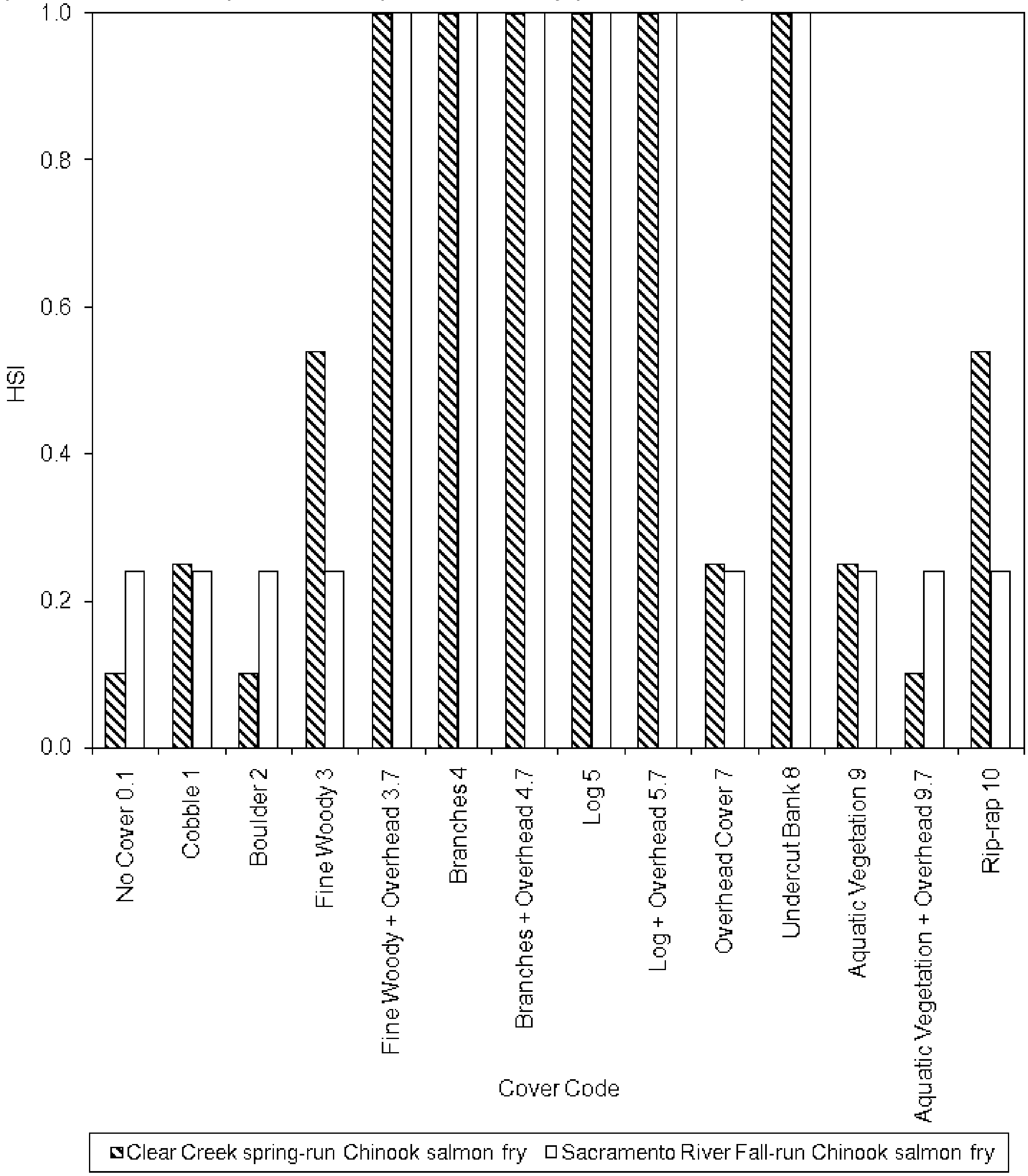
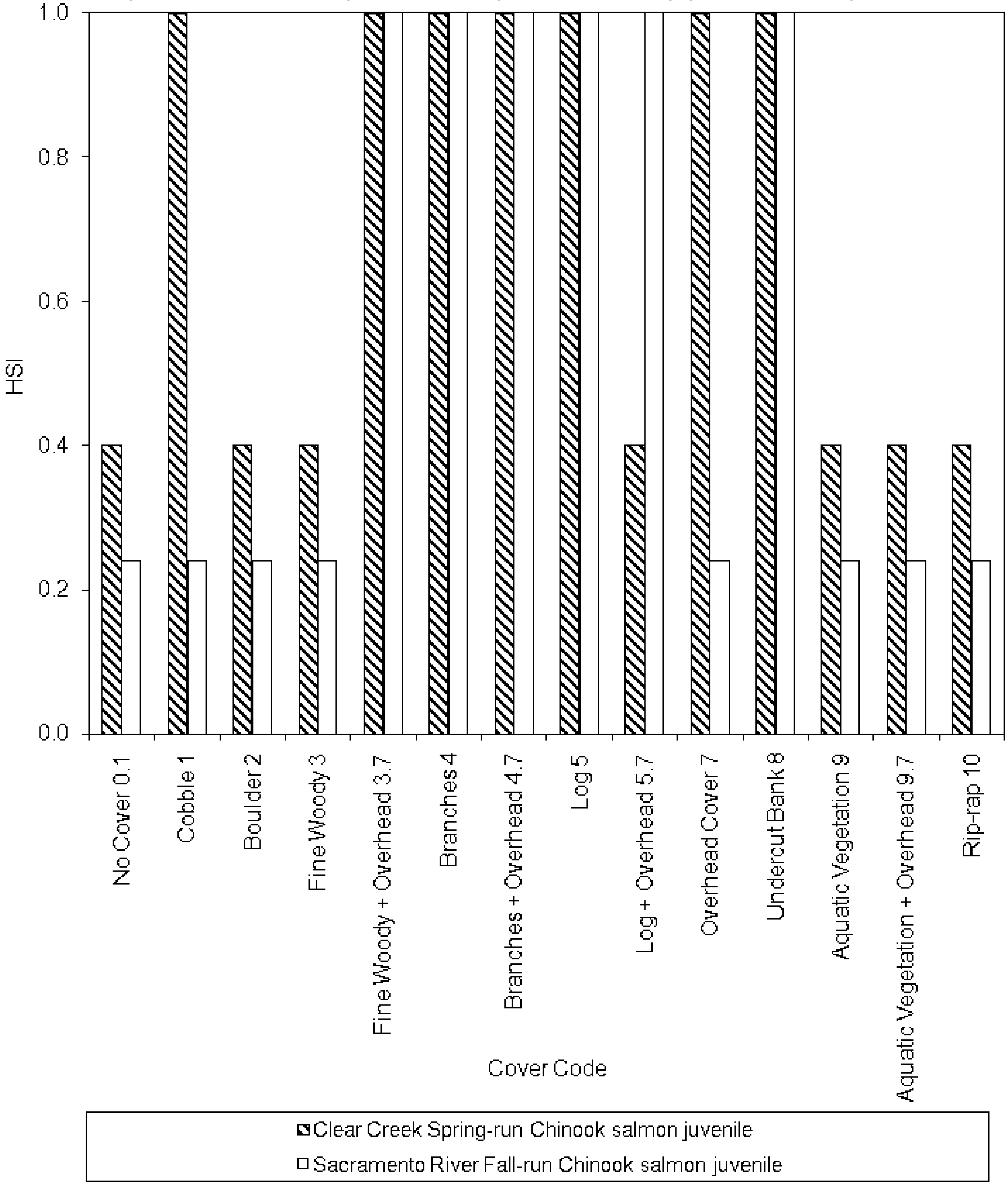


Figure 34. Comparison of spring-run Chinook salmon juvenile cover HSC from this study with other Chinook salmon juvenile cover HSC. These criteria indicate a consistent preference for composite cover (instream woody plus overhead).



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.

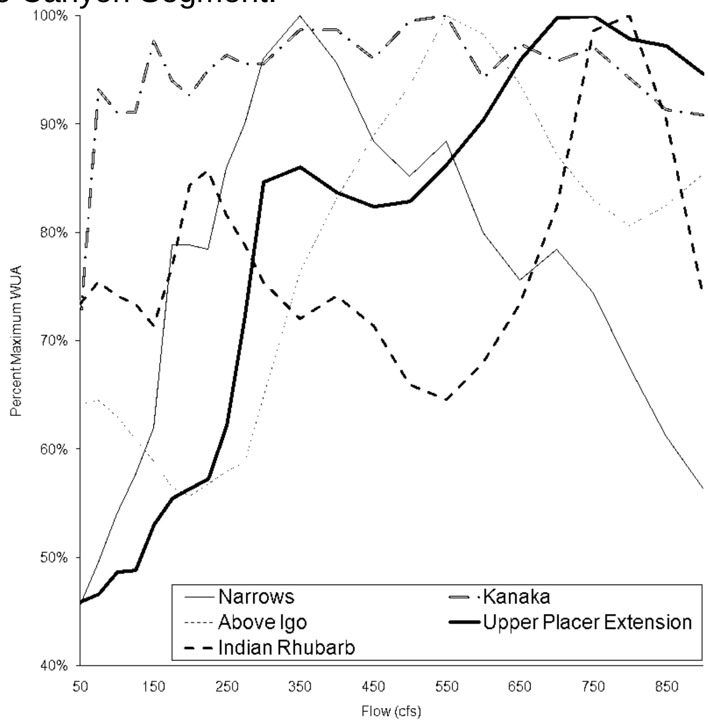


Figure 36. Comparison of steelhead/rainbow trout fry flow-habitat relationship for the five pools in the Canyon Segment.

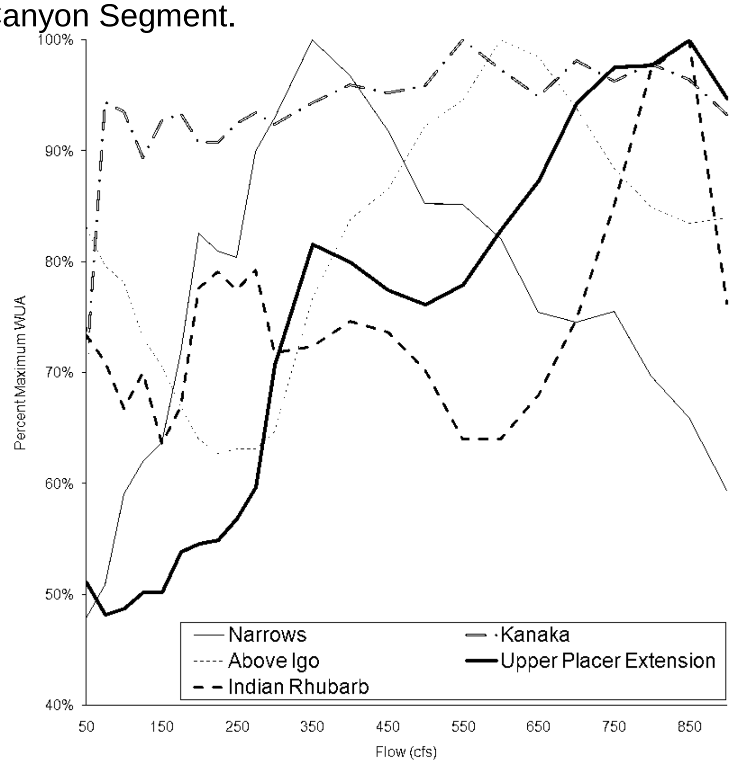
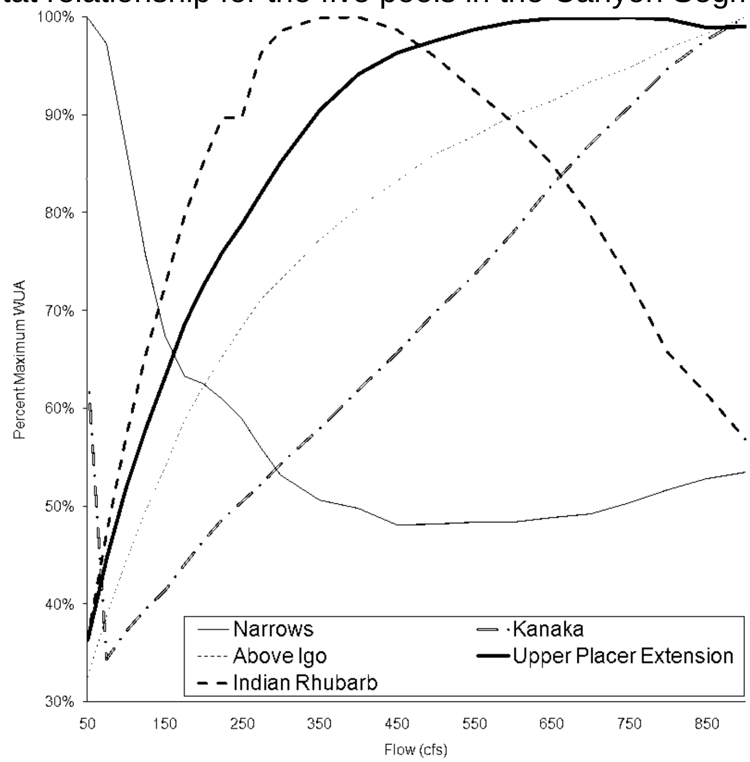


Figure 37. Comparison of steelhead/rainbow trout and spring-run Chinook salmon juvenile flow-habitat relationship for the five pools in the Canyon Segment.



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.

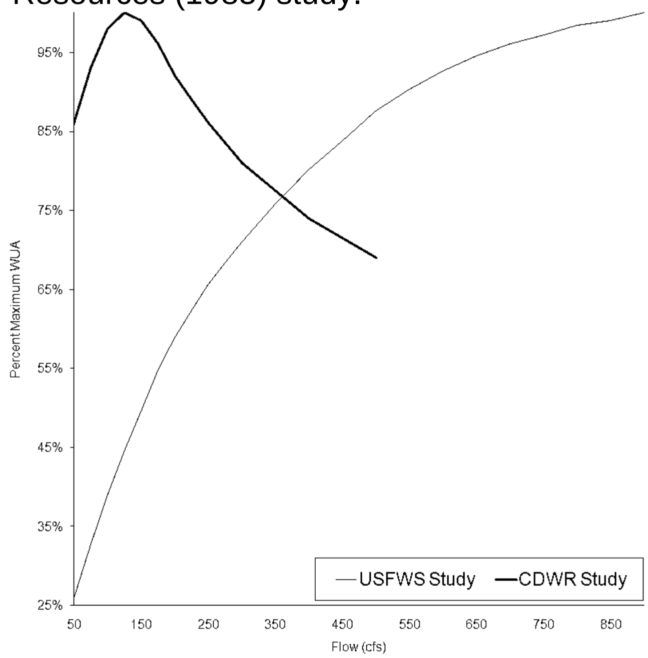


Figure 39. Comparison of steelhead fry flow-habitat relationships from California Department of Water Resources (1985) and for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985)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

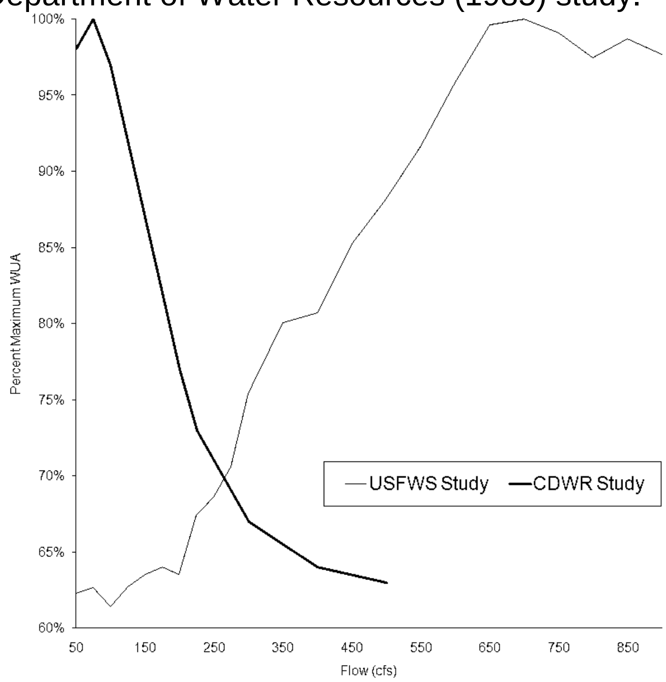
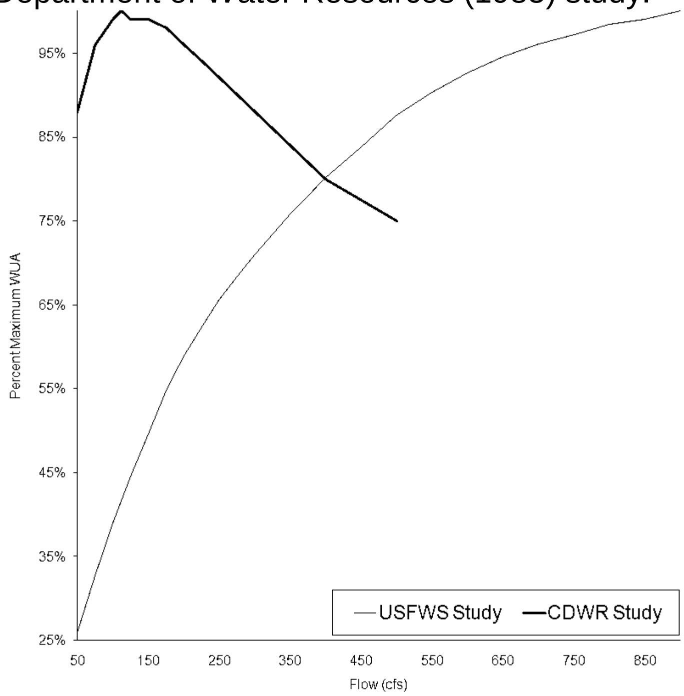


Figure 40. Comparison of steelhead juvenile flow-habitat relationships from California Department of Water Resources (1985) and for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources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

REFERENCES

Allen, M.A. 2000. Seasonal microhabitat use by juvenile spring Chinook salmon in the Yakima River Basin, Washington. Rivers 7(4):314-332.

Annear, T., I. Chirholm, H. Beecher, A. Locke, P. Aarestad, N. Burkhart, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, C. Stalnaker and R. Wentworth. 2002. Instream Flows for Riverine Resource Stewardship. Instream Flow Council, Cheyenne, Wyoming.

Baltz, D.M. and P.B. Moyle. 1984. Segregation by species and size classes of rainbow trout, *Salmo gairdneri*, and Sacramento Sucker, *Catostomus occidentalis*, in three California streams. Environmental Biology of Fishes 10: 101-110.

Bovee, K.D. 1978. Probability of use criteria for the family salmonidae. Instream Flow Information Paper 4. U.S. Fish and Wildlife Service FWS/OBS-78/07. 80 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U. S. Fish and Wildlife Service Biological Report 86(7). 235 pp.

Bovee, K.D., editor. 1996. The Complete IFIM: A Coursebook for IF 250. U.S. Geological Survey, Fort Collins, CO.

California Department of Water Resources. 1985. Clear Creek fishery study appendix, instream flow needs data, June 1985. California Department of Water Resources, Northern District, Red Bluff, CA.

California Department of Water Resources. 2005. Phase 2 report addendum evaluation of project effects on instream flows and fish habitat, SP F-16, Oroville Facilities Relicensing FERC Project No. 2100. California Department of Water Resources, Sacramento, CA.

Clackamas Instream Flow/Geomorphology Subgroup (CIFGS). 2003. Estimating salmonid habitat availability in the lower oak grove fork using expert habitat mapping, summary of methods and preliminary results. Report prepared by McBain and Trush Inc., Arcata, California, for Clackamas Instream Flow/Geomorphology Subgroup, March 5, 2003.

Cohen, J. 1992. Quantitative methods in psychology: A power primer. Psychological Bulletin 112(1): 155-159.

Crowder, D.W. and Diplas P. 2000. Using two-dimensional hydrodynamic models at scales of ecological importance. Journal of Hydrology. 230: 172-191.

Fausch, K.D. and R.J. White. 1981. Competition between brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38: 1220-1227.

Filipe, A., I. Cowx and M. Collares-pereira. 2002. Spatial modeling of freshwater fish in semi-arid river systems: a tool for conservation. River Research and Applications 18: 123-136.

Gard, M. 2006. Changes in salmon rearing and rearing habitat associated with river channel restoration. International Journal of River Basin Management 4: 201-211.

Gard, M. 2009. Demonstration flow assessment and 2-D modeling: perspectives based on instream flow studies and evaluation of restoration projects. Fisheries 34(7):320-329.

Geist, D.R., J. Jones, C.J. Murray and D.D. Dauble. 2000. Suitability criteria analyzed at the spatial scale of redd clusters improved estimates of spring Chinook salmon (*Oncorhynchus tshawytscha*) rearing habitat use in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57: 1636-1646.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1995. Two-dimensional modeling of flow in aquatic habitats. Water Resources Engineering Report 95-S1, Department of Civil Engineering, University of Alberta, Edmonton, Alberta. March 1995.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1996. Two-dimensional hydraulic simulation of physical habitat conditions in flowing streams. Regulated Rivers: Research and Management. 12: 185-200.

Gido, K.B. and D.L. Propst. 1999. Habitat use and association of native and nonnative fishes in the San Juan River, New Mexico and Utah. Copeia 1999: 321-332.

Gore, J.A. and J.M. Nestler. 1988. Instream flow studies in perspective. Regulated Rivers: Research & Management 2: 93–101.

Guay, J.C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57: 2065-2075.

Hampton, M. 1997. Microhabitat suitability criteria for anadromous salmonids of the Trinity River. U.S. Fish & Wildlife Service, Arcata, CA.

Hosmer, D.W. and S. Lemeshow. 2000. Applied Logistic Regression, Second Edition. John Wiley and Sons, Inc, New York.

Hudson, H.R., A.E. Byrom and W.L. Chadderton. 2003. A critique of IFIM – instream habitat simulation in the New Zealand context. Science for Conservation 231. New Zealand Department of Conservation, Wellington, New Zealand.

Hvidsten, H.B. 1993. High winter discharge after regulation increases production of Atlantic salmon, *Salmo salar*, smolts in the River Orkla, Norway. Pages 175-177 in: R.J. Gibson and R.E. Cutting, editors. Production of Juvenile Atlantic Salmon, *Salmo salar*, in Natural Waters. Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences 118.

Knapp, R.A. and H.K. Preisler. 1999. Is it possible to predict habitat use by rearing salmonids? A test using California golden trout (*Oncorhynchus mykiss aguabonita*). Canadian Journal of Fisheries and Aquatic Sciences 56: 1576-1584.

Leclerc, M., A. Boudreault, J.A. Bechara and G. Corfa. 1995. Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology. Transactions of the American Fisheries Society. 124(5): 645-662.

Maughan, O.E. and P.J. Barrett. 1992. An evaluation of the instream flow incremental methodology. Journal of the Arizona-Nevada Academy of Science 24-25:75-77.

McHugh, P. and P. Budy. 2004. Patterns of rearing habitat selection and suitability for two populations of spring chinook salmon, with an evaluation of generic verses site-specific suitability criteria. Transactions of the American Fisheries Society 133: 89-97.

Milhous, R.T., M.A. Updike and D.M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U. S. Fish and Wildlife Service Biological Report 89(16).

Moyle, P.B. and B. Vondracek. 1985. Persistence and structure of the fish assemblage in a small California stream. Ecology 66: 1-13.

Parasiewicz, P. 1999. A hybrid model – assessment of physical habitat conditions combining various modeling tools. In: Proceedings of the Third International Symposium on Ecohydraulics, Salt Lake City, Utah.

Pasternack G.B., C.L. Wang and J.E. Merz. 2004. Application of a 2D hydrodynamic model to design of reach-scale rearing gravel replenishment on the Mokelumne River, California. River Research and Applications. 20(2): 202-225.

Pampel, F.C. 2000. Logistic regression: a primer. Quantitative Applications in the Social Sciences 132.

Payne and Associates. 1998. RHABSIM 2.0 for DOS and Window's User's Manual. Arcata, CA: Thomas R. Payne and Associates.

Pearce, J. and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133(3): 225-245.

Raleigh, R.F., W.J. Miller and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook salmon. United States Fish and Wildlife Service, Biological Report 82(10.122). 64pp.

Rubin, S.P., T.C. Bjornn and B. Dennis. 1991. Habitat suitability curves for juvenile chinook salmon and steelhead development using a habitat-oriented sampling approach. Rivers 2(1):12-29.

Sechnick, C.W., R.F. Carline, R.A. Stein and E.T. Rankin. 1986. Habitat selection by smallmouth bass in response to physical characteristics of a simulated stream. Transactions of the American Fisheries Society 115: 314-321.

Snider, W.M., D.B. Christophel, B.L. Jackson and P.M. Bratovich. 1992. Habitat characterization of the Lower American River. California Department of Fish and Game, Sacramento, CA.

Steffler, P. 2002. River2D_Bed. Bed Topography File Editor. User's manual. University of Alberta, Edmonton, Alberta. 32 pp. http://www.River2D.ualberta.ca/download.htm

Steffler, P. and J. Blackburn. 2002. River2D: Two-dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat. Introduction to Depth Averaged Modeling and User's Manual. University of Alberta, Edmonton, Alberta. 120 pp. http://www.River2D.ualberta.ca/download.htm

SYSTAT. 2002. SYSTAT 10.2 Statistical Software. SYSTAT Software Inc., Richmond, CA.

Thielke, J. 1985. A logistic regression approach for developing suitability-of-use functions for fish habitat. Pages 32-38 in F.W. Olson, R.G. White, and R.H. Hamre, editors. Proceedings of the symposium on small hydropower and fisheries. American Fisheries Society, Western Division and Bioengineering Section, Bethesda, Maryland.

Tiffan, K.E., R.D. Garland and D.W. Rondorf. 2002. Quantifying flow-dependent changes in subyearling spring Chinook salmon rearing habitat using two-dimensional spatially explicit modeling. North American Journal of Fisheries Management 22: 713-726.

Tirelli, T., L. Pozzi and D. Pessani. 2009. Use of different approaches to model presence/absence of salmon marmoratus in Piedmont (NorthWestern Italy). Ecological Informatics 4: 234-243.

U.S. Fish and Wildlife Service. 1994. Using the computer based physical habitat simulation system (PHABSIM). Fort Collins, CO: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 2000. Effects of the January 1997 flood on flow-habitat relationships for steelhead and spring-run Chinook salmon in the Lower American River. U.S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2001. Final restoration plan for the anadromous fish restoration program. A plan to increase natural production of anadromous fish in the Central Valley of California. January 9, 2001. Prepared for the U. S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. U.S. Fish and Wildlife Service, Stockton, CA.

U. S. Fish and Wildlife Service. 2005. Flow-habitat relationships for Chinook salmon rearing in the Sacramento River between Keswick Dam and Battle Creek. U.S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2007. Flow-habitat relationships for spring Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Whiskeytown dam and Clear Creek Road. U.S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2010. Flow-habitat relationships for fall/spring-run Chinook salmon and steelhead/rainbow trout spawning in the Yuba River. U.S. Fish and Wildlife Service, Sacramento, CA.

Waddle, T. and P. Steffler. 2002. R2D_Mesh - Mesh Generation Program for River2D Two Dimensional Depth Averaged Finite Element. Introduction to Mesh Generation and User's manual. U.S. Geological Survey, Fort Collins, CO. 32 pp. http://www.River2D.ualberta.ca/download.htm

Yalin, M.S. 1977. Mechanics of Sediment Transport. Pergamon Press, New York.

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

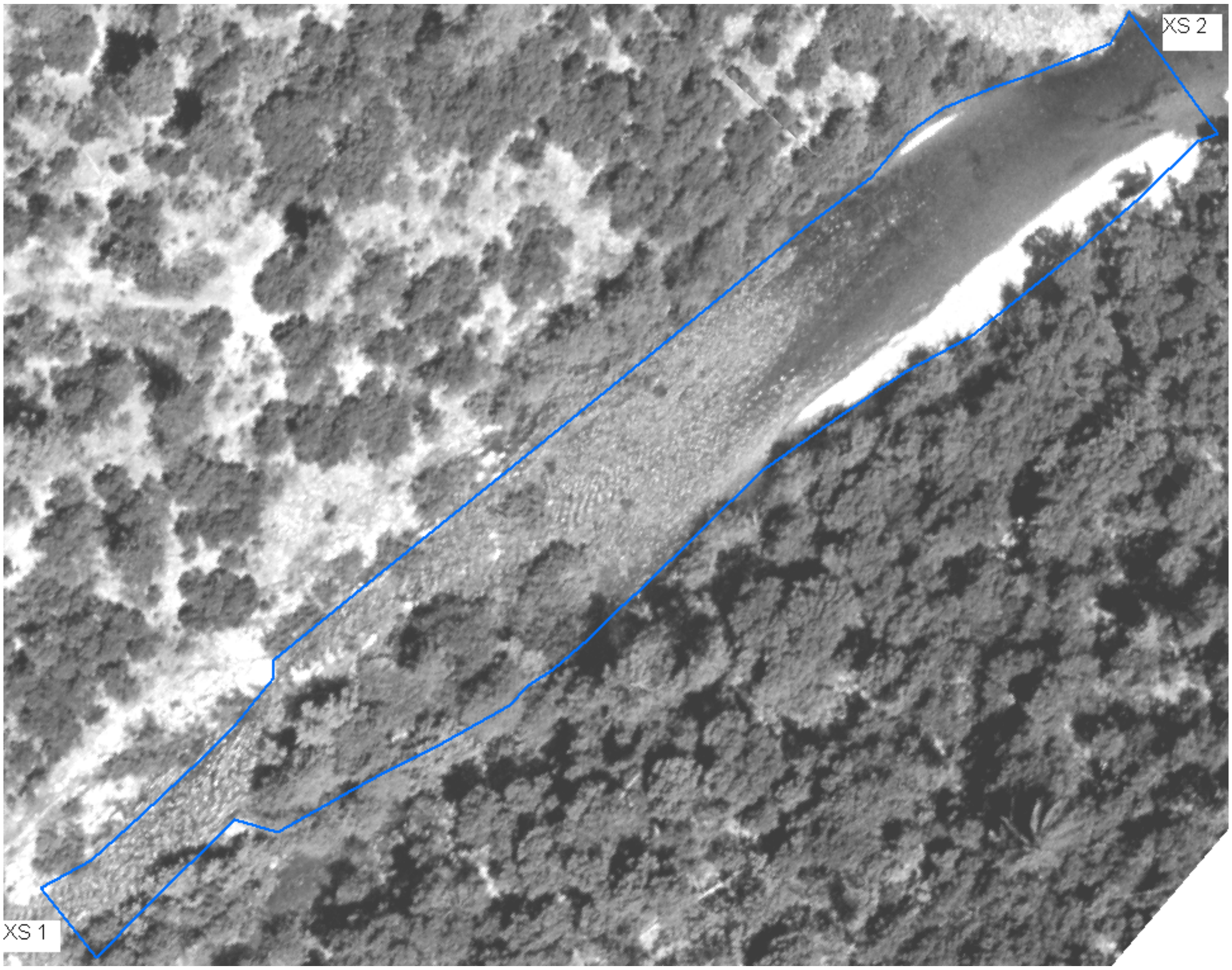
Subsegment #	Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
3	36	Main Channel Riffle	876
3	37	Main Channel Run	208
3	38	Main Channel Riffle	246
3	39	Main Channel Pool	578
3	40	Main Channel Riffle	286
3	41	Main Channel Run	454
3	42	Main Channel Cascade	918
3	43	Main Channel Pool	199
3	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

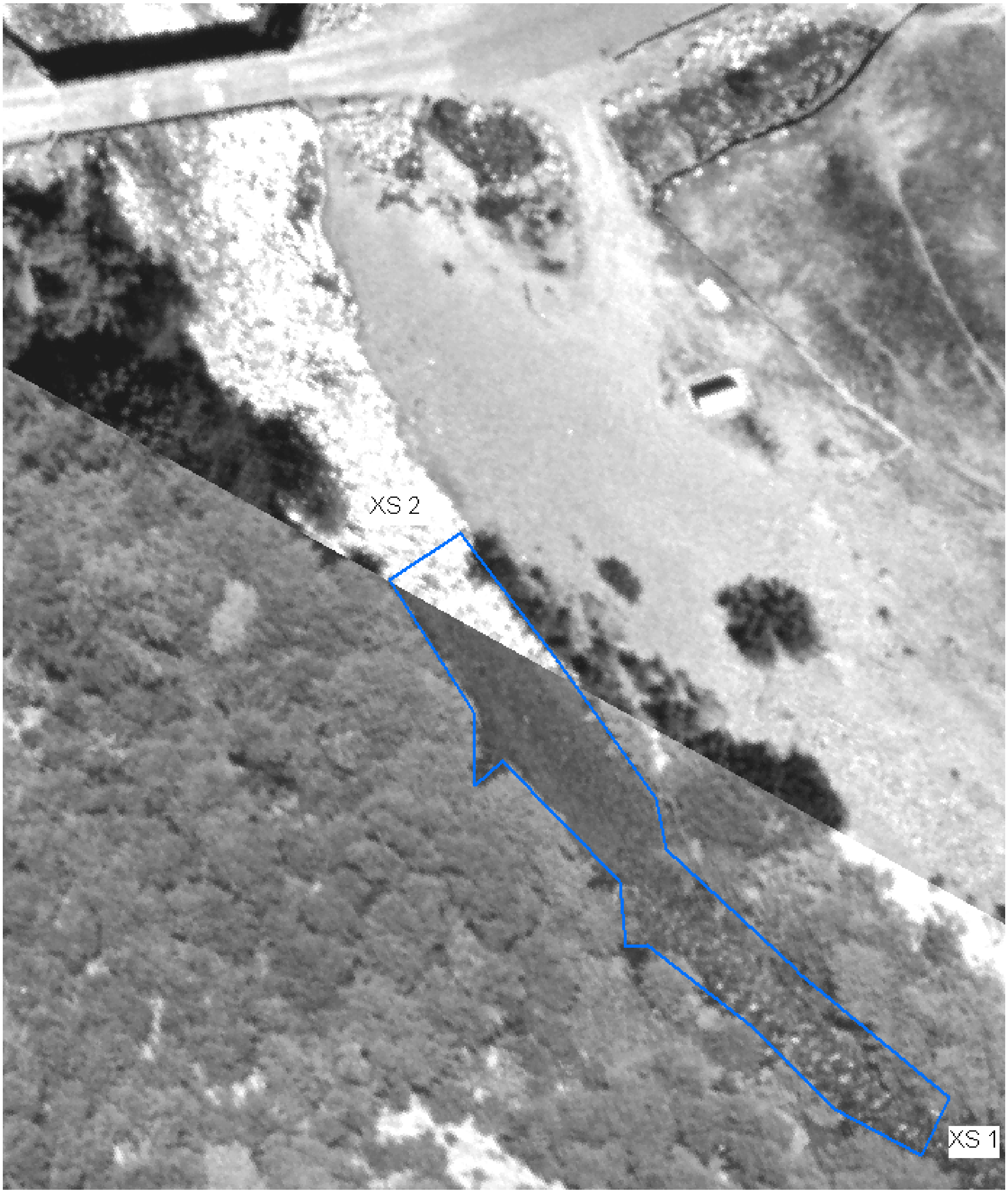
APPENDIX B
STUDY SITE AND TRANSECT LOCATIONS

DOG GULCH STUDY SITE



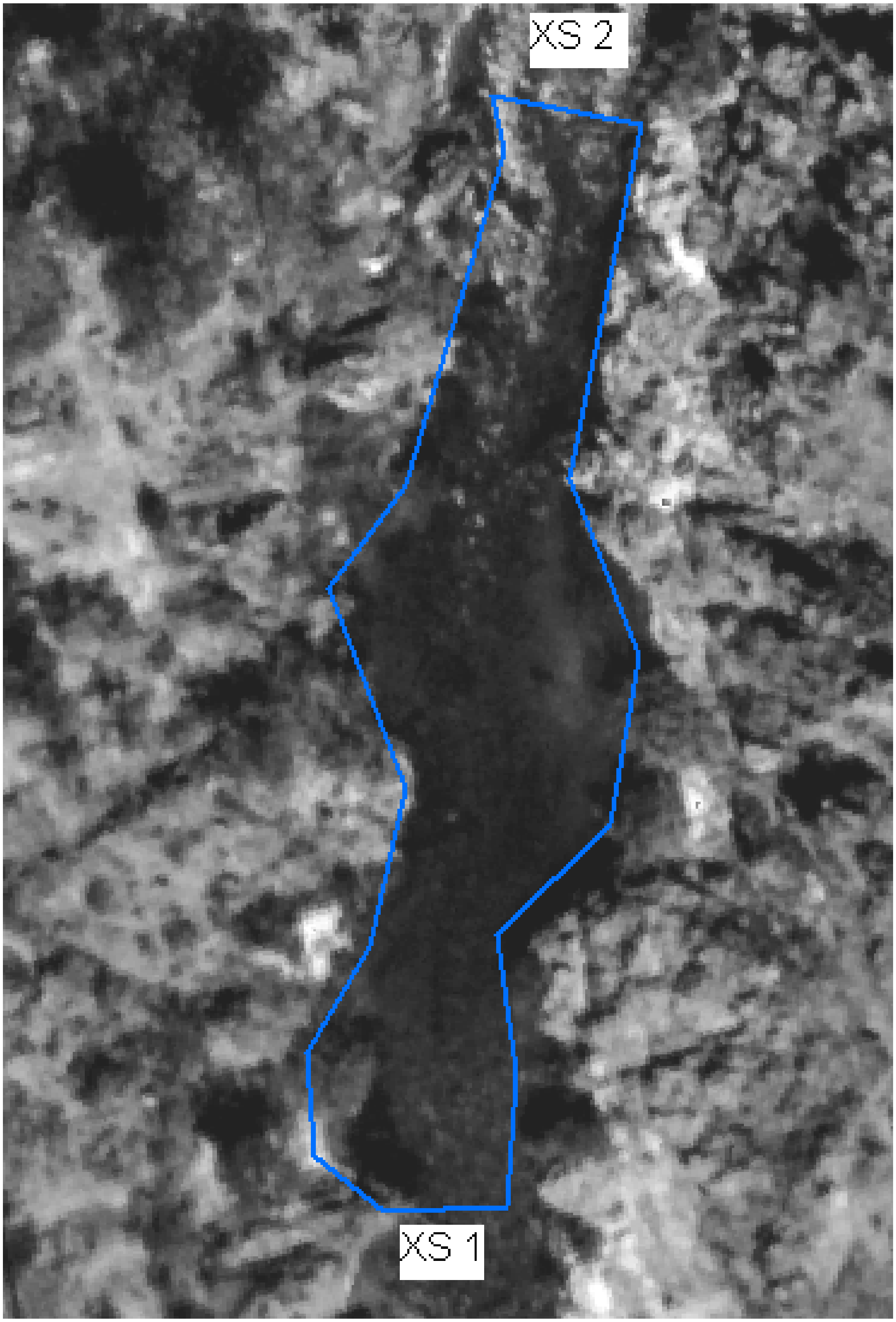
Scale: 1: 1,294

UPPER CANYON STUDY SITE



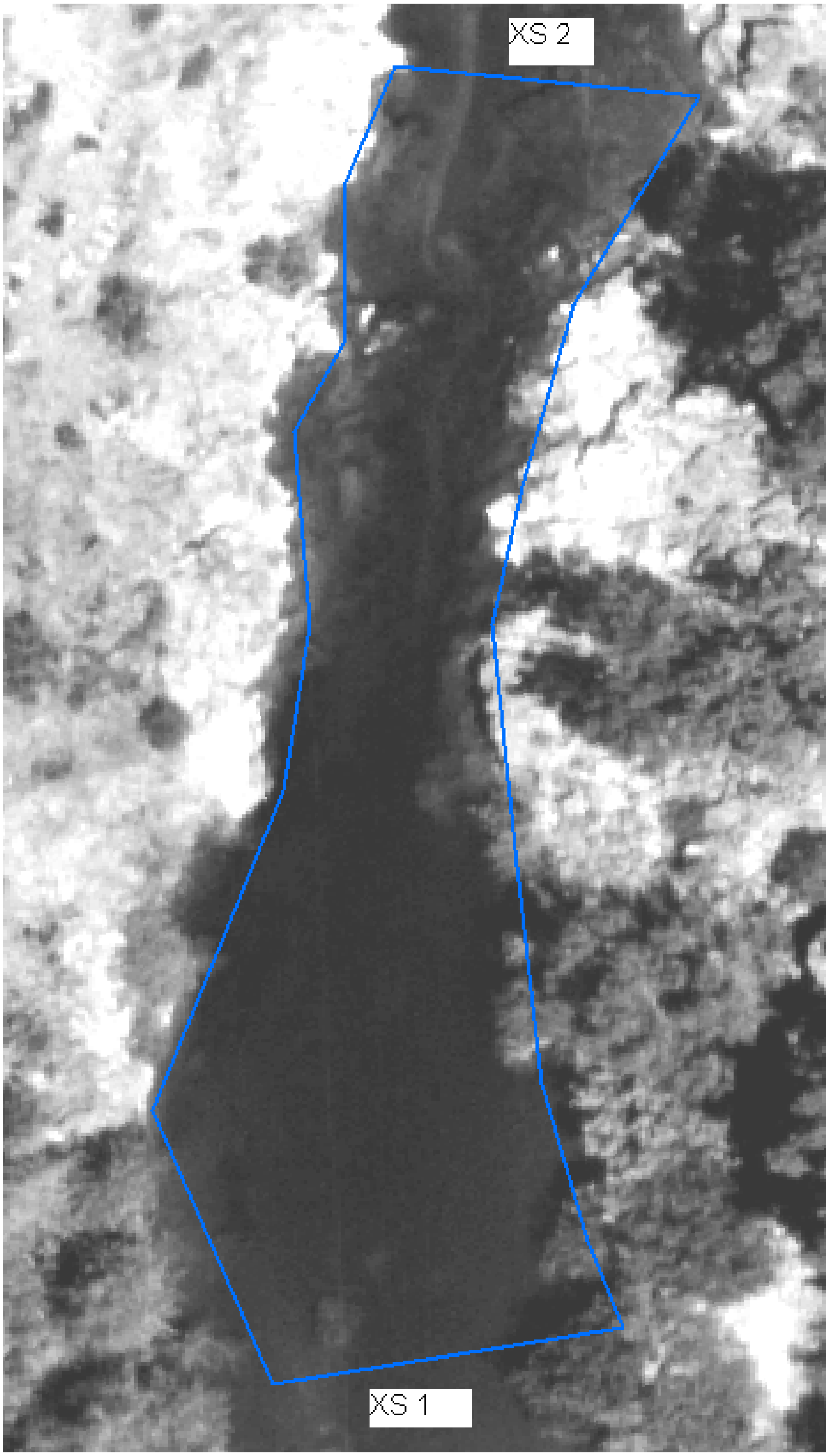
Scale: 1: 450

NARROWS STUDY SITE



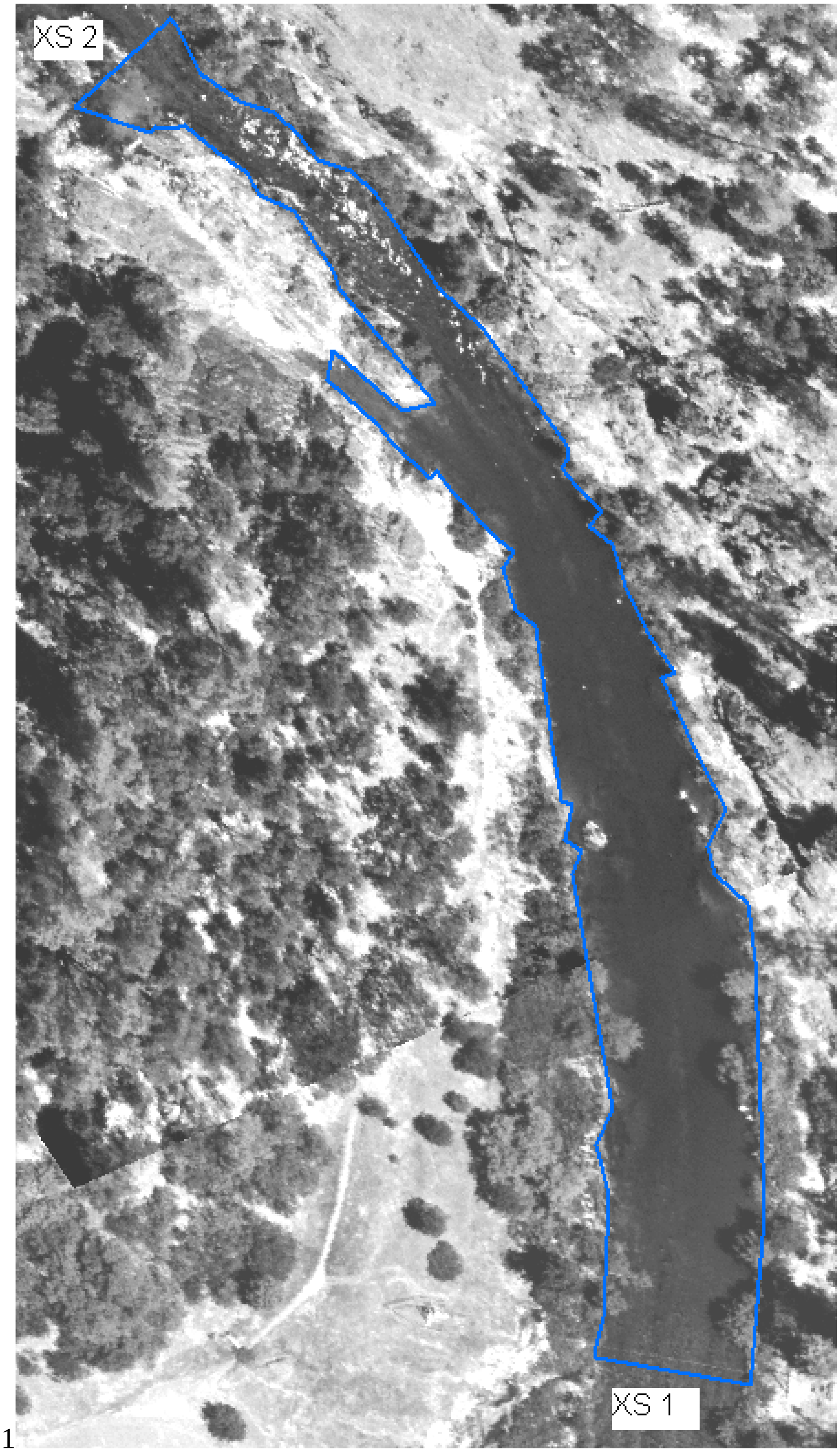
Scale: 1: 313

KANAKA STUDY SITE



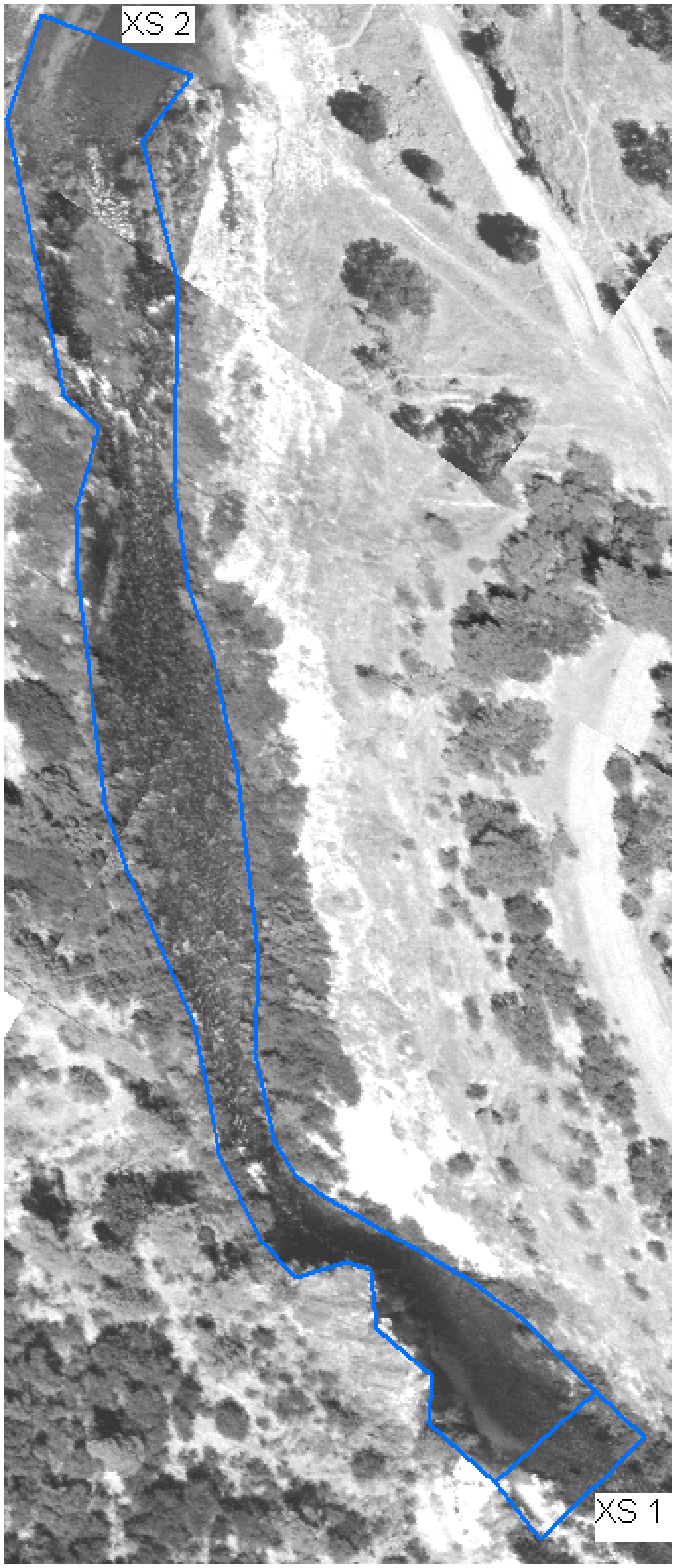
Scale: 1: 1,027

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

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	91	127	207	290	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

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	91	127	155	207	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

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

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	207	441	793	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

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	91	127	155	214	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

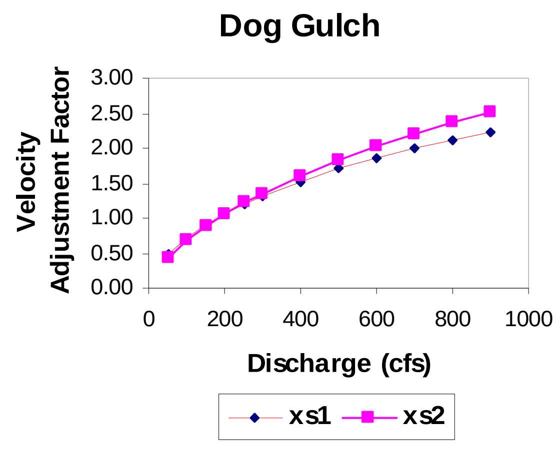
	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	214	441	793	214	441	793
2	2.55	2.1	1.3	3.2	1.9	0.01	0.04	0.03

APPENDIX D
VELOCITY ADJUSTMENT FACTORS[36]

[36] Units of discharge are cfs.

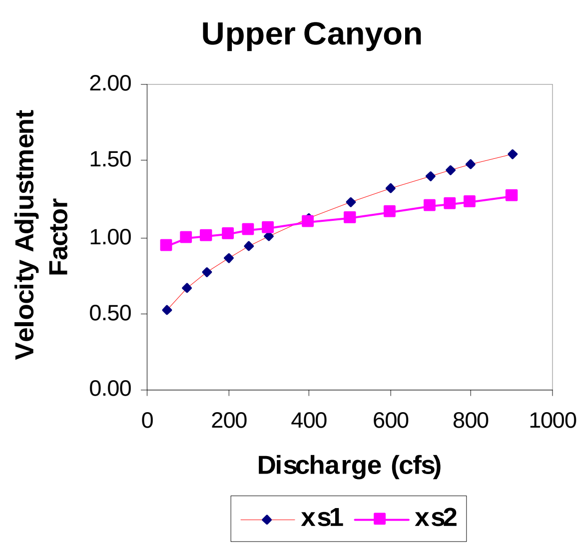
Dog Gulch

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



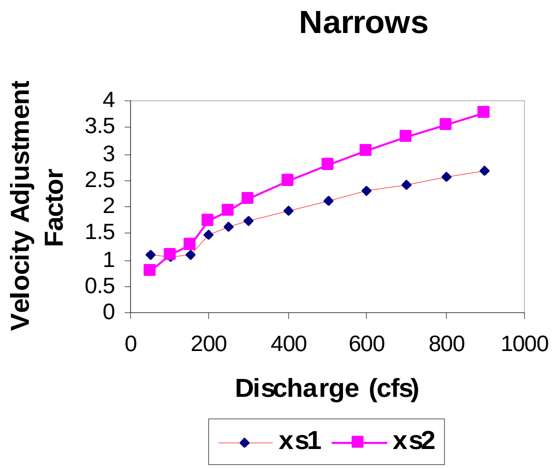
Upper Canyon

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



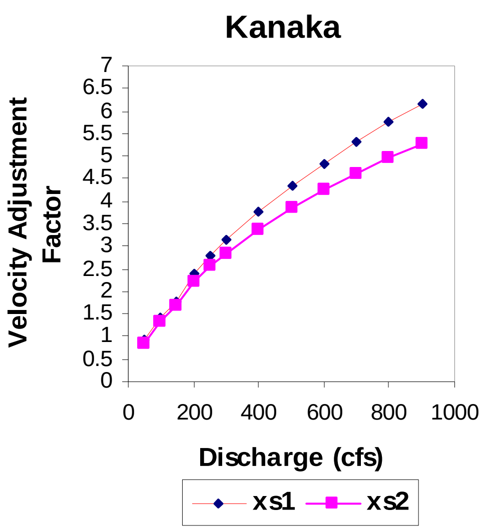
Narrows

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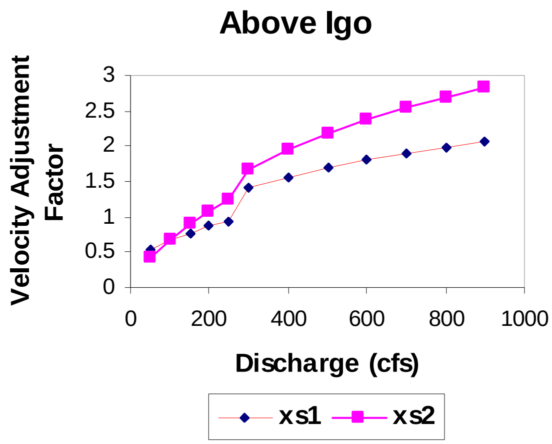
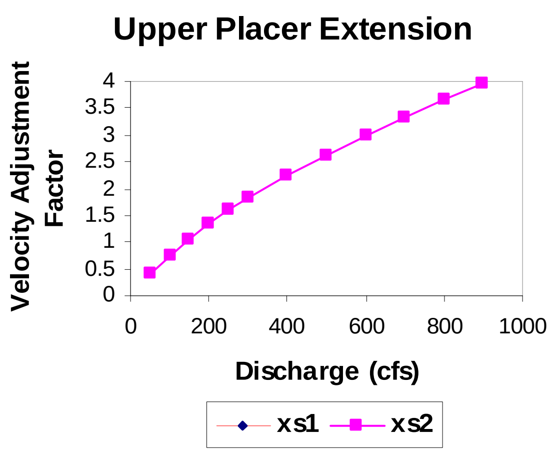
	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.53	0.43
100	0.67	0.69
150	0.78	0.90
200	0.87	1.08
250	0.94	1.25
300	1.41	1.66
400	1.56	1.94
500	1.69	2.18
600	1.80	2.37
700	1.90	2.54
800	1.99	2.70
900	2.07	2.83

Above Igo



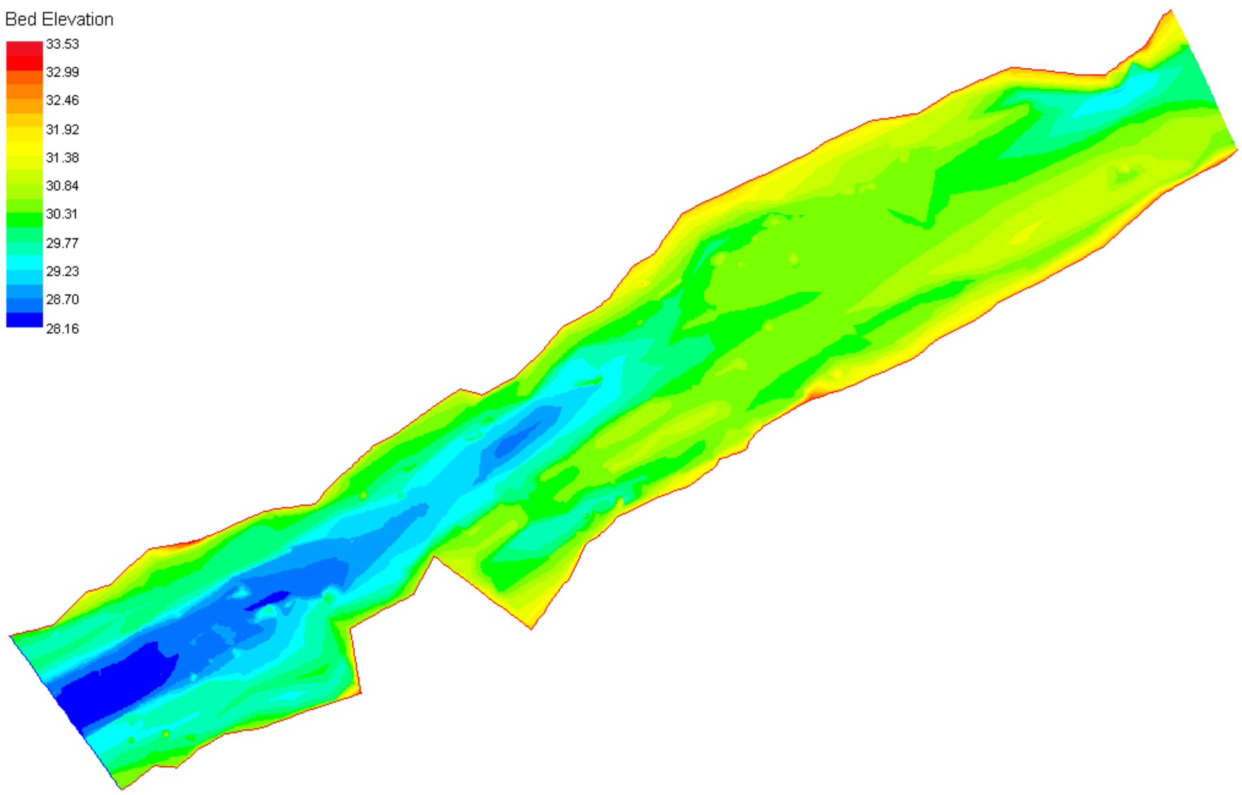
Upper Placer Extension

	Velocity Adjustment Factors
Discharge	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



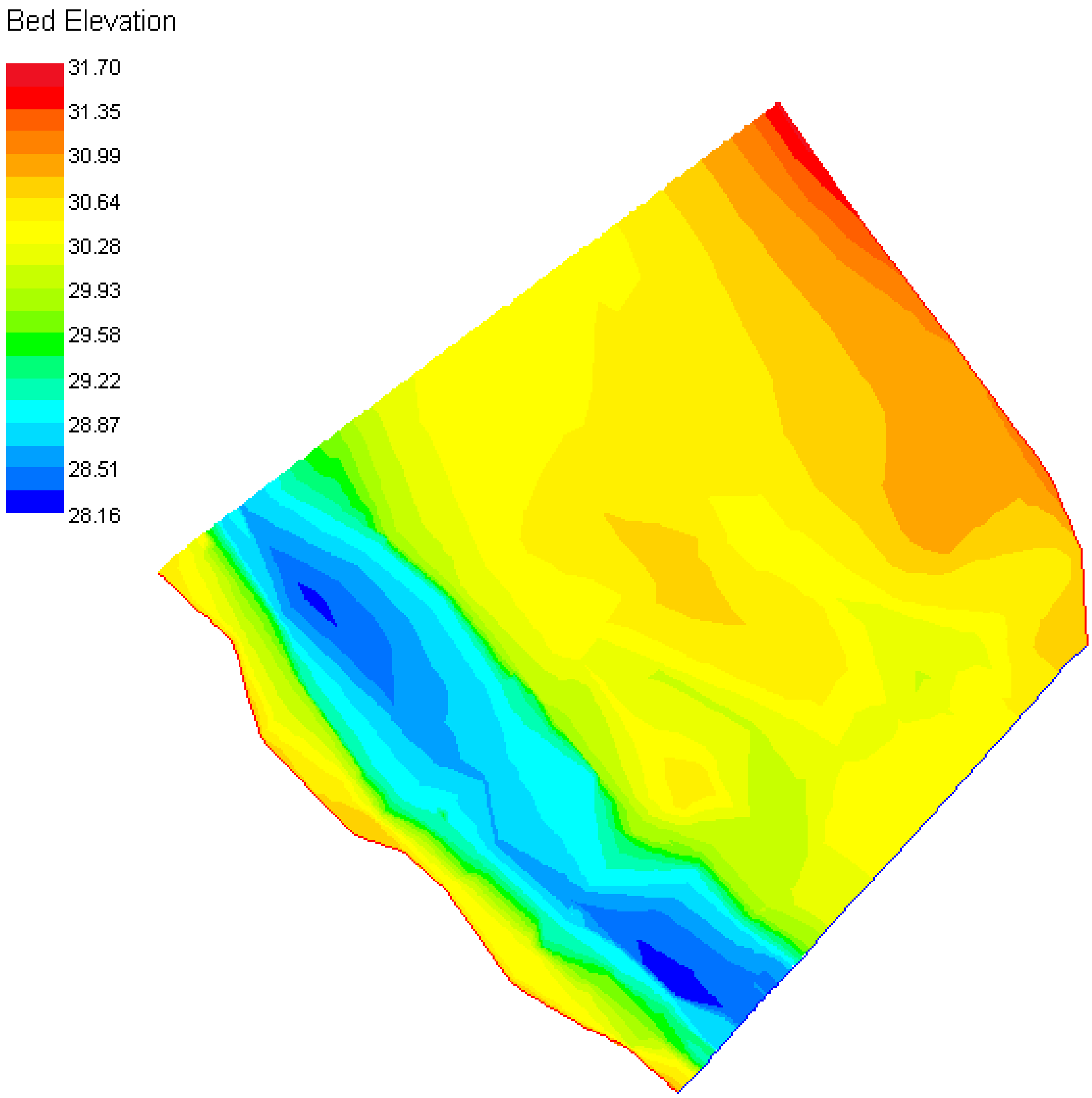
APPENDIX E
BED TOPOGRAPHY OF STUDY SITES

Dog Gulch Study Site



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

Upper Canyon Study Site



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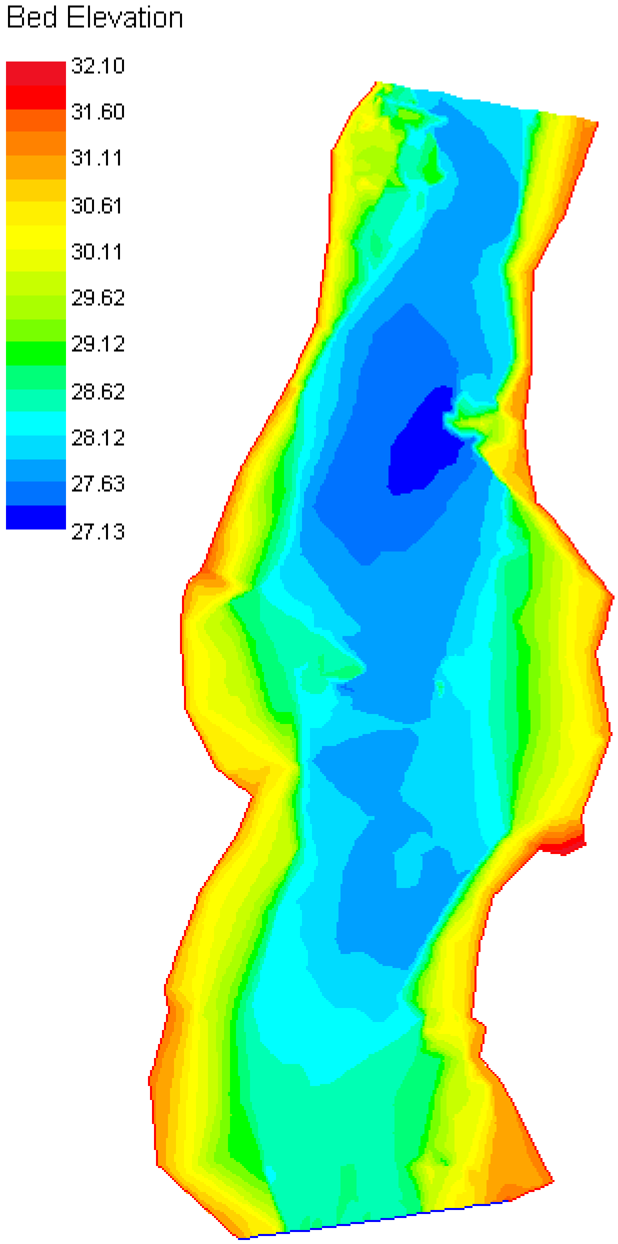
Units of Bed Elevation are meters.

Narrows Study Site



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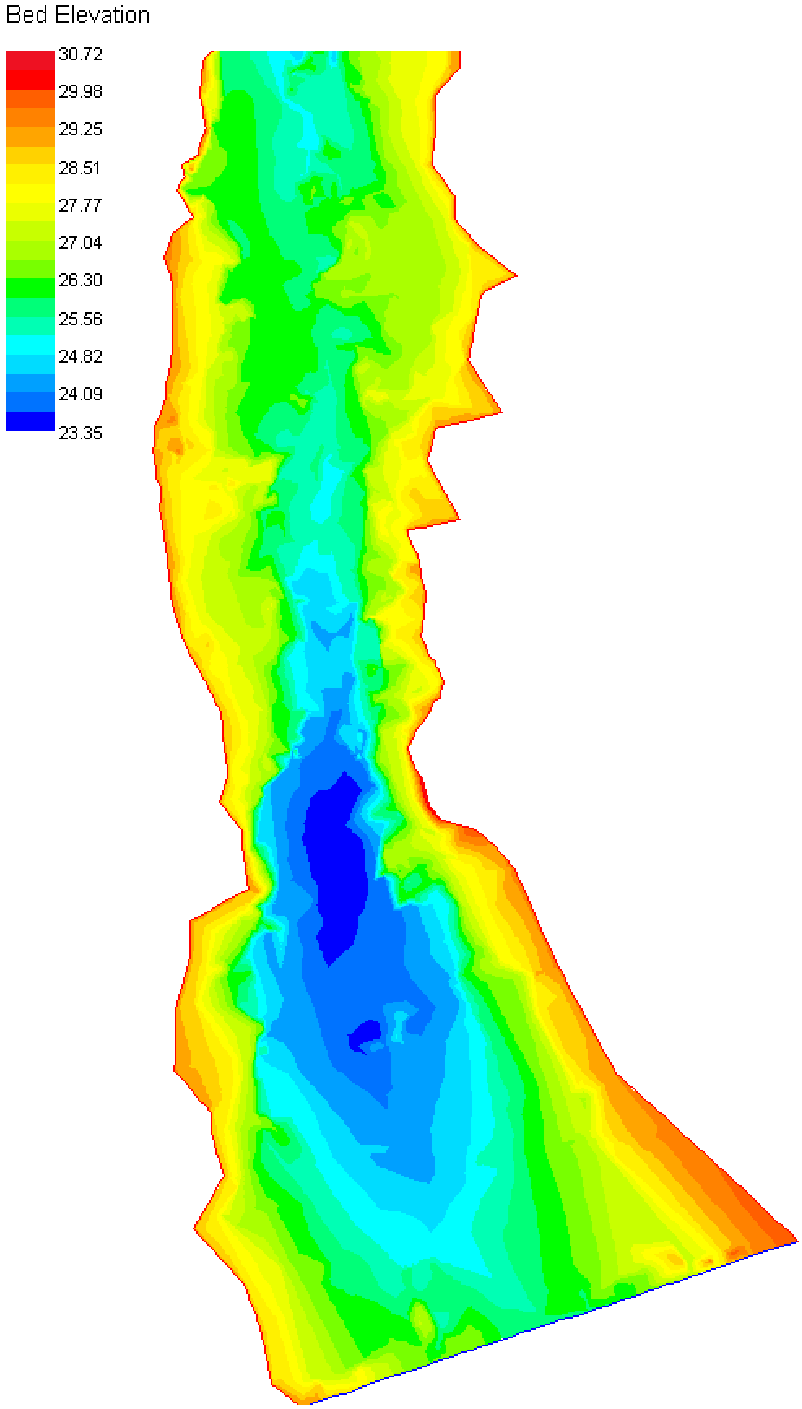
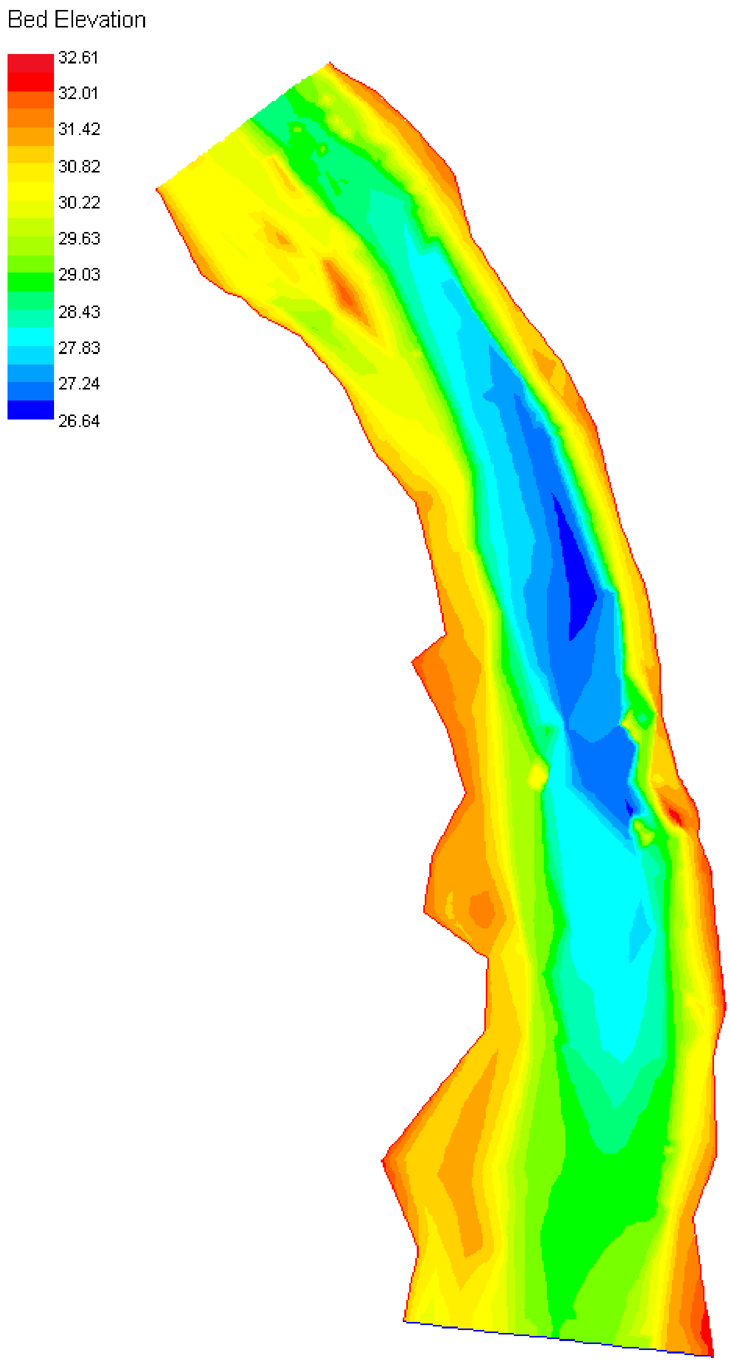
Units of Bed Elevation are meters.

Kanaka Study Site



Scale: 1: 1,091
Units of Bed Elevation are meters.

Above Igo Study Site



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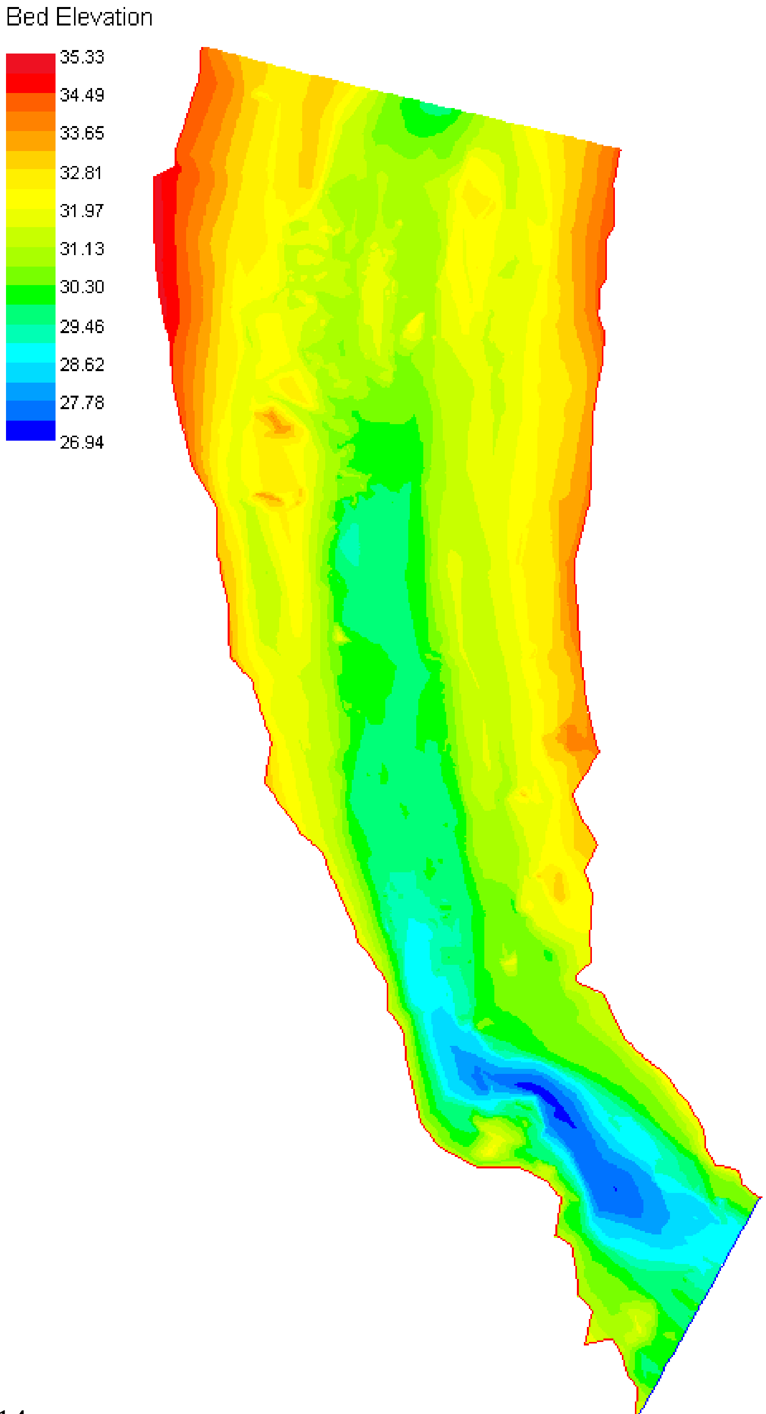
Units of Bed Elevation are meters.

Upper Placer Extension Study Site



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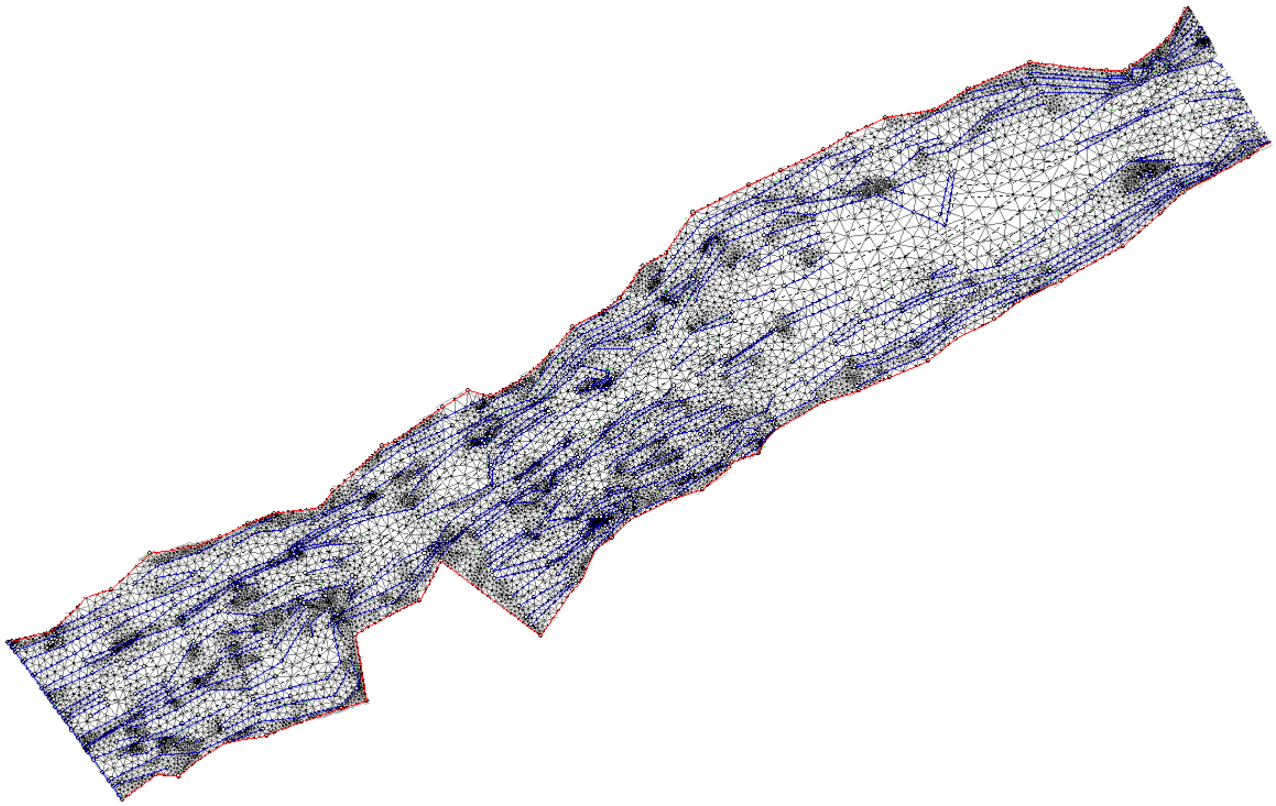
Units of Bed Elevation are meters.

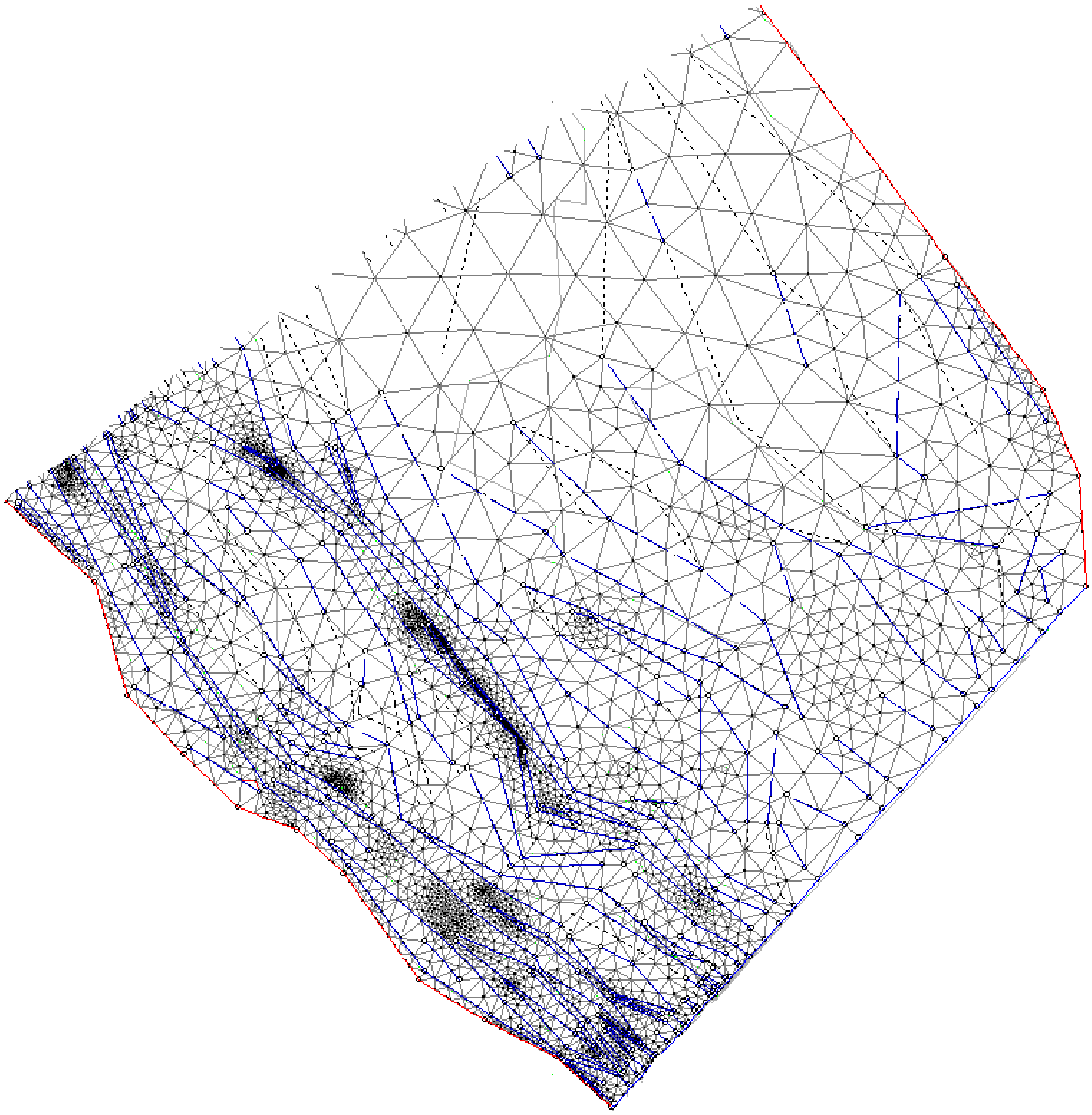
APPENDIX F
COMPUTATIONAL MESHES OF STUDY SITES

Dog Gulch Study Site



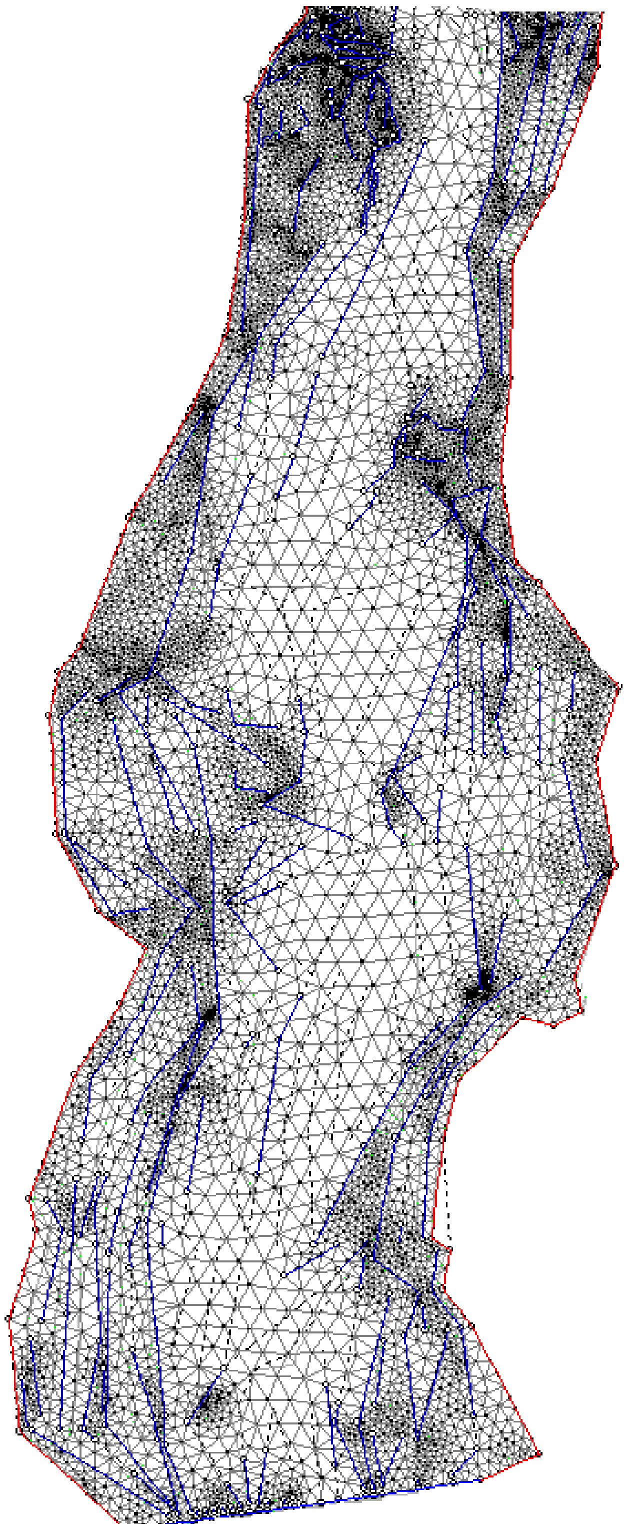
Scale: 1: 1,373

Upper Canyon Study Site



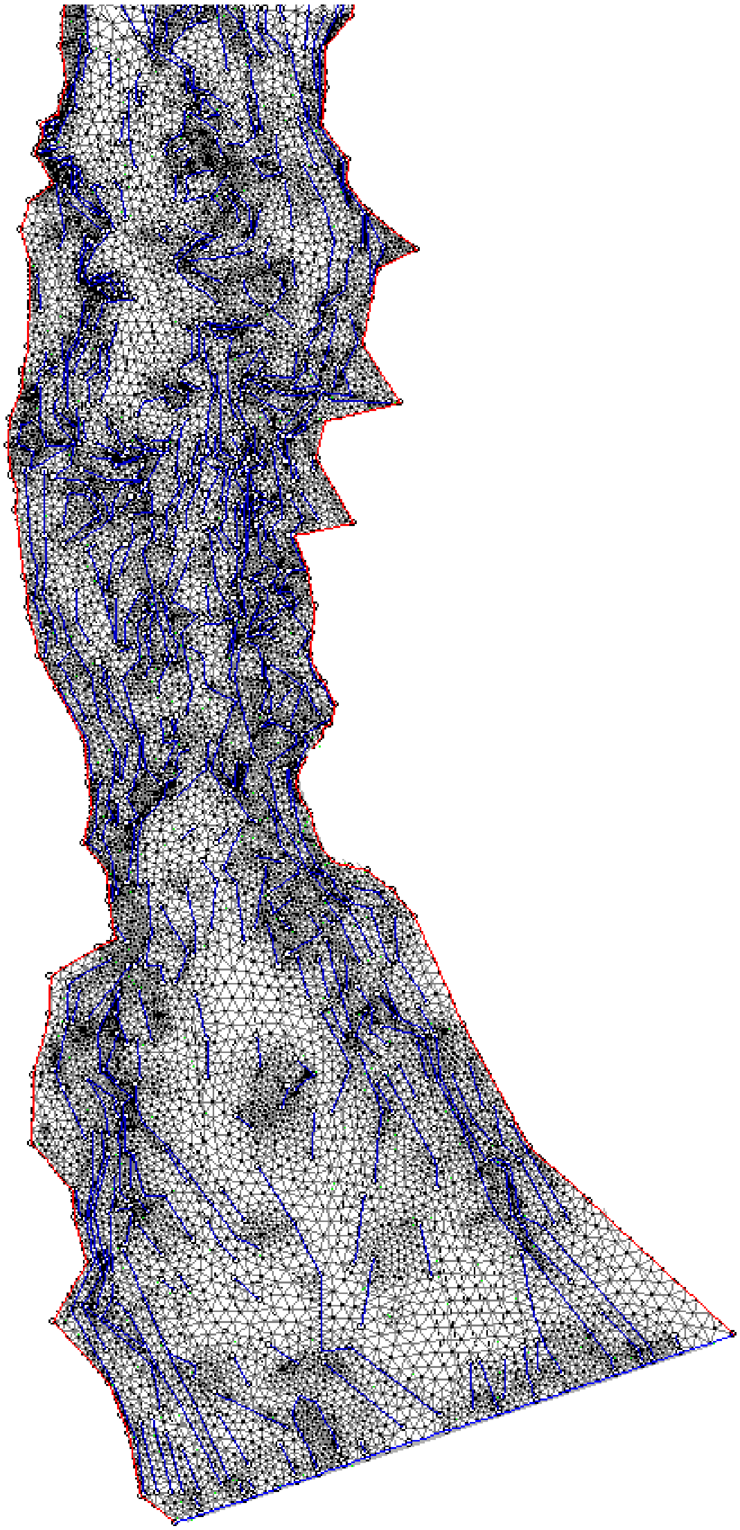
Scale: 1: 554

Narrows Study Site



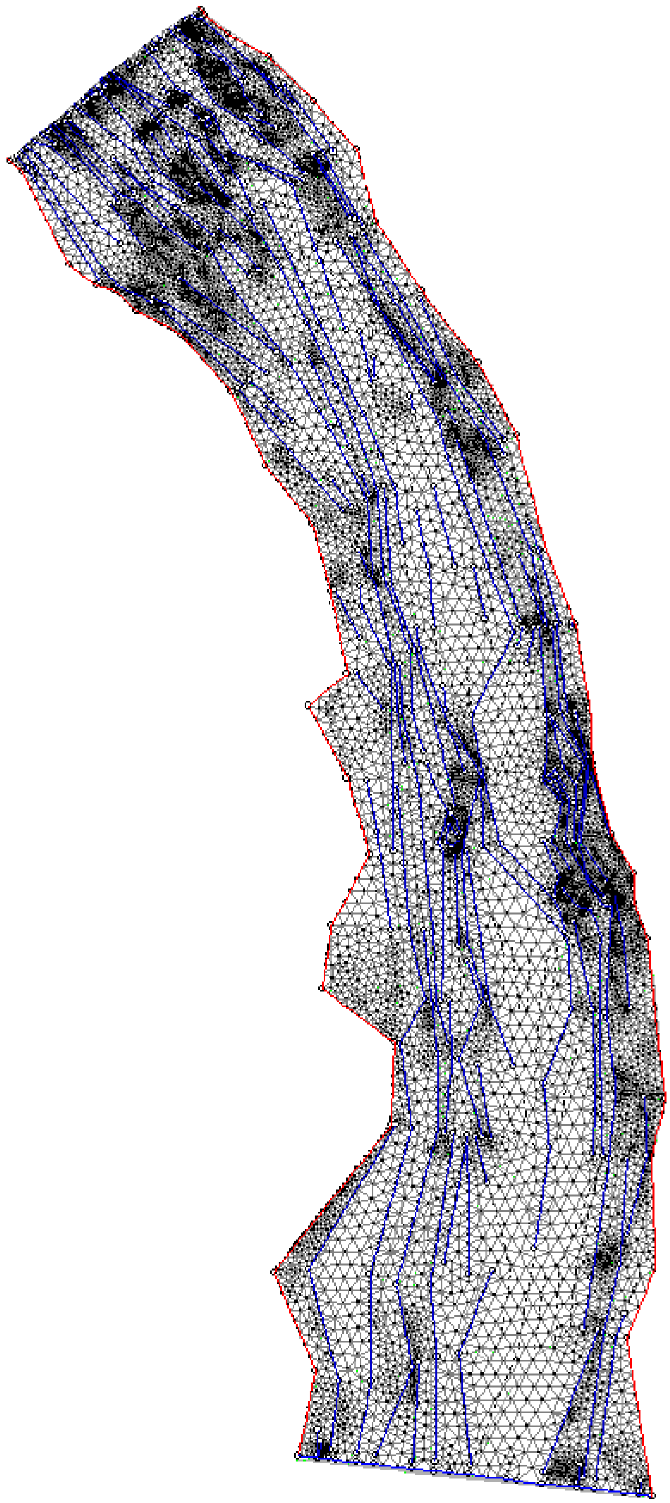
Scale: 1: 277

Kanaka Study Site



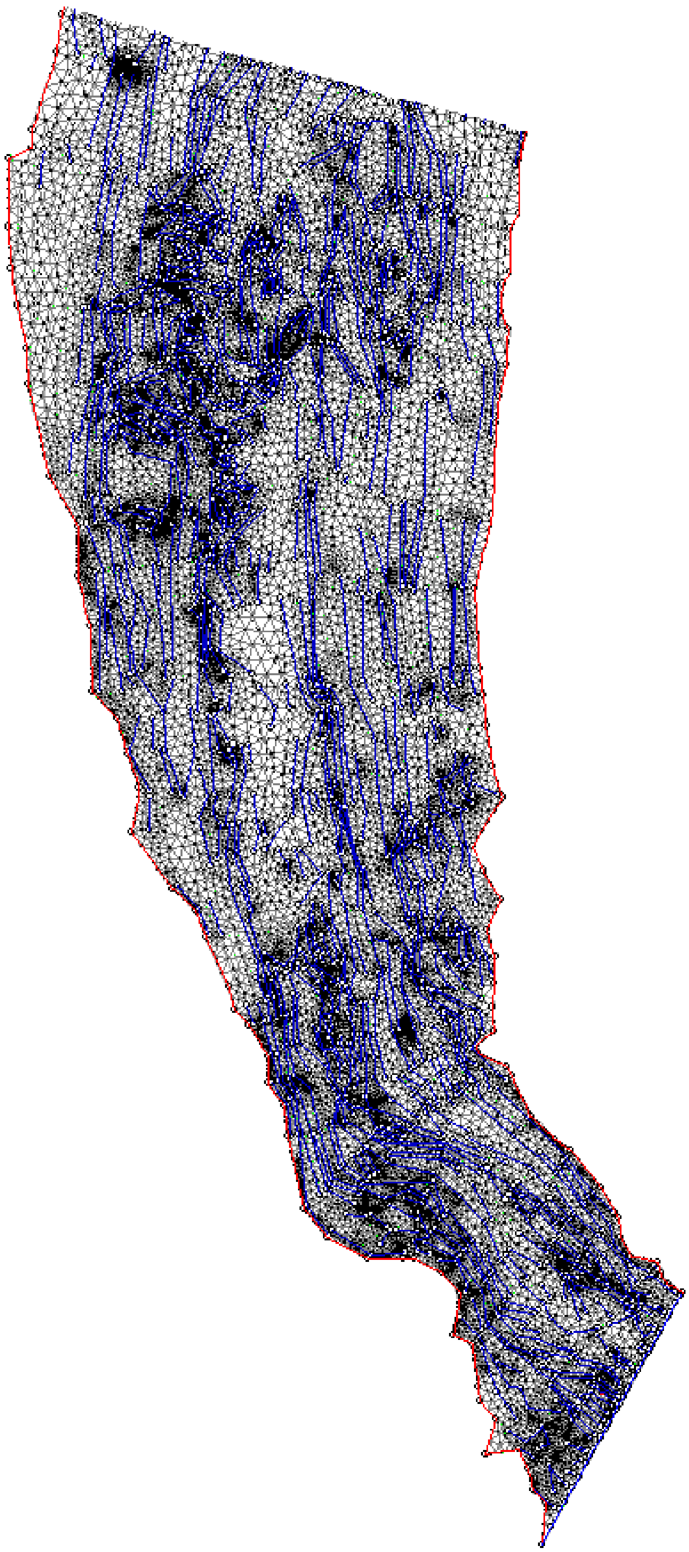
Scale: 1: 970

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.

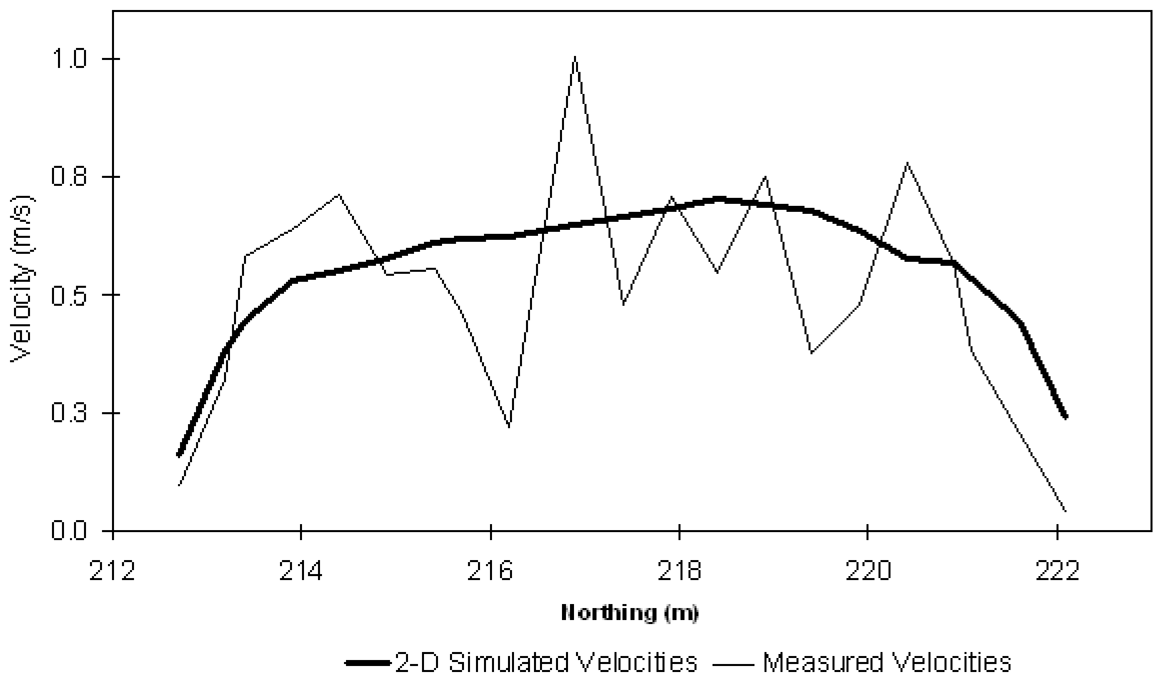
Measured Velocities greater than 3 ft/s

Percent difference (measured vs. pred. velocities)

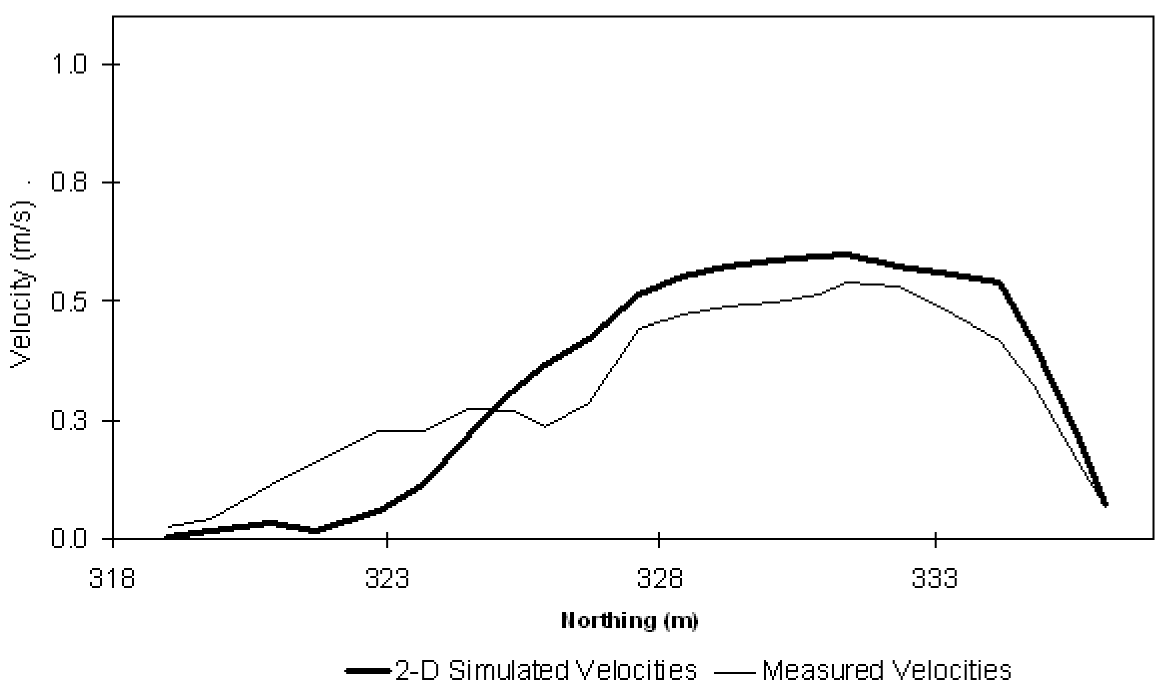
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Dog Gulch	16	36%	33%	100%
Upper Canyon	45	23%	12%	44%
Narrows	N/A	N/A	N/A	N/A
Kanaka	N/A	N/A	N/A	N/A
Above Igo	N/A	N/A	N/A	N/A
Upper Placer Extension	15	23%	19%	72%

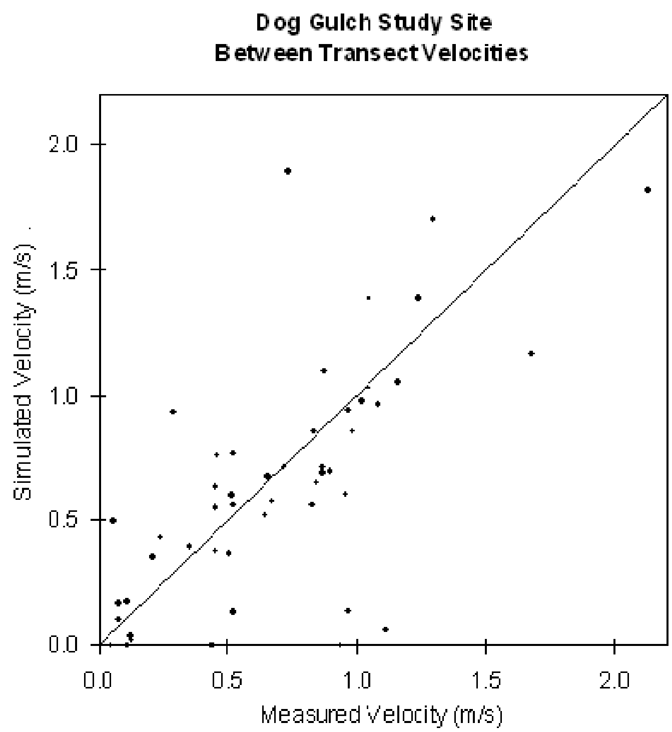
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

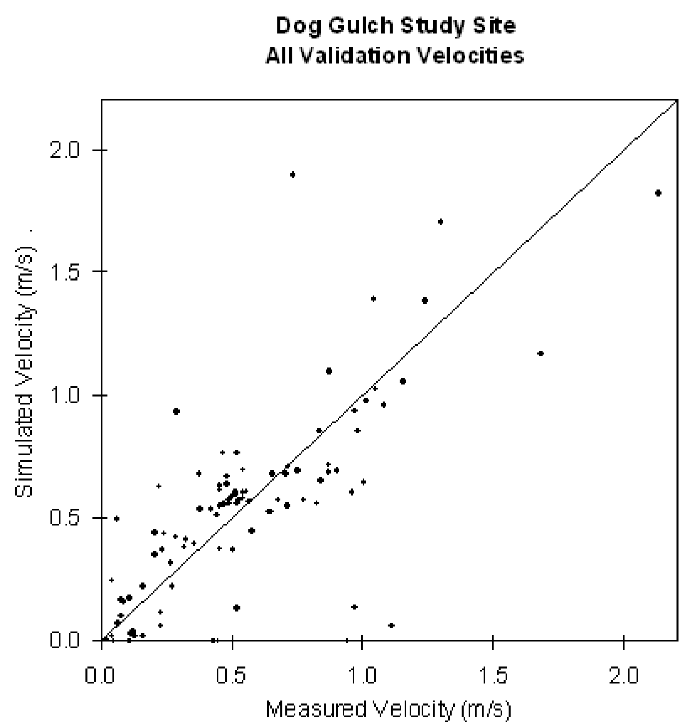
Dog Gulch Site XS1, Q = 200 cfs



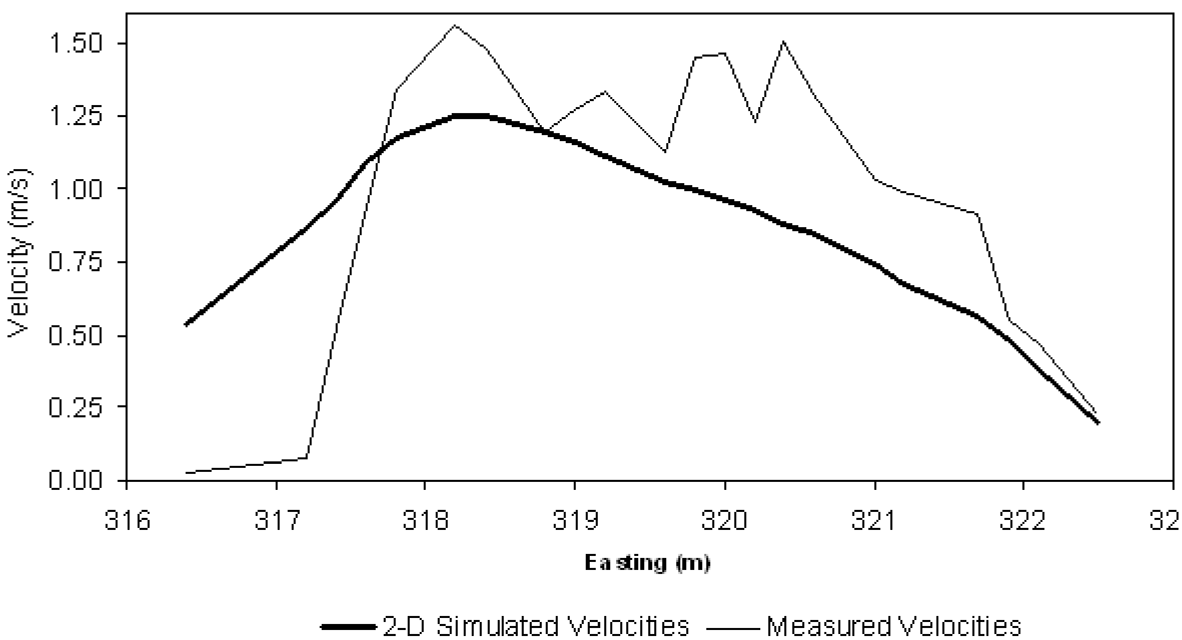
Dog Gulch Site XS2, Q = 200 cfs



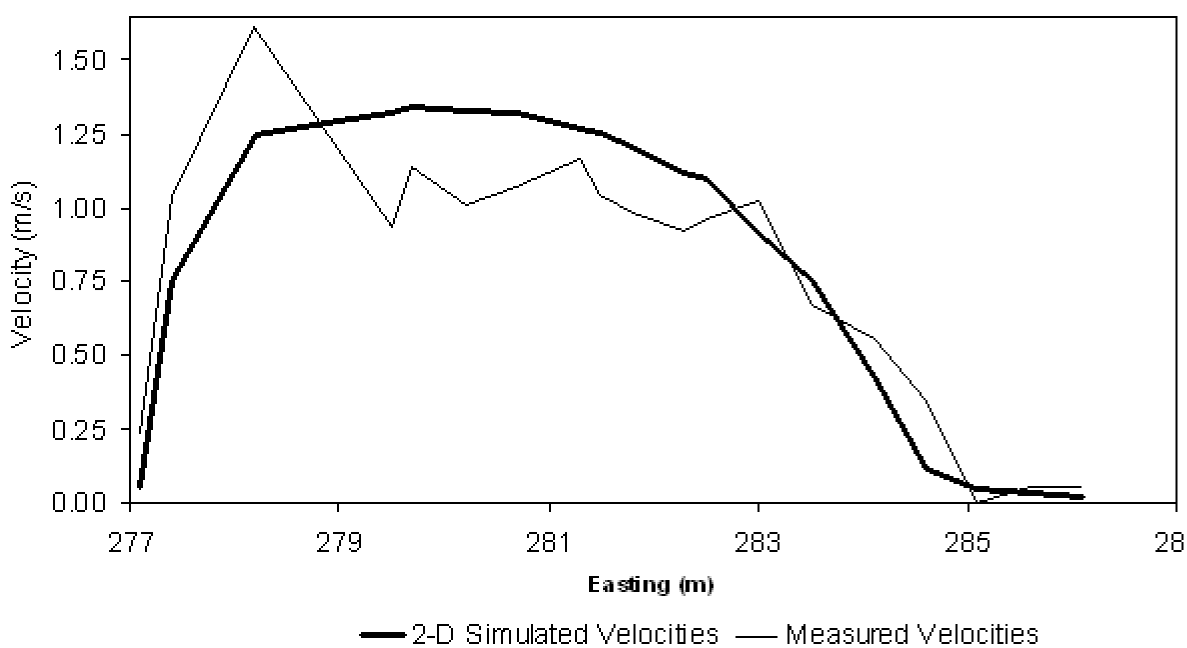

Dog Gulch Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5
2.0

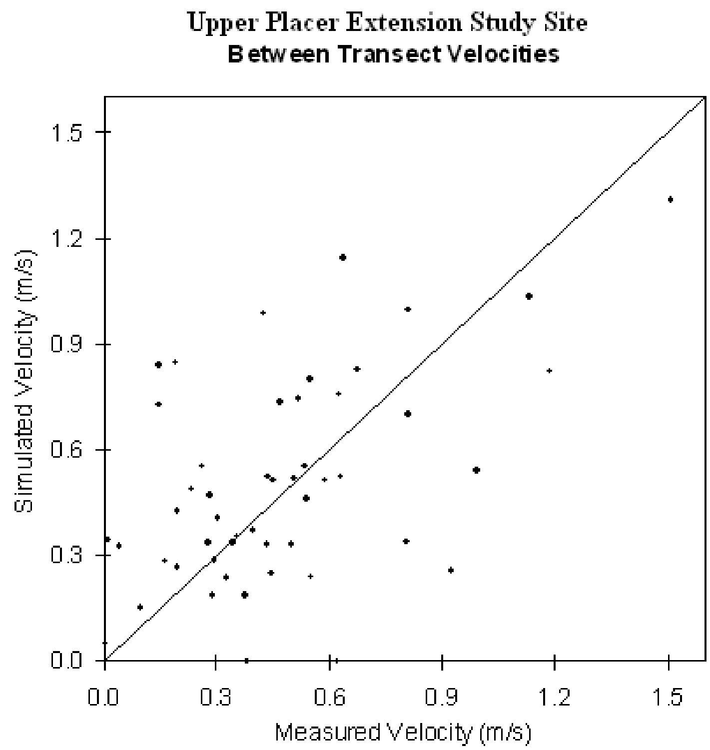

Dog Gulch Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5
2.0

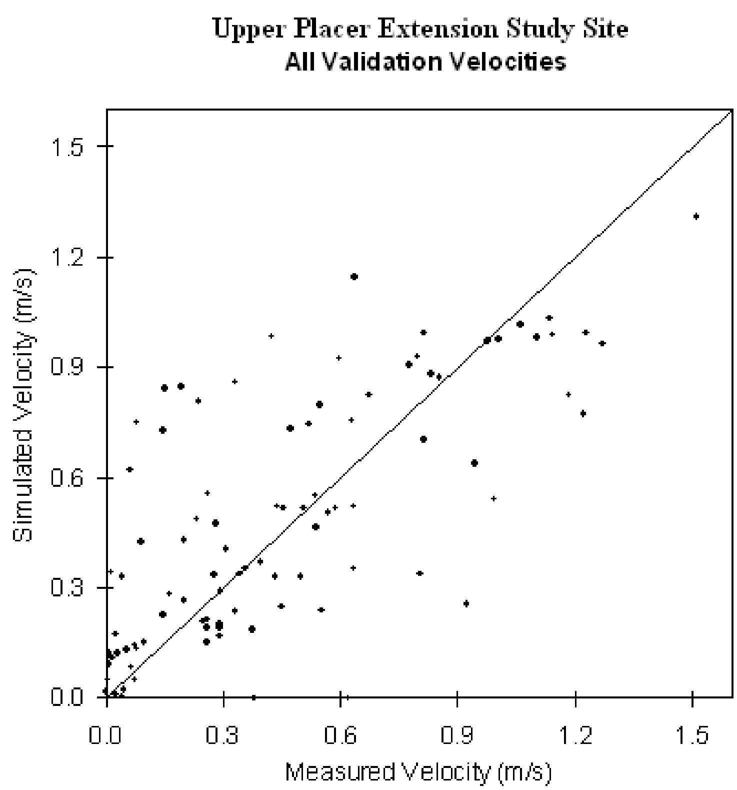
Upper Canyon Site XS1, Q= 227 cfs

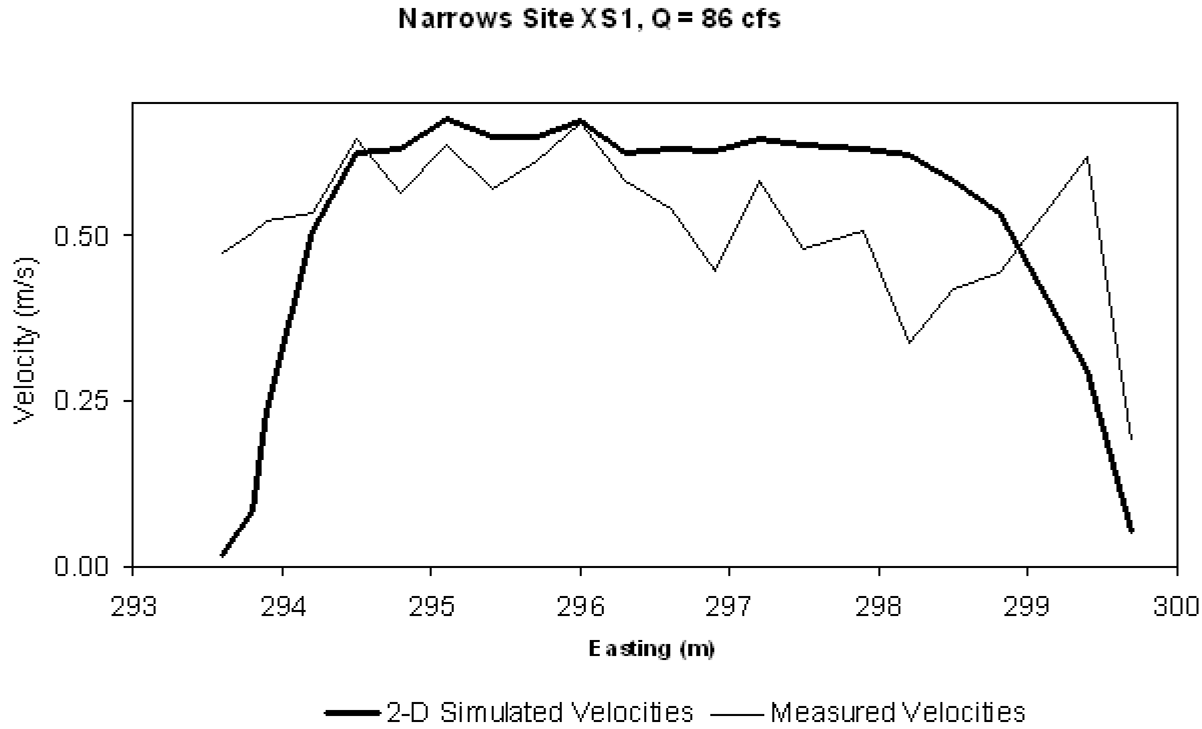


Upper Canyon Site XS2, Q= 227 cfs



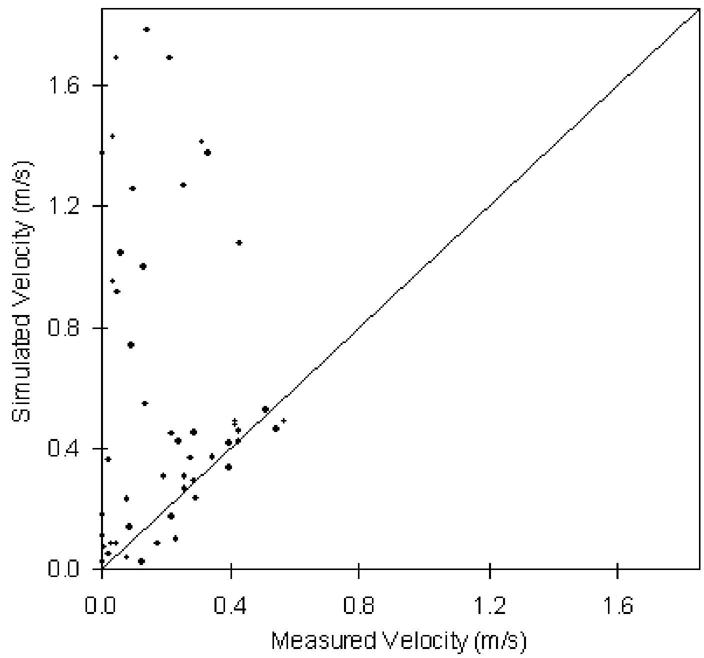

Upper Placer Extension Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.3
0.6
0.9
1.2
1.5


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

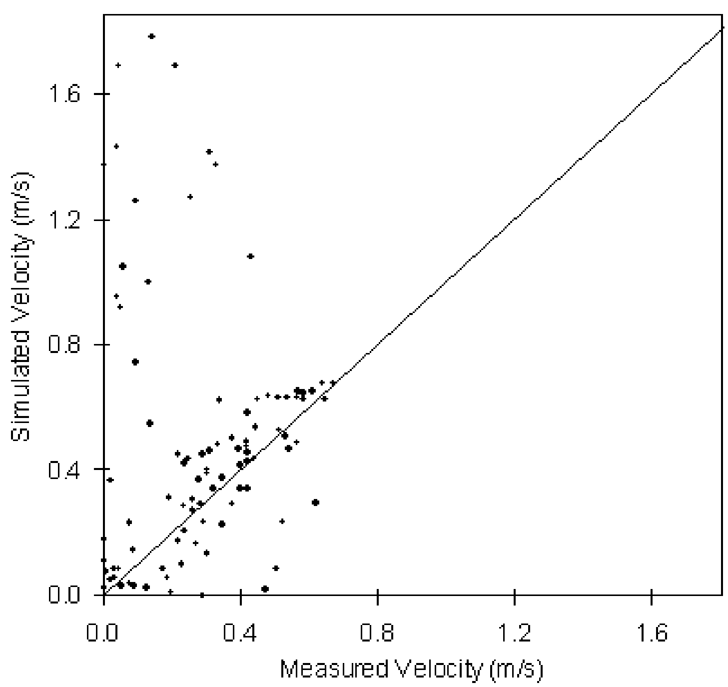

Narrows Site XS1, Q = 86 cfs
Velocity (m/s)
0.50
0.25
0.00
293
294
295
296
297
298
299
300
Easting (m)
2-D Simulated Velocities
Measured Velocities

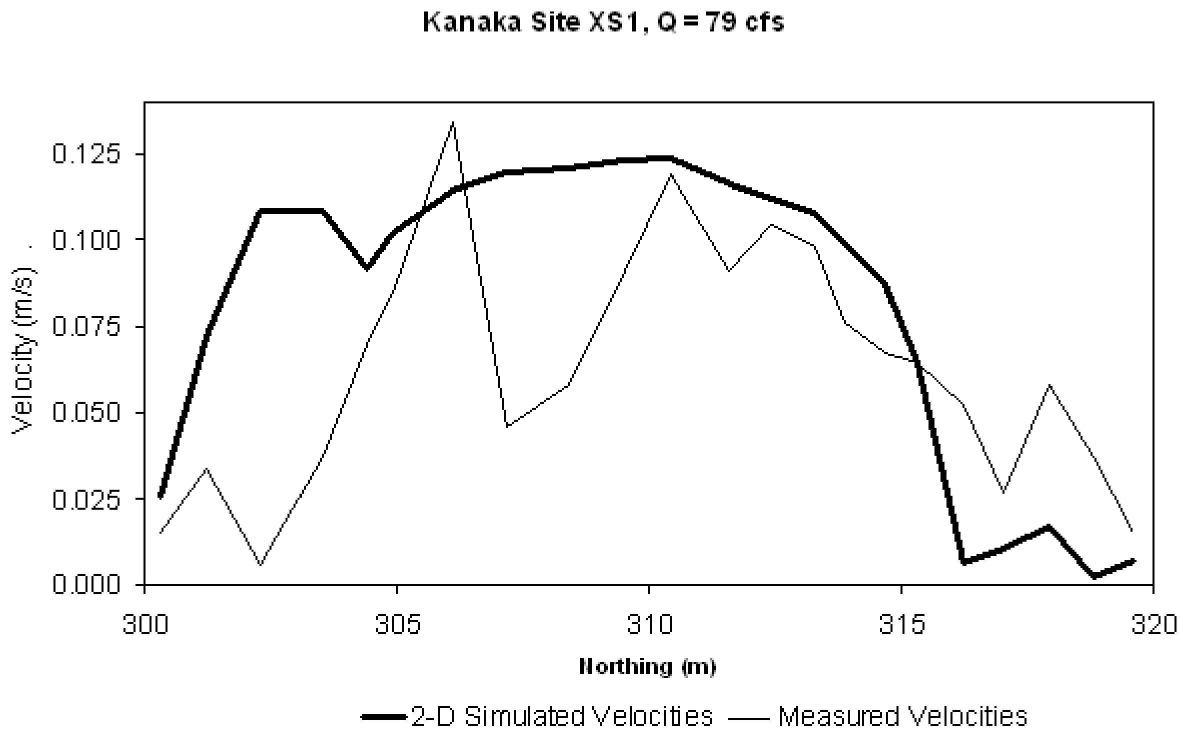

Narrows Site XS2, Q = 86 cfs
Velocity (m/s)
0.50
0.25
0.00
298
299
300
301
302
303
304
305
Easting (m)
2-D Simulated Velocities
Measured Velocities

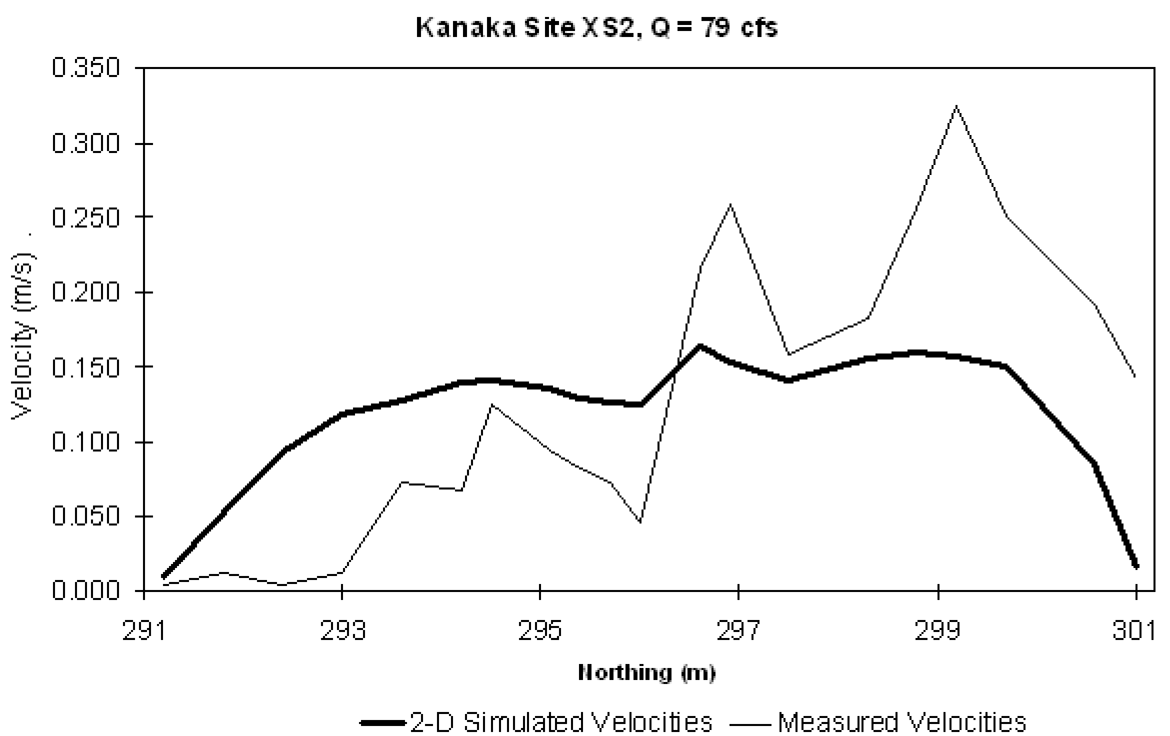
Narrows Study Site
Between Transect Velocities

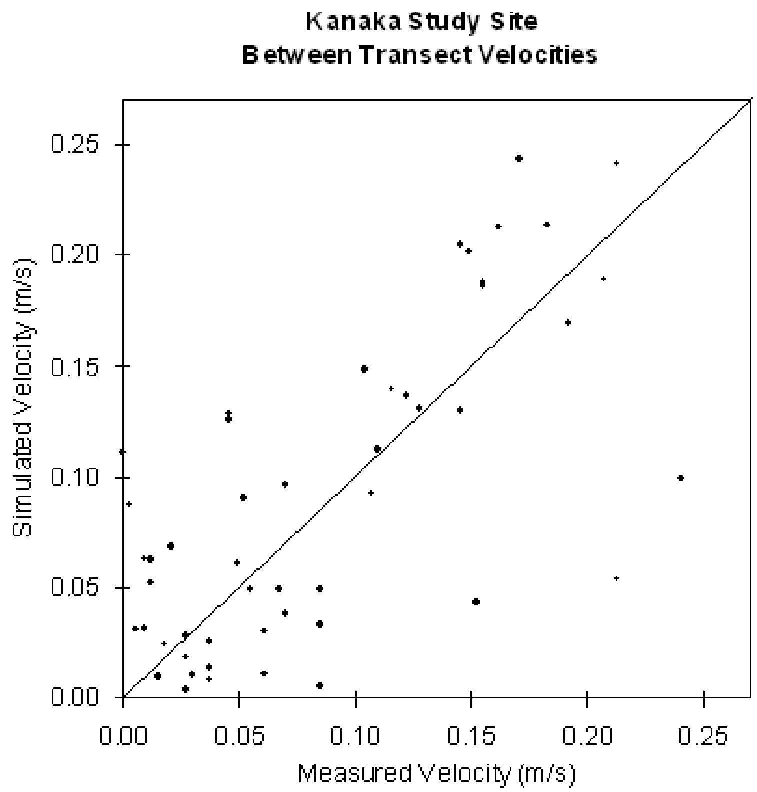


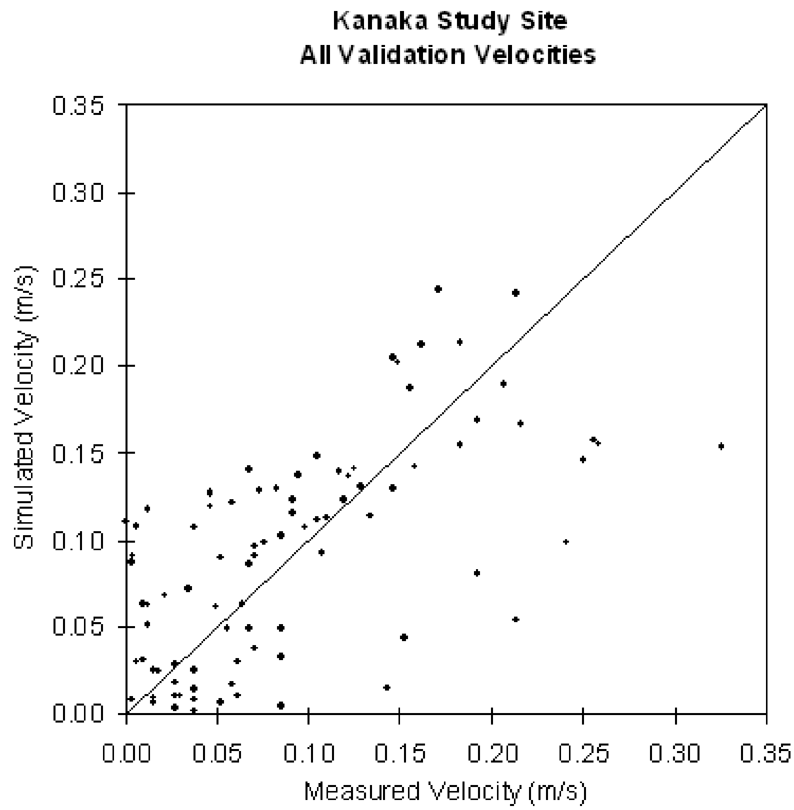
Narrows Study Site
All Validation Velocities

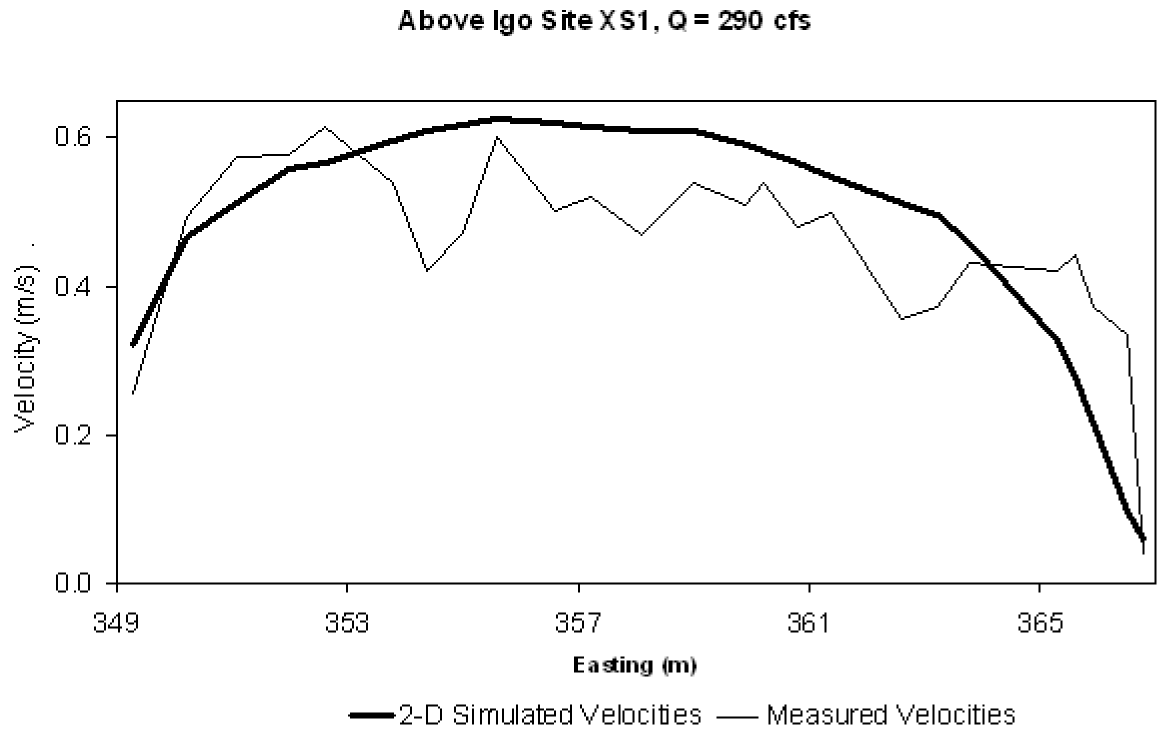


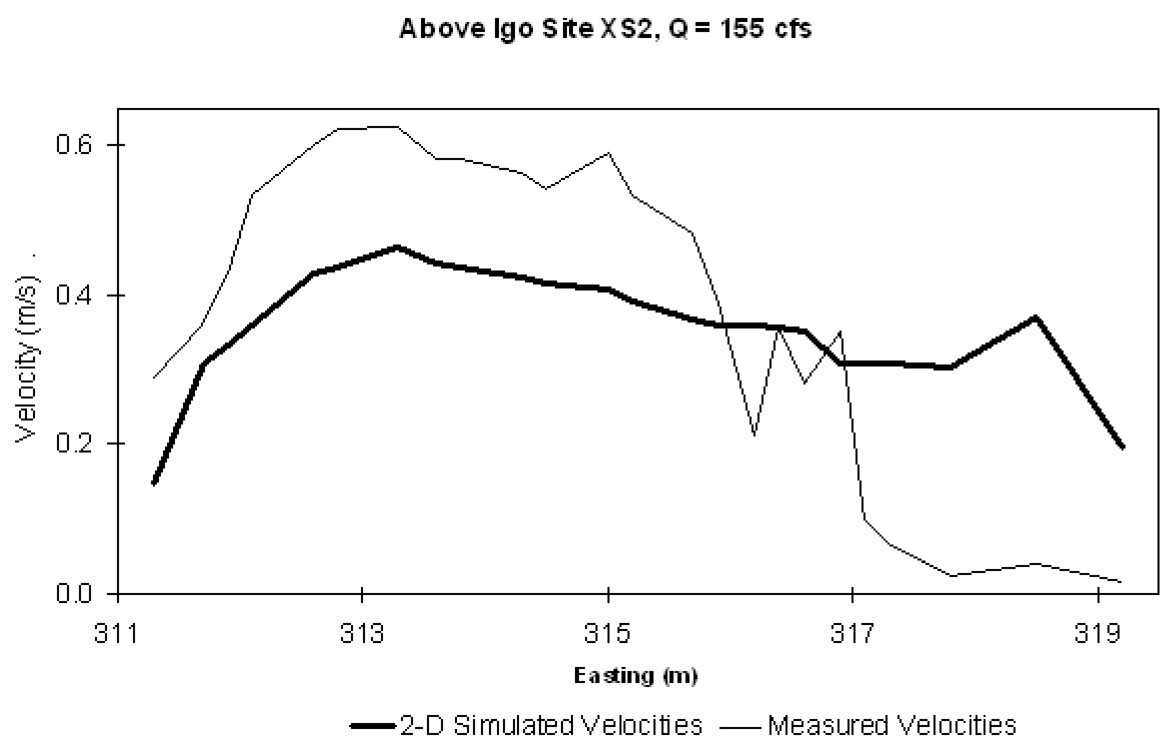

Kanaka Site XS1, Q = 79 cfs
Velocity (m/s)
0.125
0.100
0.075
0.050
0.025
0.000
300
305
310
315
320
Northing (m)
2-D Simulated Velocities
Measured Velocities


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

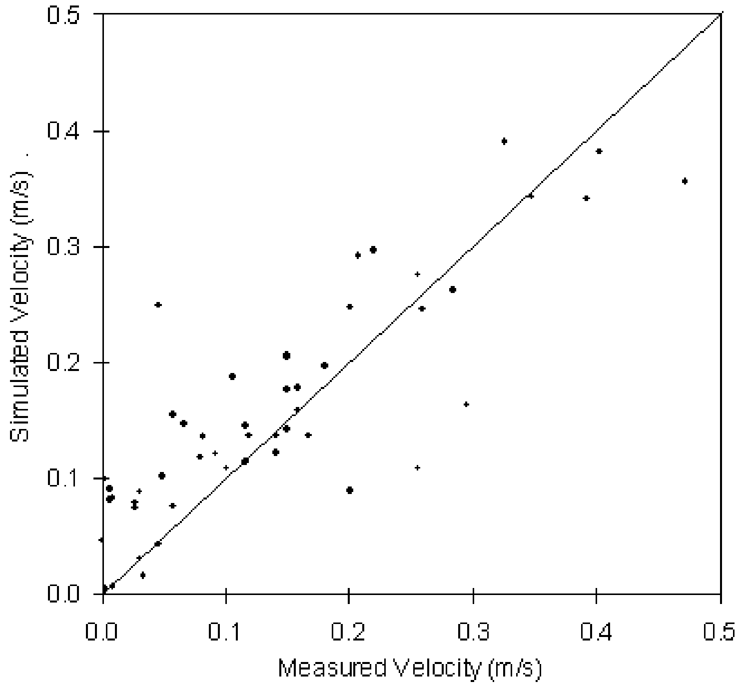

Kanaka Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.00
0.05
0.10
0.15
0.20
0.25


Kanaka Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35

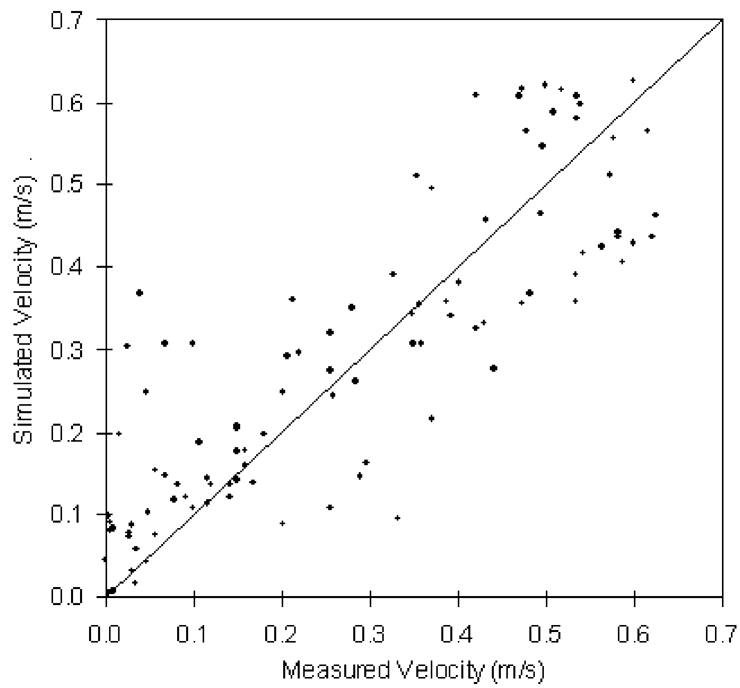

Above Igo Site XS1, Q = 290 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
349
353
357
361
365
Easting (m)
2-D Simulated Velocities
Measured Velocities


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

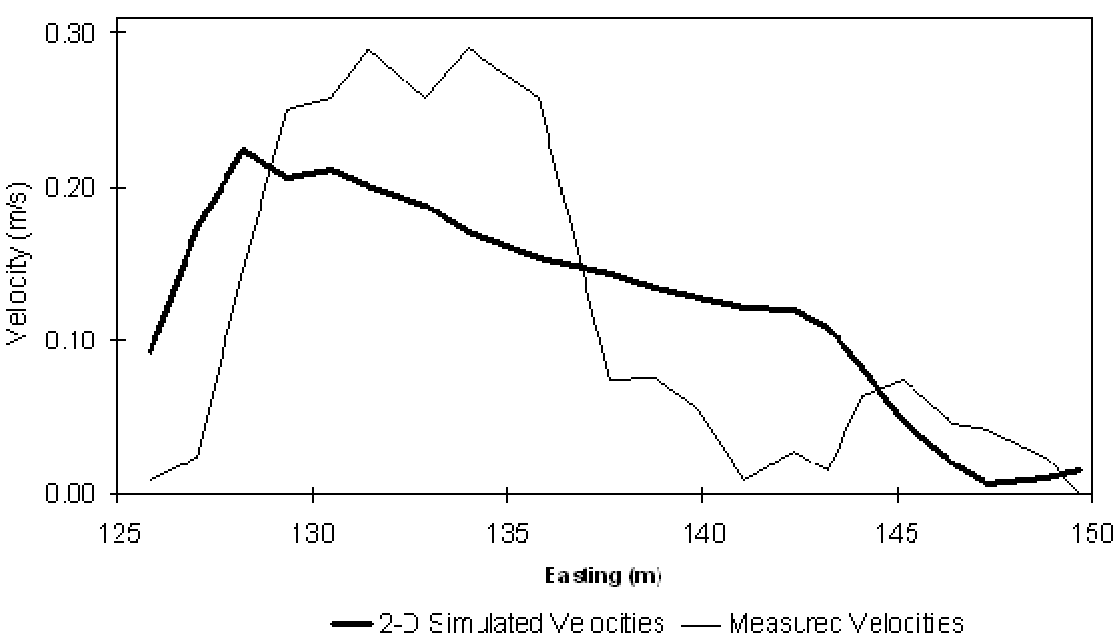


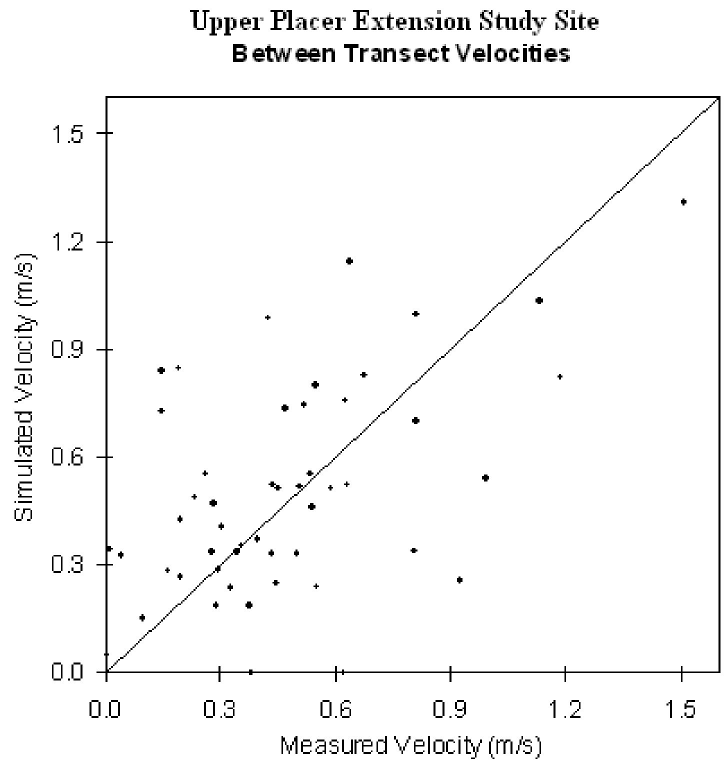
Above Igo Study Site
All Validation Velocities

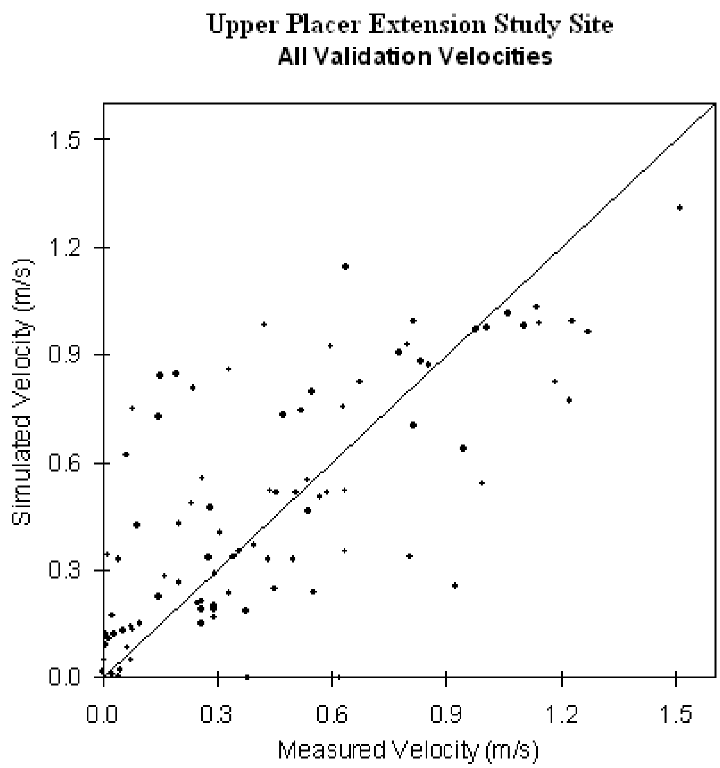


Upper Placer Extension Site XS 1, Q = 251 cfs

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




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


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

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

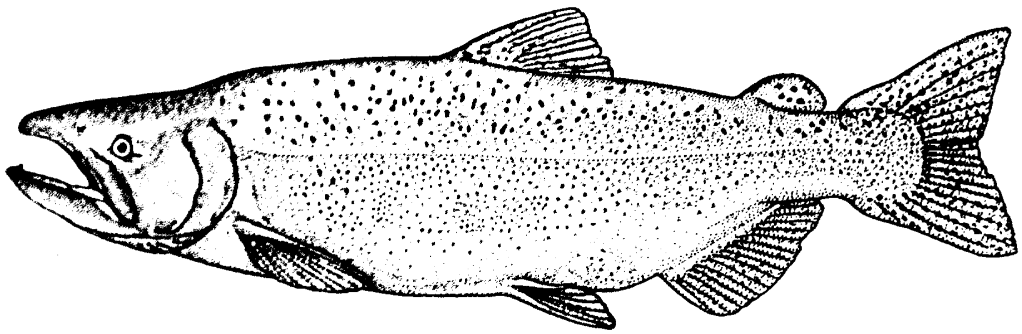
Upper Alluvial Segment WUA (ft^2)

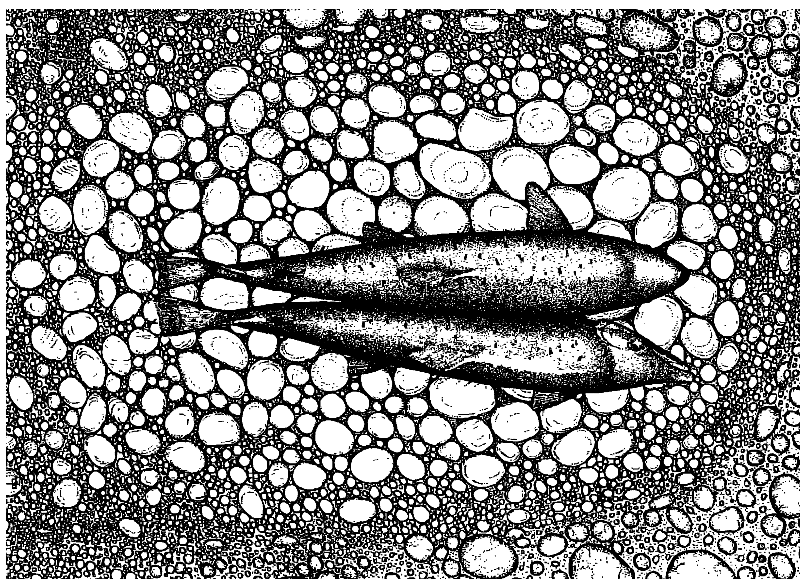
Flow (cfs)	Spring-run Chinook Salmon Fry	Steelhead/Rainbow Trout Fry	Spring-run Chinook Salmon/ Steelhead/Rainbow Trout Juvenile
50	111,496	69,405	41,405
75	105,592	68,867	54,279
100	107,039	67,107	65,641
125	112,173	70,706	76,214
150	114,039	72,571	86,324
175	118,857	73,787	96,403
200	121,064	73,936	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

FLOW-HABITAT RELATIONSHIPS FOR FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING IN CLEAR CREEK BETWEEN CLEAR CREEK ROAD AND THE SACRAMENTO RIVER





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The Restoration and Monitoring Program

CVPIA INSTREAM FLOW INVESTIGATIONS CLEAR CREEK FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING

PREFACE

The following is the final report for the U. S. Fish and Wildlife Service's investigations on anadromous salmonid spawning habitat in Clear Creek between Clear Creek Road and the Sacramento River. These investigations are part of the Central Valley Project Improvement Act (CVPIA) Instream Flow 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 (CDFG). The purpose of these investigations is to provide scientific data to the U. S. Fish and Wildlife Service Central Valley Project Improvement Act 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 Flow Investigations, which ran from February 1995 through September 2001.

ACKNOWLEDGMENTS

The field work for this study was conducted by Mark Gard, Ed Ballard, Bill Pelle, Rick Williams, Damon Goodman and Nick Hindman. Data analysis and report preparation were performed by Ed Ballard and Mark Gard. Funding was provided by the Central Valley Project Improvement Act.

ABSTRACT

Flow-habitat relationships were derived for fall-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Clear Creek Road Bridge and the Sacramento River. A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this study to model available habitat. Habitat was modeled for five sites in the Lower Alluvial segment, which were among those which received the heaviest use by spawning fall-run Chinook salmon. Bed topography was collected for these sites using a total station. 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 in 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. Fall-run Chinook salmon habitat suitability criteria (HSC) were developed from depth, velocity and substrate measurements collected on 442 fall-run Chinook salmon redds. The horizontal location of a subset of the fall-run Chinook salmon redds, located in the five study sites, was measured with a total station to use in biological validation of the habitat models. Logistic regression, along with a technique to adjust spawning depth habitat utilization curves to account for low availability of deep waters with suitable velocities and substrates (Gard 1998), was used to develop the depth HSC, while the velocity HSC were developed solely from the habitat use data. Substrate HSC were developed based on the relative frequency of redds with different substrate codes. Biological validation was accomplished by testing, with a Mann-Whitney U test, whether the combined suitability predicted by RIVER2D was higher at redd locations versus at locations where redds were absent. The steelhead/rainbow trout HSC used in this study were those developed in a previous study of the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2007). No biological validation was performed for the steelhead/rainbow trout in the Lower Alluvial segment. The optimum depth for fall-run Chinook salmon was 1.10 feet (0.34 m), while optimum velocities were 1.83 to 1.97 ft/s (0.56 to 0.60 m/s) and optimum substrate was 1 to 3 inches (2.5 to 7.5 cm). The flow with the maximum habitat was 300 cfs for both fall-run Chinook salmon and steelhead/rainbow trout.

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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 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 is a 7-year effort, the goals of which are 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. Clear Creek was selected for study because of a number of factors, including the presence of listed threatened or endangered species, the number of target species or races, and whether current instream flows were inadequate. There are 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]. Spawning habitat study sites for the third phase of the study were selected that encompassed the Lower Alluvial segment of the creek, excluding a 2-mile restoration reach (U.S. Fish and Wildlife Service 2005). The goal of this study was to produce models predicting the availability of physical habitat in Clear Creek between Clear Creek Road and the Sacramento River, excluding the 2-mile restoration reach, for fall-run Chinook salmon and steelhead/rainbow trout spawning over a range of stream flows that meet, to the extent feasible, the levels of accuracy specified in the methods section. 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

[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
field reconnaissance and study site selection	select study sites which receive heavy spawning use by spring and fall-run Chinook salmon and steelhead/rainbow trout
transect placement (study site setup)	delineate the upstream and downstream boundaries of the study sites, coinciding with the boundaries of the heavy spawning use areas
hydraulic and structural data collection	collect the data necessary to: 1) develop stage-discharge relationships at the upstream and downstream boundaries of the site; 2) develop the site topography and substrate distribution; and 3) validate 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 and substrate data for spring and fall-run Chinook salmon and steelhead/rainbow trout redds to be used in developing habitat suitability criteria (HSC)
biological verification data collection	record the horizontal location of redds within the study sites to use in the biological verification of the habitat models of the study sites
habitat suitability criteria development	develop indices to translate the output of the hydraulic models into habitat quality
biological verification	determine if the combined suitability of locations with redds had higher suitability that those of unoccupied locations
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

(Service) to assess instream flow problems (Bovee 1996). The decision variable generated by the IFIM is total habitat for each life stage (fry, juvenile and spawning) of each evaluation species (or race as applied to Chinook salmon). Habitat incorporates both macro- and microhabitat features. Macrohabitat features, with a spatial scale of 10 to 100 km, include longitudinal changes in channel characteristics, base flow, water quality, and water temperature. Microhabitat features, with a spatial scale of 1 to 5 m, include 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.

Conceptual models are essential for establishing theoretical or commonly-accepted frameworks, upon which data collection and scientific testing can be interpreted meaningfully. A conceptual model of the link between spawning habitat and population change (Figure 1) may be described as follows (Bartholow 1996, Bartholow et al. 1993, Williamson et al. 1993). Changes in flows result in changes in water depths and velocities. These changes, in turn, along with the distribution of substrate, alter the amount of habitat area available for adult spawning for anadromous salmonids. Changes in the amount of habitat for adult spawning could affect reproductive success through the use of habitat of different suitability or alterations in the amount of redd superimposition. These alterations in reproductive success could ultimately result in changes in salmonid populations.

There are a variety of techniques available to quantify the functional relationship between flow and spawning habitat availability, but they can be broken down into three general categories: 1) habitat modeling; 2) biological response correlations; and 3) demonstration flow assessment (Annear et al. 2002). Biological response correlations can be used to evaluate spawning habitat by examining the degree of redd superposition at different flows (Snider et al. 1996). 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 for intermediate levels of spawning – at low spawning levels, there will not be any redd superposition even at low habitat levels, while at high spawning levels, the amount of superposition cannot be determined because individual redds can no longer be identified; 4) the need to assume a linear relationship between superposition and flow between each observed flow; and 5) 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 2009a). Based on the above discussion, we concluded that habitat modeling was the best technique for evaluating anadromous salmonid spawning habitat in Clear Creek. 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.

The results of this study are intended to support or revise the flow recommendations above. The range of Clear Creek flows to be evaluated for management generally falls within the range of 50 cfs (the minimum required release from Whiskeytown Dam) to 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 to be evaluated for management. The assumptions of this study are: 1) that physical habitat is the limiting

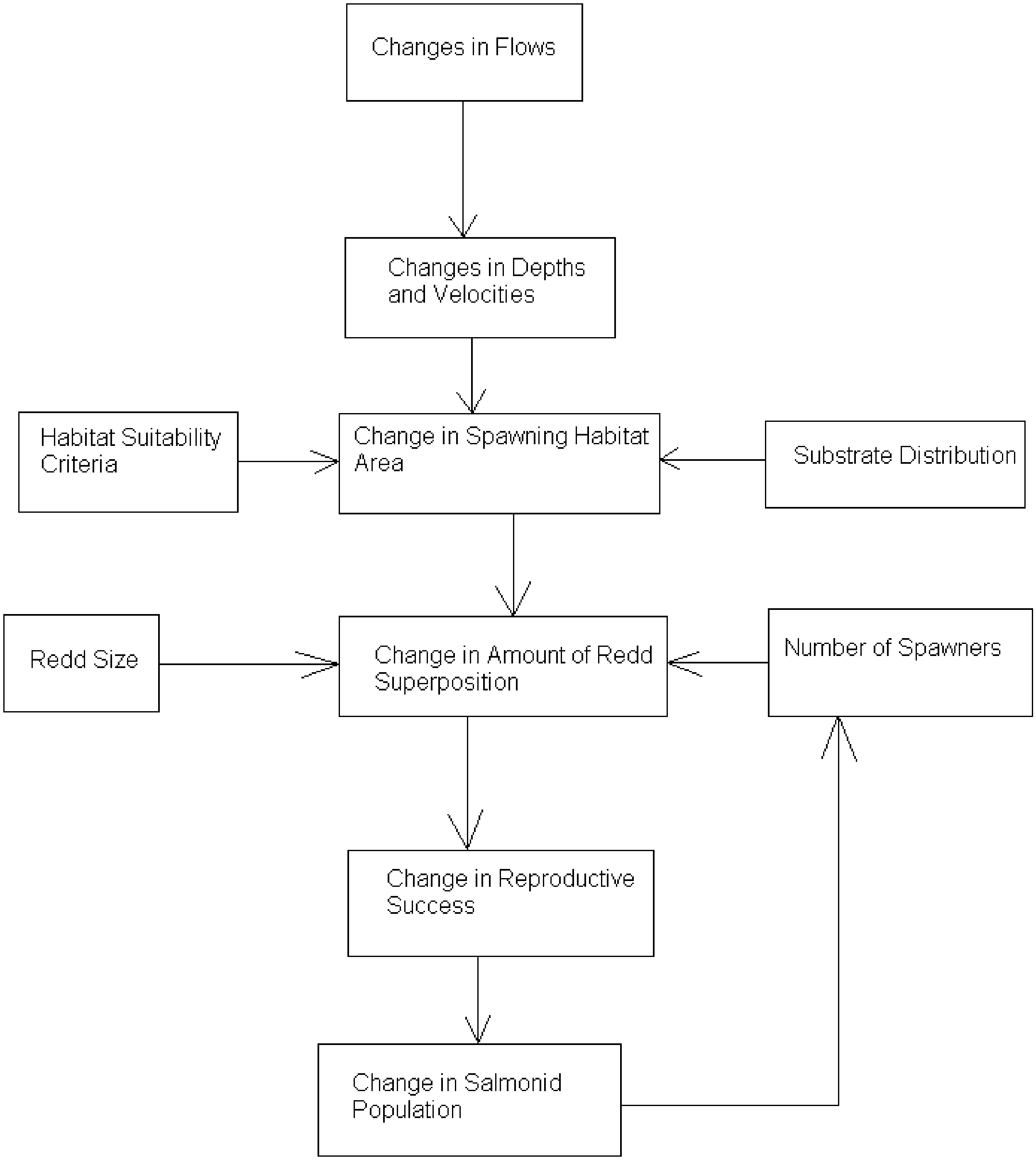

Figure 1. Conceptual model of the linkage between flow and salmonid populations.

factor for salmonid populations in Clear Creek; 2) that spawning habitat quality can be characterized by depth, velocity and substrate; 3) that the depths and velocities present during habitat suitability index (HSI) data collection were the same as when the redds were constructed; 4) that the five study sites are representative of anadromous salmonid spawning habitat in Clear Creek between Clear Creek Road and the Sacramento River, excluding the 2-mile restoration reach; 5) that the selected unoccupied locations were representative for the Lower Alluvial segment, excluding the 2-mile restoration reach, for the entire 3 year period for all the spawning data that were collected; and 6) that theoretical equations of physical processes along with a description of stream bathymetry 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]) component of IFIM. 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 (Gard 2009b). 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 and a velocity adjustment factor (Leclerc et al. 1995). 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

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[3] PHABSIM is the collection of one dimensional hydraulic and habitat models which are used to predict the relationship between physical habitat availability and streamflow over a range of river discharges.

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. Bed topography and substrate 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.

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, Tiffan et al. 2002, McHugh and Budy 2004) 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. 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 substrate). One concern with this technique is the effect of availability of habitat on the observed frequency of habitat use. For example, if a substrate size is relatively rare in a stream, fish will be found primarily not using that substrate size simply because of the rarity of that substrate size, rather than because they are selecting areas without that substrate size. Guay et al. (2000) proposed a modification of the above technique where depth, velocity, and substrate data are collected both in locations where redds are present and in locations where redds are absent, and a logistic regression is used to develop the criteria.

Study Segment Delineation

Study segments were delineated within the study reach of Clear Creek (Figure 2), based on hydrology and other factors.

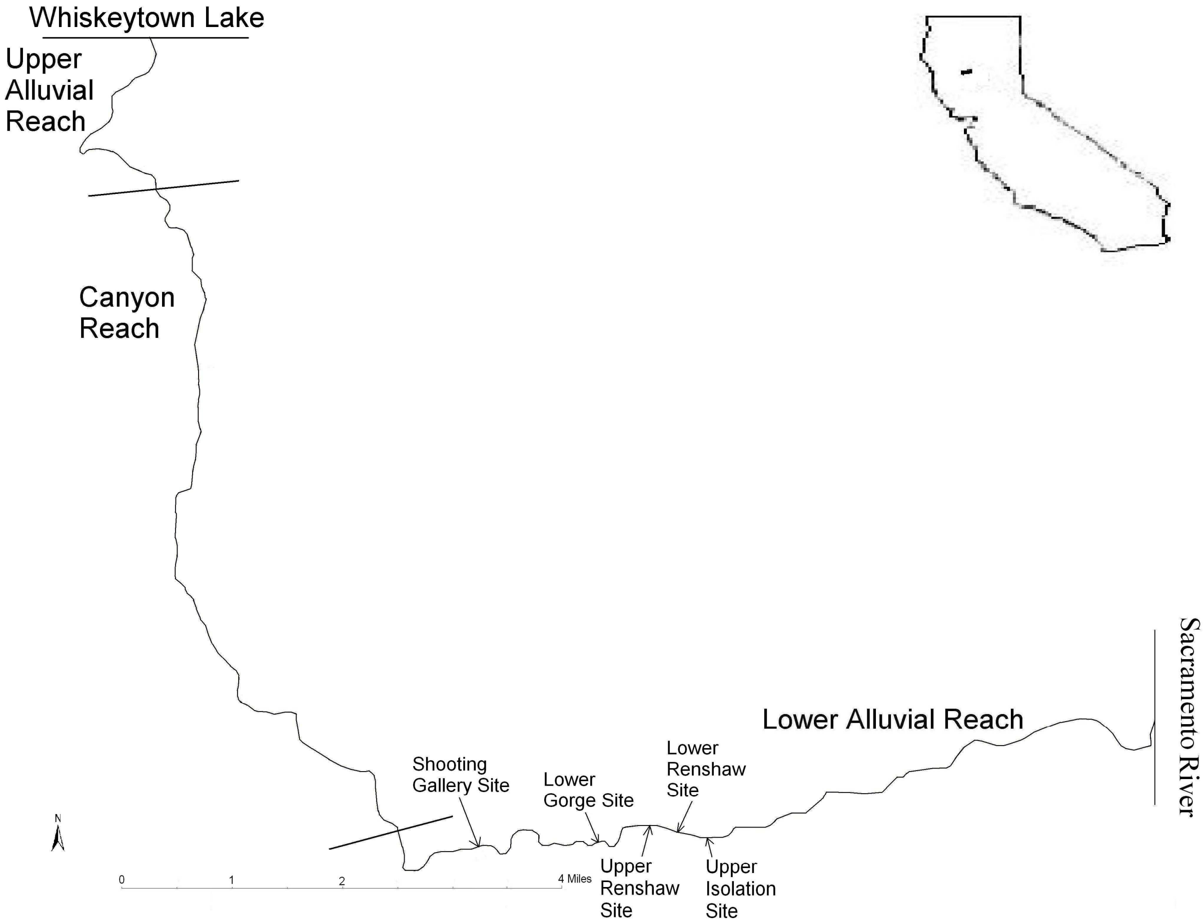

Figure 2. Clear Creek stream segments and spawning study sites.

Field Reconnaissance and Study Site Selection

Fall-run Chinook salmon redd count data from 2000-2005 and steelhead/rainbow trout redd count data from 2002-2006 collected by the Service's Red Bluff Fish and Wildlife Office were used to select study sites. These sites were among those that received heaviest use by spawning fall-run Chinook salmon and steelhead/rainbow trout. In May 2006, we conducted a reconnaissance of the selected study sites in the Lower Alluvial study segment to determine their viability as study sites. Each site was evaluated based on morphological and channel characteristics which facilitate the development of reliable hydraulic models. Also noted were riverbank and floodplain characteristics (e.g., steep, heavily vegetated berms or gradually sloping cobble benches) which might affect our ability to collect the necessary data to build these models. For 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 setup)

The study sites were established in July and August 2006. The study site boundaries (upstream and downstream) were generally selected to coincide with the upstream and downstream ends of the heavy spawning use areas. A PHABSIM transect was placed at the upstream and downstream end of each study 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 water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. Transect pins (headpins and tailpins) were marked on each river bank above the 900 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 Data Collection

Vertical benchmarks were established at each site to serve as the vertical elevations to which all elevations (streambed and water surface) were referenced. Vertical benchmarks were tied together, using differential leveling, to achieve a level loop accuracy (ft) of at least 0.05 x (level loop distance [mi]) $^{0.5}$. Vertical benchmarks consisted of lag bolts driven into trees and fence posts or painted bedrock points. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site to serve as the horizontal locations to which all horizontal locations (northings and eastings) were referenced. The precise northing and easting coordinates and vertical elevations of two horizontal benchmarks were established for each site using survey-grade RTK GPS. The elevations of these benchmarks were tied into the vertical benchmarks on our sites using differential leveling.

Hydraulic and structural data collection began in August 2006 and was completed in December 2007. The data collected on the upstream and downstream transect included: 1) water surface elevations (WSELs), measured to the nearest 0.01 foot (0.003 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 bank-full 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 and cover classification (Tables 2 and 3) at these same locations and also where dry ground elevations were surveyed. In between these transects, the following data were collected: 1) bed elevation;

Table 2. 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)

2) horizontal location (northing and easting, relative to horizontal benchmarks); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the site.

Water surface elevations were measured along both banks and, when possible, in the middle of each transect. The water surface elevations at each transect were then derived by averaging the two-three values, except when the difference in elevation exceeded 0.1 foot (0.031 m). When the difference in water surface elevation between left and right banks exceeded 0.1 foot (0.031 m), the water surface elevation for the side of the river that was considered most representative was used. Starting at the water's edge, water depths and velocities were made at measured intervals

Table 3. 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

using a wading rod and Marsh-McBirney® model 2000 or Price AA velocity meter. The distance intervals of each depth and velocity measurement from the headpin or tailpin were measured using a hand held laser range finder[4] or measuring tape.

We collected the data between the upstream and downstream transects by obtaining the bed elevation and horizontal location of individual points with a total station, while the cover and substrate were visually assessed at each point by one observer based on the visually-estimated average of multiple grains. Topography data, including substrate and cover data, were also

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

collected for a minimum of a half-channel width upstream of the upstream transect to improve the accuracy of the flow distribution at the upstream end of the sites. All substrate and cover data on the transects were assessed by one observer based on the visually-estimated average of multiple grains. At each change in substrate size class or cover type, the distance from the headpin or tailpin was measured using a hand held laser range finder or measuring tape.

To validate the velocities predicted by the 2-D model, depth, velocities, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. These 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 per site.

For sites where there was a gradual gradient change in the vicinity of the downstream transect, there could be a point in the thalweg a short way downstream of the site that was higher than that measured at the downstream transect thalweg simply due to natural variation in topography (Figure 3). This stage of zero flow downstream of the site acts as a control on the water surface elevations at the downstream transect, and could cause errors in the WSELs. Because the true stage of zero flow is needed to accurately calibrate the water surface elevations on the downstream transect, this stage of zero flow in the thalweg downstream of the downstream transect was surveyed in using differential leveling. If the true stage of zero flow was not measured as described above, the default stage of zero flow would be the thalweg elevation at the transect.

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

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. By calibrating the upstream and downstream transects with PHABSIM using the collected calibration water surface elevations (WSELs), we were able to predict the WSELs for these transects for the various simulation flows that were to be modeled using River2D. We calibrated the River2D models using the highest simulation flow. The highest simulation WSELs predicted by PHABSIM for the upstream and downstream transects were 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

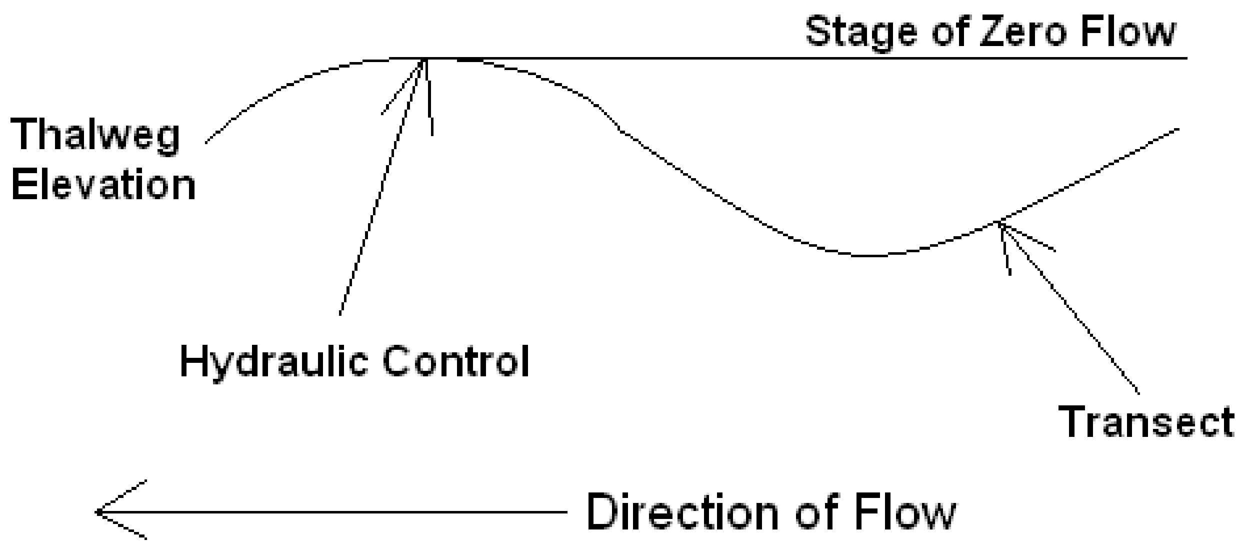

Figure 3. Stage of zero flow diagram.

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. The following describes the PHABSIM WSEL calibration process for the upstream and downstream transects.

All data were compiled and checked before entry into PHABSIM data files. A table of substrate ranges/values was created to determine the substrate for each vertical/cell (e.g, if the substrate size class was 2-4 inches (5 to 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 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[5] files. A separate PHABSIM file was constructed for each study site. All of the measured WSELs were checked to make sure that water was not flowing uphill. The slope for each transect was computed at each measured flow as the difference in 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. A total of four or five WSEL sets at low, medium, and high flows were used. If WSELs were available for several closely spaced flows, the WSEL that

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

corresponded with the velocity set or the WSEL collected at the lowest flow was used in the PHABSIM data files. Calibration flows in the data files were the flows calculated from gage readings. The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. 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 each deck 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 condition 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 given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs[6]. *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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[6] The first three criteria are from U.S. Fish and Wildlife Service (1994), while the fourth criterion is our own criterion.

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.

RIVER2D Model Construction

After completing the PHABSIM calibration process to arrive at the simulation WSELs that will be used as inputs to the RIVER2D model, the next step is 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 substrate) for the 2-D modeling program. An artificial extension one channel-width-long was added upstream of the topography data collected upstream of the study 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 upsteam 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 substrate files contain the horizontal location, bed elevation and substrate code 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 4, with the bed roughness value for each point computed as the sum of the substrate bed roughness value and the cover bed roughness value for the point. The resulting initial bed roughness value for each point was therefore a combined matrix of the substrate and cover roughness values. The bed roughness values for substrate in Table 4 were computed as five times the average particle size[7]. The bed roughness values for cover in Table 4 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 substrate files were exported from the spreadsheet 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[8] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. The first step in refining the TIN was to conduct a quality assurance/quality control process, consisting of a point-by-point inspection to eliminate quantitatively wrong points, and a qualitative process

[7] 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).

[8] 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 fall on the breaklines (Steffler 2002).

Table 4. 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, 0.71, 1.95[9]	9	0.29
10	1.4	9.7	0.57
		10	3.05

where we checked the features constructed in the TIN against aerial photographs to make sure we had represented landforms correctly. 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 and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final bed file as an input. The first stage in creating the

[9] For substrate code 9, we used bed roughnesses of 0.71 and 1.95, respectively, for cover codes 1 and 2, and a bed roughness of 0.05 for all other cover codes. 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.

computational mesh was to define mesh breaklines[10] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and then additional nodes were added as needed 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) 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.

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. 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 upstream transect. The minimum groundwater depth was adjusted to a value of 0.05 m 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 $\varepsilon_3 = 0.1$). 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,

[10] Mesh breaklines are a feature of the R2D_MESH program which force edges of the computation mesh elements to fall on the mesh breaklines and force the TIN of the computational mesh to linearly interpolate the bed elevation and bed roughness values of mesh nodes between the nodes at the end of each breakline segment (Waddle and Steffler 2002). A better fit between the bed and mesh TINs is achieved by having the mesh and bed breaklines coincide.

solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than 1[11]. 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 transect[12].

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 the velocities measured on the upstream and downstream transects, and the 50 velocities per site measured in between the upstream and downstream transects. The criterion used to determine whether the model was validated was whether the correlation coefficient (R) 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 provide initial boundary conditions for simulating hydrodynamics of the sites at the simulation flows. The cdg file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each discharge 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 will usually have a Max F of less than 1.

Habitat Suitability Criteria (HSC) Data Collection

Habitat suitability curves (HSC or HSI Curves) are used within 2-D habitat modeling to translate hydraulic and structural elements of rivers into indices of habitat quality (Bovee 1986). The primary habitat variables which are used to assess physical habitat suitability for spawning Chinook salmon and steelhead/rainbow trout are water depth, velocity, and substrate composition. One HSC set for fall-run Chinook salmon and one HSC set for steelhead/ rainbow trout were used in this study. The fall-run Chinook salmon criteria were based on data collected

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[11] This criteria is based on the assumption that flow in low gradient streams is usually subcritical, where the Froude number is less than 1 (Peter Steffler, personal communication).

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

by staff of the Red Bluff Fish and Wildlife Office on fall-run Chinook salmon redds in Clear Creek in 2004-2005 and by the staff of the Service's Sacramento Fish and Wildlife Office in 2006. The steelhead/rainbow trout HSC used in this study were based on data collected in the Upper Alluvial and Canyon reaches during the phase one spawning study (U.S. Fish and Wildlife Service 2007).

For habitat suitability criteria data collection, all of the active redds (those not covered with periphyton growth) which could be distinguished were measured. Data were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. Depth was recorded to the nearest 0.1 foot (0.031 m) and average water column velocity was recorded to the nearest 0.01 ft/s (0.003 m/s). Measurements were taken with a wading rod and a Marsh-McBirney[R] model 2000 velocity meter. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2 inches [2.5 to 5 cm]) at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. The substrate coding system used is shown in Table 2. All data were entered into spreadsheets for analysis and development of HSCs.

Biological Verification Data Collection

Biological validation data were collected to test the hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds were present versus locations where redds were absent. The compound suitability is the product of the depth suitability, the velocity suitability, and the substrate suitability. The collected biovalidation data were the horizontal locations of redds. Depth, velocity, and substrate size as described in the previous section on habitat suitability criteria data collection were also measured. The hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds were present versus locations where redds were absent was statistically tested with a one-tailed Mann-Whitney U test (Gard 2006, Gard 2009b, McHugh and Budy 2004).

The horizontal location of the redds found in the study sites during the survey for fall-run Chinook salmon redds conducted on October 16-19, 2006 were recorded by sighting from the total station to a stadia rod and prism. The horizontal location of the redds constructed subsequent to the October 16-19, 2006 surveys were also recorded in Shooting Gallery and Lower Gorge sites on October 30-31, 2006. Due to significant superposition of redds at the Lower Gorge site by the end of October, there were several large areas which were completely filled with redds, making it impossible to distinguish new redds from those previously surveyed. For these areas, a series of points, recorded by sighting from the total station to a stadia rod and prism, were collected around the outer edge of these areas so that polygons could be developed. These polygons were used subsequently to exclude these areas from selection as unoccupied locations. No biological verification data were collected for steelhead/rainbow trout in the Lower Alluvial segment[13]. All data for the fall-run Chinook salmon redds were entered into spreadsheets.

Habitat Suitability Criteria (HSC) Development

The collected redd depth and velocity data must be processed through a series of steps to arrive at the HSC that will be used in the RIVER2D model to predict habitat suitability. Using the fall-run Chinook salmon HSC data that were collected in 2004-2006, we applied a 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). Criteria are developed by using a logistic regression procedure, with presence or absence of redds as the dependent variable and depth and velocity as the independent variables, with all of the data (in both occupied and unoccupied locations) used in the regression.

Velocity and depth data were obtained for locations within each site where redds were not found (unoccupied). These data were obtained by running a final River2D cdg file for each site at the average flow for the period leading up to the date the location of extant redds were recorded using a total station and the depth and velocity data were collected. After running the final River2D models for each study site, velocity and depth data at each node within the file were then downloaded. Using a random numbers generator, approximately 300 unoccupied points[14] were selected for each site that had the following characteristics: 1) were more than 3 feet (0.91 m) from a redd recorded during the 2006 survey and were outside of the polygons delineated for the Lower Gorge site; 2) were inundated; 3) were more than 3 feet (0.91 m) from any other point that was selected; and 4) were located in the site, rather than in the upstream extension of the file.

We then 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:

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

[13] Biological verification was previously conducted for steelhead/rainbow trout spawning in the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2007).
[14] The actual number of points varied from site to site and were slightly less than 300 due to points that were deleted because they were within 3 feet (0.9 m) of a redd or were within polygons delineated for the Lower Gorge site.

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 included all of the terms. 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 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 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.

In cases where the results of the logistic regression were biologically unrealistic, we developed the criteria by calculating frequency distributions from the use data and input into the PHABSIM suitability index curve development program (CURVE). The HSI curves were then developed using exponential smoothing. The curves generated were exported into a spreadsheet and modified by truncating at 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 value of zero; and eliminating points above the optimal suitability to account for the effects of availability on habitat use.

A technique to adjust depth habitat utilization curves for spawning to account for low availability of deep waters with suitable velocity and substrate (Gard 1998) was applied to the fall-run Chinook salmon HSC data. The technique begins with the construction of multiple sets of HSC, differing only in the suitabilities assigned for optimum depth increments, to determine how the available creek area with suitable velocities and substrates varied with depth. Ranges of suitable velocities and substrates were determined from the velocity and substrate HSC curves, with suitable velocities and substrates defined as those with HSC values greater than 0.5. A range of depths is selected, starting at the depth at which the initial depth HSC reached 1.0, through the greatest depth at which there were redds or available habitat. A series of HSC sets are constructed where: 1) all of the sets have the same velocity and substrate HSC curves, with values of 1.0 for the suitable velocity and substrate range with all other velocities and substrates assigned a value of 0.0; and 2) each set has a different depth HSC curve. To develop the depth HSC curves, each HSC set is assigned a different half-foot (0.15 m) depth increment within the selected depth range to have an HSC value of 1.0, and the other half-foot (0.15 m) depth increments and depths outside of the depth range a value of 0.0 (e.g., 1.1-1.59 foot (0.34-0.48 m) depth HSC value equal 1.0, < 1.1 foot (0.34 m) and >1.59 foot (0.48 m) depths HSC value equals 0.0 for a depth increment of 1.1-1.59 feet (0.34-0.48 m)). Each HSC set is used in RIVER2D with the calibrated RIVER2D file for each study site at which HSC data were collected for that run. The resulting habitat output is used to determine the available river area with suitable velocities and substrates for all half-foot (0.15 m) depth increments.

To modify the fall-run Chinook salmon HSC depth curve to account for the low availability of deep water having suitable velocities and substrates, a sequence of linear regressions (Gard 1998) was used to determine the relative rate of decline of use versus availability with increasing depth. Habitat use by spawning fall-run Chinook salmon is defined as the number of redds observed in each depth increment. Availability data were determined using the output of the calibrated hydraulic River2D files for the spawning habitat modeling sites, while 2006 redd data from the sites were used to assess use. Availability and use are normalized by computing relative availability and use, so that both measures have a maximum value of 1.0. Relative availability and use are calculated by dividing the availability and use for each depth increment by the largest value of availability or use. To produce linearized values of relative availability and use at the midpoints of the depth increments (i.e., 1.35 feet (0.41 m) for the 1.1-1.59 foot (0.34-0.48 m) depth increment, we used linear regressions of relative availability and use versus the midpoints of the depth increments. Linearized use is divided by linearized availability for the range of depths where the regression equations predict positive relative use and availability. The resulting use-availability ratio is standardized so that the maximum ratio is 1.0. To determine the depth at which the depth HSC would reach zero (the depth at which the scaled ratios reach zero), we used a linear regression with the scaled ratios versus the midpoint of the depth increments.

Substrate criteria were developed by: 1) determining the number of redds with each substrate code (Table 2); 2) calculating the proportion of redds with each substrate code (number of redds with each substrate code divided by total number of redds); and 3) calculating the HSI value for each substrate code by dividing the proportion of redds in that substrate code by the proportion of redds with the most frequent substrate code. The steelhead/rainbow trout HSC utilized in this study were those developed for the phase one study of the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2007).

Biological Verification

We compared the combined habitat suitability predicted by RIVER2D at each fall-run Chinook salmon redd location to that at unoccupied locations in the spawning habitat modeling sites. We ran the RIVER2D cdg files at the average flows for the period from the start of the spawning season up to the date of redd location data collection for fall-run Chinook salmon (October 1 – October 19, 2006) to determine the combined habitat suitability at individual points for RIVER2D. We also ran RIVER2D cdg files at the average flow for the period October 19-30, 2006 for the data collected in Shooting Gallery and Lower Gorge sites during the second data collection period of October 30-31, 2006. We used the horizontal location measured for each redd to determine the location of each redd in the RIVER2D sites. We used a random number generator to select locations without redds in each site. Locations were eliminated that: 1) were less than 3 feet (0.91 m) from a previously-selected location; 2) were less than 3 feet (0.91 m) from a redd location or were within polygons delineated for the Lower Gorge site; 3) were located in the wetted part of the site; and 4) were located in the site (between the upstream and downstream transects). We used one-tailed Mann-Whitney U tests (Zar 1984) to determine whether the combined suitability predicted by RIVER2D was higher at redd locations versus locations where redds were absent.

Habitat Simulation

The final step was to simulate available habitat for each site. Preference curve files were created containing the digitized HSC developed for the Clear Creek fall-run Chinook salmon and steelhead/rainbow trout (Appendix I). RIVER2D was used with the final cdg production files, the substrate file and the preference curve file to compute WUA for each site over the desired range of simulation flows for all sites. The process for determining WUA from the HSC was to multiply together the suitability of each of the three variables, and then multiply this product by the area represented by each node. The sum for all of the nodes of this product is the WUA. The WUA values for the sites in the Lower Alluvial segment were added together and multiplied by the ratio of total redds counted in the segment, excluding the 2-mile restoration reach, to the number of redds in the modeling sites for that segment to produce the total WUA in the Lower Alluvial segment, excluding the 2-mile restoration reach. The fall-run Chinook salmon and steelhead/rainbow trout multipliers were calculated using redd counts from, respectively, 2000-2005 and 2002-2006.

RESULTS

Study Segment Delineation

We 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 addressed spring-run Chinook salmon and steelhead/rainbow trout while the last segment where this study occurred addresses fall-run Chinook salmon and steelhead/rainbow trout.

Field Reconnaissance and Study Site Selection

After reviewing the field reconnaissance notes and considering time and manpower constraints, five study sites (Table 5, Appendix A) were selected for modeling in Lower Alluvial segment: 1) Shooting Gallery; 2) Lower Gorge; 3) Upper Renshaw; 4) Lower Renshaw; and 5) Upper Isolation.

Table 5. Top-ranked Lower Alluvial segment areas for fall-run Chinook salmon and steelhead/rainbow trout spawning based, respectively, on 2000-2005 and 2002-2006 redd survey data.

	Number of Redds										
	Fall-run Chinook salmon						Steelhead				
Site Name	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2002**	**2003**	**2004**	**2005**	**2006**
Shooting Gallery	0	8	12	1	6	23	2	2	3	0	0
Lower Gorge	5	7	91	133	98	137	3	0	8	1	0
Upper Renshaw	152	121	139	66	85	124	0	0	4	2	2
Lower Renshaw	310	369	311	413	488	567	0	0	15	20	19
Upper Isolation	87	80	39	69	75	95	0	0	1	2	3

Hydraulic and Structural Data Collection

All sites met the standard for level loops (Table 6). Errors for the horizontal benchmarks established by dual frequency survey-grade differential GPS were in all cases less than 0.021 feet (0.64 cm, Table 7). Water surface elevations were measured at all sites at the following flow ranges: 82-83 cfs, 151-259 cfs, 424-440 cfs, and 678-740 cfs. Depth and velocity measurements on the transects were collected at the Shooting Galley transects at 82 cfs, Lower Gorge transects at 83 cfs, Upper Renshaw transects at 259 cfs, Lower Renshaw transects at 151 cfs, and Upper Isolation transects at 153 cfs. The number and density of points collected for each site are given in Table 8.

Shooting Gallery validation velocities were collected at flows of 81 and 82 cfs, Lower Gorge validation velocities were collected at a flows of 83, 198 and 225 cfs, Upper Renshaw validation velocities were collected at flows of 225 and 259 cfs, Lower Renshaw validation velocities were collected at flows of 151 and 211 cfs, and Upper Isolation validation velocities were collected at flows of 153 and 212 cfs. While 50 validation velocities were collected at the other four sites, we only collected 49 validation velocities at Upper Renshaw due to an error in recording data in the field notebook.

Table 6. Level loop error results.

Site Name	Level Loop Distance (mi)	Level loop error (ft)	
		Allowable error	**Actual error**
Shooting Gallery	0.312 (0.187 km)	0.03 (0.009 m)	0.00 (0.00 m)
Lower Gorge	0.305 (0.183 km)	0.03 (0.009 m)	0.01 (0.003 m)
Upper Renshaw	0.237 (0.142 km)	0.02 (0.006 m)	0.00 (0.00 m)
Lower Renshaw	0.686 (0.412 km)	0.05 (0.015 m)	0.01 (0.003 m)
Upper Isolation	0.269 (0.161 km)	0.03 (0.009 m)	0.01 (0.003 m)

Table 7. Horizontal benchmark error results.

Site benchmark	Precision (US feet)	
	Horizontal	**Vertical**
Shooting Gallery HBM1	0.012 (0.37 cm)	0.017 (0.52 cm)
Shooting Gallery HBM2	0.012 (0.37 cm)	0.018 (0.55 cm)
Shooting Gallery HBM3	0.013 (0.40 cm)	0.019 (0.58 cm)
Lower Gorge HBM1	0.013 (0.40 cm)	0.021 (0.64 cm)
Lower Gorge HBM2	0.011 (0.33 cm)	0.015 (0.46 cm)
Lower Gorge HBM3	0.014 (0.43 cm)	0.020 (0.61 cm)
Lower Gorge HBM4	0.013 (0.40 cm)	0.017 (0.52 cm)
Lower Gorge VBM2	0.010 (0.30 cm)	0.012 (0.37 cm)
Upper Renshaw HBM1	0.009 (0.27 cm)	0.011 (0.33 cm)
Upper Renshaw HBM2	0.008 (0.24 cm)	0.012 (0.37 cm)
Upper Renshaw HBM3	0.012 (0.37 cm)	0.012 (0.37 cm)
Upper Renshaw HBM4	0.012 (0.37 cm)	0.017 (0.52 cm)
Upper Renshaw HBM5	0.011 (0.33 cm)	0.012 (0.37 cm)
Lower Renshaw HBM1	0.007 (0.21 cm)	0.011 (0.33 cm)
Lower Renshaw HBM2	0.014 (0.43 cm)	0.014 (0.43 cm)
Lower Renshaw TP2	0.013 (0.40 cm)	0.015 (0.46 cm)
Upper Isolation HBM1	0.014 (0.43 cm)	0.019 (0.58 cm)
Upper Isolation HBM2	0.011 (0.33 cm)	0.013 (0.40 cm)

Table 8. Number and density of data points collected for each study site.

Site Name	Number of Points: Points on Transects	Number of Points: Points Between Transects Collected with Total Station	Density of Points (points/100 m^2)
Shooting Gallery	68	1526	19.7
Lower Gorge	99	5984	82.8
Upper Renshaw	66	3078	70.5
Lower Renshaw	77	7592	39.3
Upper Isolation	61	4544	69.0

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

All five study sites had water flowing downhill at all of the measured flows. A total of five WSEL sets at low, medium, and high flows were used for Upper Renshaw and Upper Isolation, and four WSEL sets were used for Shooting Gallery and Lower Gorge. In the case of Lower Renshaw, we were only able to use three WSEL sets (151 cfs, 425 cfs, and 678 cfs) as a result of changes in the stage-discharge relationship that occurred after the earlier collection of WSEL sets at 84 cfs and 194 cfs. The change in the stage-discharge relationship was the result of alterations in the bed topography caused by fall-run Chinook salmon spawning that occurred during the fall of 2006. Calibration flows for the PHABSIM calibration were interpolated based on river mile between the gage flows for the Reading Bar and CC3A gages operated by Graham Matthews and Associates. Calibration flows in the PHABSIM data files and the SZFs used for each transect are given in Appendix B.

For all of the transects, *IFG4* met the criteria described in the methods for *IFG4* (Appendix B). With the exception of the Upper Renshaw upstream transect, none of the transects deviated significantly from the expected pattern of VAFs (Appendix C). A minor deviation in the expected pattern was observed with the Lower Renshaw downstream transect. In the case of the Upper Renshaw upstream transect, the VAF value decreased, rather than increased monotonically with increasing flows. VAF values for all transects (ranging from 0.48 to 3.01) were all within an acceptable range for all transects.

RIVER2D Model Construction

For the Lower Renshaw site, we put a "glass wall" in the lowest-most portion of the north bank of the site to exclude an off channel area from the site. The bed topography of the sites is shown in Appendix D. The finite element computational mesh (TIN) for each of the study sites is shown in Appendix E. As shown in Appendix F, the meshes for all sites had QI values of at least 0.30. The percentage of the original bed nodes for which the mesh differed by less than 0.1 foot (0.031 m) from the elevation of the original bed nodes ranged from 79.7% to 92.7% (Appendix F).

RIVER2D Model Calibration

The Shooting Gallery, Lower Renshaw and Upper Isolation sites were calibrated at 900 cfs, the highest simulation flow. In the cases of Lower Gorge and Upper Renshaw sites, we used the highest measured flow within the range of simulated flows because the simulated WSELs at the highest simulation flow of 900 cfs varied across the channel by more than 0.1 foot (0.031 m), thus resulting in the RIVER2D simulated WSELs differing from the PHABSIM simulated WSELs by more than 0.1 foot (0.031 m). The calibrated cdg files all had a solution change of less than 0.00001, with the net Q for all sites less than 1% (Appendix E). The calibrated cdg file for all study sites had a maximum Froude Number of greater than 1, with the exception of Upper Renshaw (Appendix E). All three study sites calibrated at 900 cfs had calibrated cdg files with WSELs that were within 0.1 foot (0.031 m) of the PHABSIM predicted WSELs (Appendix F). Of the two study sites calibrated at the highest measured flow, Upper Renshaw had a calibrated cdg file with WSELs that were within 0.1 foot (0.031 m). In the case of Lower Gorge, the average and maximum WSELs exceeded the 0.1 foot (0.031 m) criterion.

RIVER2D Model Velocity Validation

For all sites, there was a strong to very strong correlation between predicted and measured velocities (Appendix G). However, there were significant differences between individual measured and predicted velocities. The models for all of the study sites were validated, since the correlation between the predicted and measured velocities was greater than 0.6 for those sites. In general, the simulated and measured cross-channel velocity profiles at the upstream and downstream transects (Appendix G[15]) were relatively similar in shape, with some differences in magnitude that fall within the amount of variation in the Marsh-McBirney velocity measurements.

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[15] 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.

The Lower Gorge downstream transect was the one exception, with the model under-predicting the velocities on the south side of the channel and over-predicting the velocities on the north side of the channel.

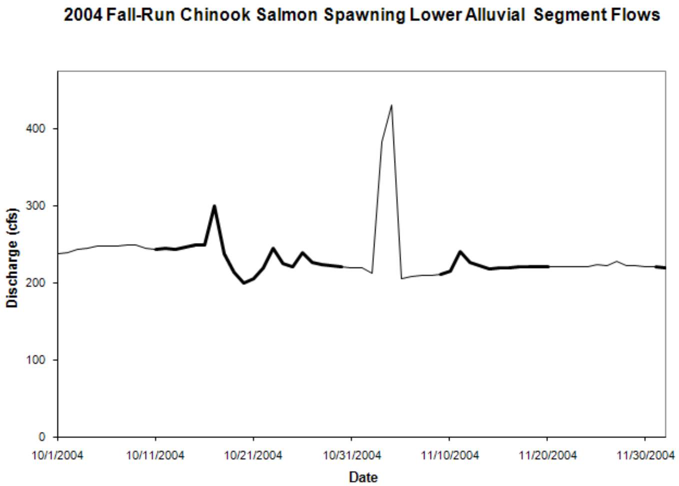
RIVER2D Model Simulation Flow Runs

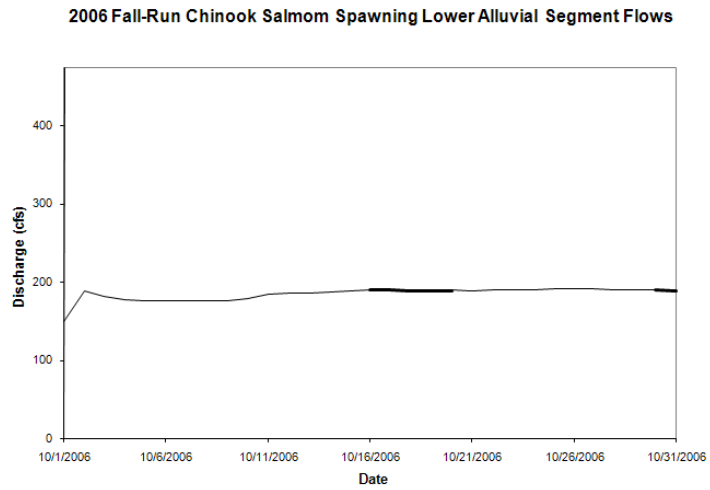
The simulation flows were 50 cfs to 300 cfs by 25 cfs increments and 300 cfs to 900 cfs by 50 cfs increments. The production cdg files all had a solution change of less than 0.00001. The net Q was less than 1% for four of the five sites. The exception was Lower Renshaw, with three flows that exceeded 1% (Appendix H). The maximum Froude Number was greater than one for all of the simulated flows for Shooting Gallery, Lower Renshaw, and Upper Isolation, 22 of the 23 simulated flows for Lower Gorge, and 15 of the 23 simulated flows for Upper Renshaw (Appendix H).

Habitat Suitability Criteria (HSC) Data Collection

The location of fall-run Chinook salmon depth and velocity measurements was generally about 4 to 8 feet (2.44 m) upstream of the pit of the redd; however on rare occasions it was necessary to make measurements at a 45 degree angle upstream. Depth, velocity, and substrate size data were collected for 123 fall-run Chinook salmon redds in the Lower Alluvial Segment of Clear Creek during surveys conducted October 10-October 29, 2004, November 9-November 19, 2004 and December 2, 2004. Data were collected for 174 fall-run Chinook salmon redds in the Lower Alluvial Segment of Clear Creek during surveys conducted October 20-28, 2005, November 1, 2005, and November 25, 2005. During 2006, data were collected for a total of 464 fall-run Chinook salmon redds in the Lower Alluvial Segment during surveys conducted October 16-19, 2006 and October 30-31, 2006.

During the 2004 fall-run Chinook salmon spawning period from October 1 through the end of the data collection on December 2, 2004, flows in the Lower Alluvial Segment remained relatively constant, ranging primarily between 200-299 cfs, with the exception of November 3-4, 2004 when flows averaged 382 and 430 cfs. During the 2005 fall-run Chinook salmon spawning period from October 1 through the end of the data collection on November 25, 2005, flows in the Lower Alluvial Segment remained relatively constant, ranging primarily between 200-263 cfs, with the exception of November 16-17, 2005 when flows averaged 456 and 388 cfs. The spike in flows that occurred over a two day period in 2004 and 2005 was due to special releases scheduled in order to gather middle and high flow water surface elevations on study site transects. During the 2006 fall-run Chinook salmon spawning period from October 1 through the end of the data collection on October 31, 2006, flows in the Lower Alluvial Segment again remained relatively constant, ranging between 149 and 191 cfs (Figure 4).





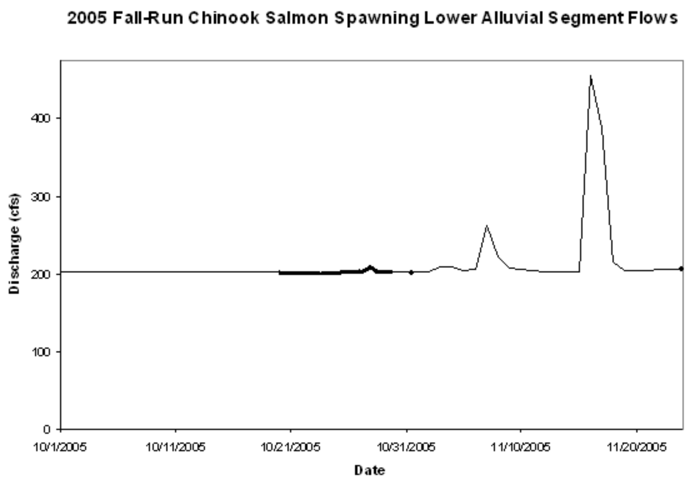


Figure 4. 2004-2006 flows in the Lower Alluvial Segment during the fall-run Chinook salmon spawning data collection. The thicker lines show the sampling periods.

The steelhead/rainbow trout HSC used in this study were based on data collected in the Upper Alluvial and Canyon reaches during the phase one spawning study (U.S. Fish and Wildlife Service 2007).

Biological Verification Data Collection

During the fall-run Chinook salmon redd surveys on October 16-19, 2006, we collected data for 10 redds at Shooting Gallery, 68 redds at Lower Gorge, 72 redds at Upper Renshaw, 226 redds at Lower Renshaw, and 66 redds at Upper Isolation, for a total of 442 redds for the surveys done during that time period. During the fall-run Chinook salmon redd surveys on October 30-31, 2006, we collected data for 1 redd at Shooting Gallery and 21 redds at Lower Gorge for a total of 22 redds for the surveys done during that time period**.**

Habitat Suitability Criteria (HSC) Development

The coefficients for the final logistic regressions for depth and velocity for fall-run Chinook salmon are shown in Table 9. The p values for all of the non-zero coefficients in Table 9 were less than 0.05, as were the p values for the overall regressions.

The initial fall-run Chinook salmon HSC showed suitability rapidly decreasing for depths greater than 1.1 feet (0.34 m). Suitable velocities for fall-run Chinook salmon spawning were between 0.95 and 4.15 ft/sec (0.29 and 1.26 m/sec), while suitable substrate codes were 1.3 and 2.4. The results of the initial regressions showed that availability dropped with increasing depth, but not as quickly as use (Figure 5) The result of the final regression conducted to modify the HSC depth curve to account for the low availability of deep water having suitable velocities and substrate was that the scaled ratio reached zero at 6.7 feet (2.04 m): thus, the fall-run Chinook salmon depth criteria were modified to have a linear decrease in suitability from 1.1, the greatest depth in the original criteria which had a suitability of 1.0, to a suitability of 0.0 at 6.7 feet (2.04 m).

The results of the logistic regression for velocity were biologically unrealistic (Figure 6), with an optimal velocity of 6.3 ft/s (1.92 m/s). Accordingly, we developed the velocity criteria solely from the use data. We modified the upper end of the resulting criteria (by eliminating all of the points in between 2.04 and 6.31 ft/sec (0.62 and 1.92 m/sec)) to increase the suitability of faster conditions, since the logistic regression indicated that use was being largely controlled by availability. This resulted in the velocity suitability decreasing linearly from a suitability of 0.99 at 2.04 ft/sec (0.62 m/sec) to a suitability of 0 at 6.31 ft/sec (1.92 m/sec). The final depth and velocity criteria for fall-run Chinook salmon, along with the frequency distributions of occupied and unoccupied locations, are shown in Figures 7-8 and Appendix I. The final fall-run Chinook substrate criteria are shown in Figure 9 and Appendix I. The steelhead/rainbow trout spawning criteria from (U.S. Fish and Wildlife Service 2007) are given in Appendix I.

Table 9. Logistic regression coefficients and R^2 values. The R^2 values are McFadden's Rho-squared values.

parameter	I	J	K	L	M	R^2
depth	-7.239688	18.717276	-15.898104	5.384454	-0.640331	0.08
velocity	-2.863829	2.794626	-0.792777	0.070910	--	0.08

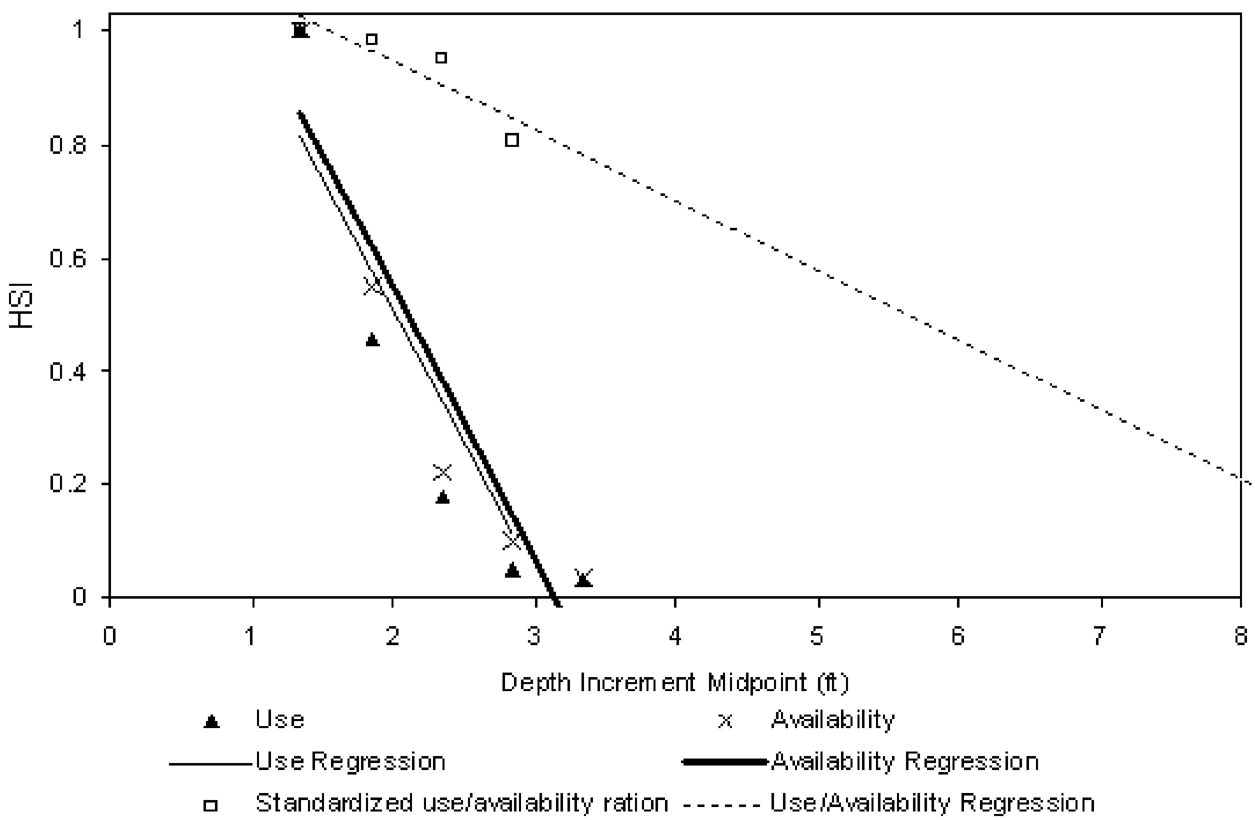


Figure 5. Relations between availability and use and depth for fall-run Chinook salmon. Points are relative use, relative availability, or the standardized ratio of linearized use to linearized availability. Lines are the results of the linear regressions of the depth increment midpoint versus relative availability, relative use, and the standardized ratio of linearized use to linearized availability. The availability dropped with increasing depth, but not as quickly as use. The use-availability regression reached zero at 6.7 feet (2.04 m).

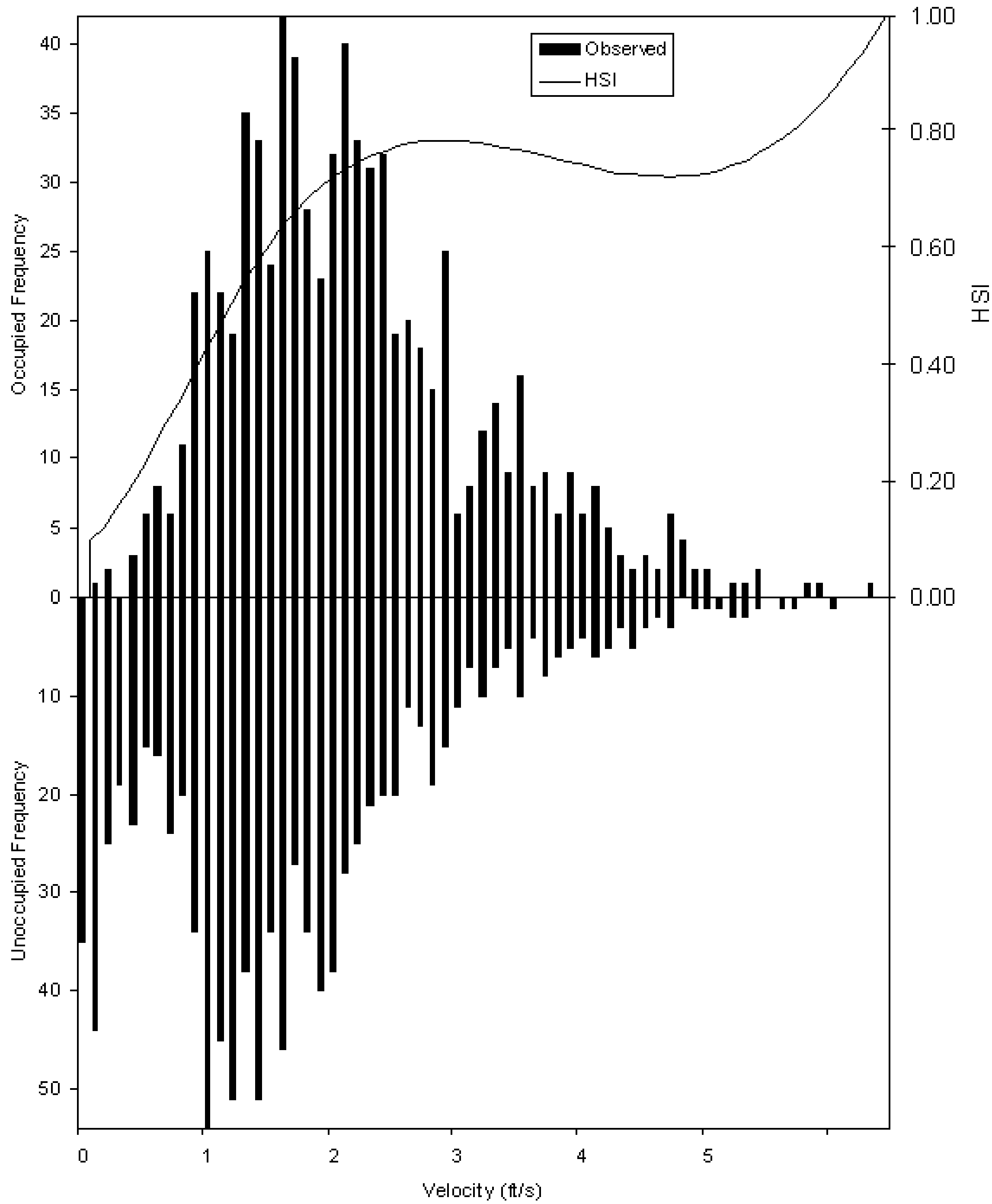


Figure 6. Fall-run Chinook salmon spawning velocity HSC using occupied and unoccupied data. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for velocities of 0.10 to 6.30 ft/sec (0.03 and 1.92 m/sec) and an optimum suitability at velocity of 6.30 ft/sec (1.90 m/sec).

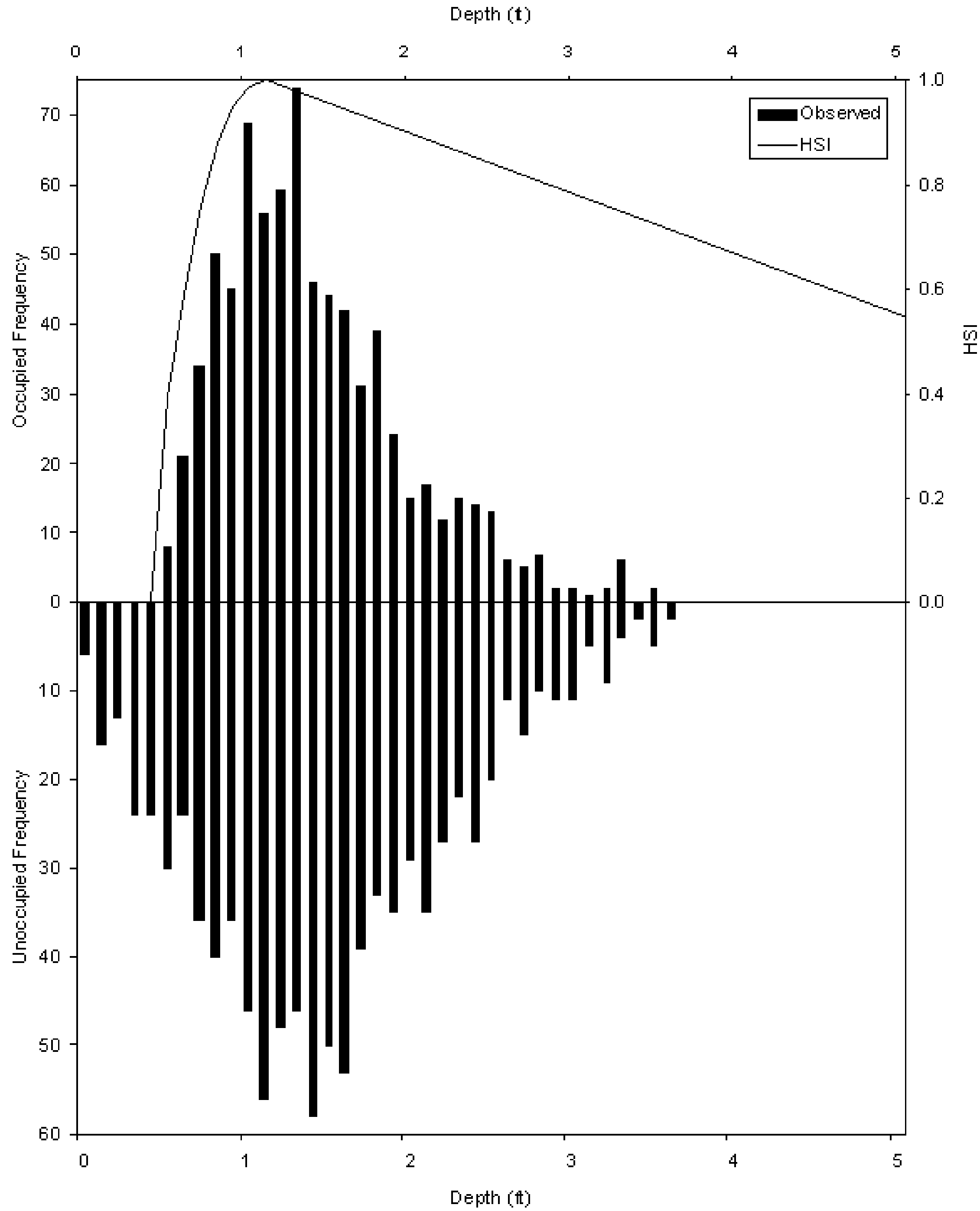


Figure 7. Fall-run Chinook salmon spawning depth HSC. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for depths of 0.5 to 6.7 feet (0.15 to 2.04 m) and an optimum suitability at a depth of 1.1 feet (0.34 m).

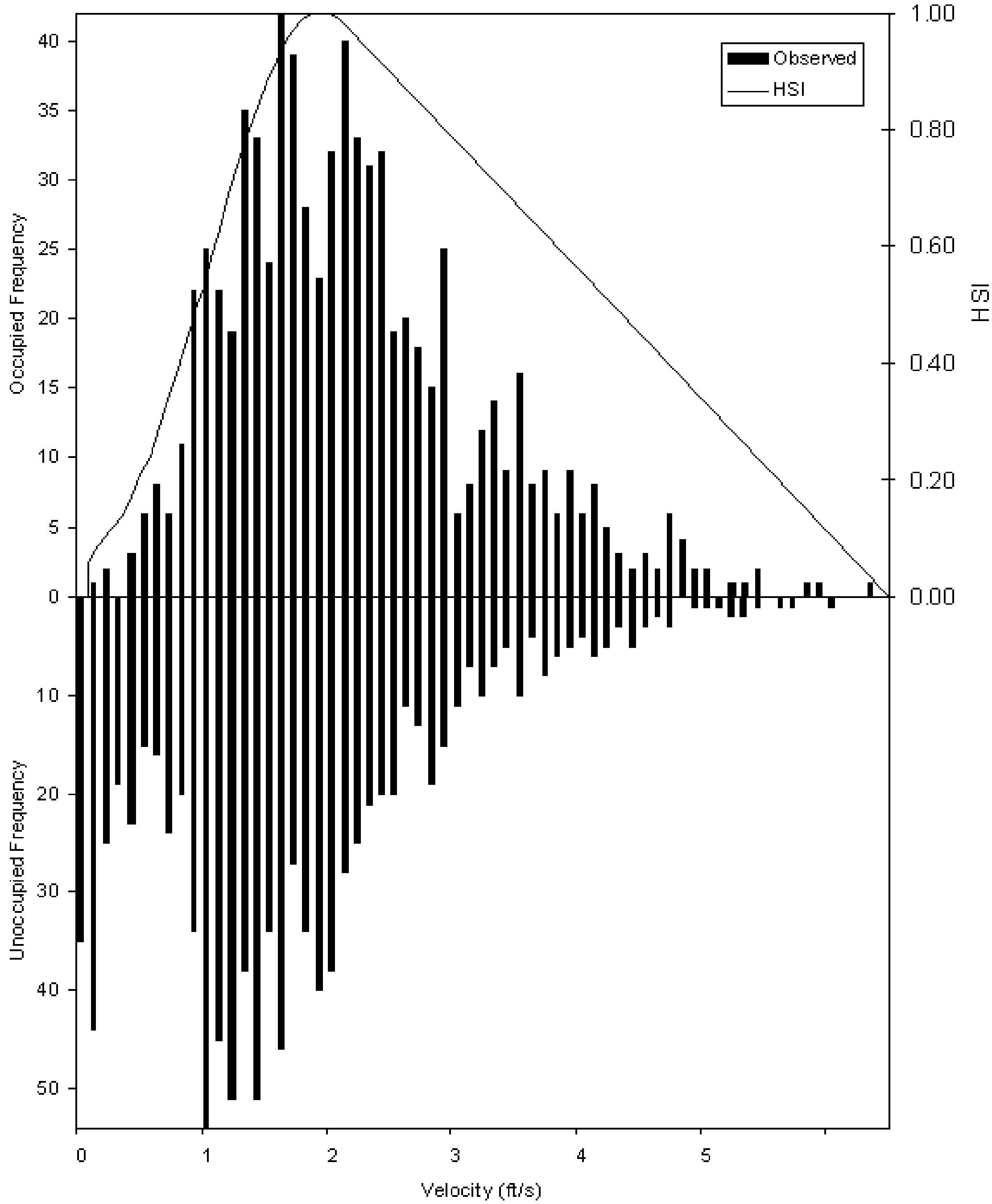


Figure 8. Fall-run Chinook salmon spawning velocity HSC using only occupied data. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for velocities of 0.10 to 6.30 ft/sec (0.03 and 1.92 m/sec) and an optimum suitability at velocity of 1.83 to 1.97 ft/sec (0.56 to 0.60 m/sec).

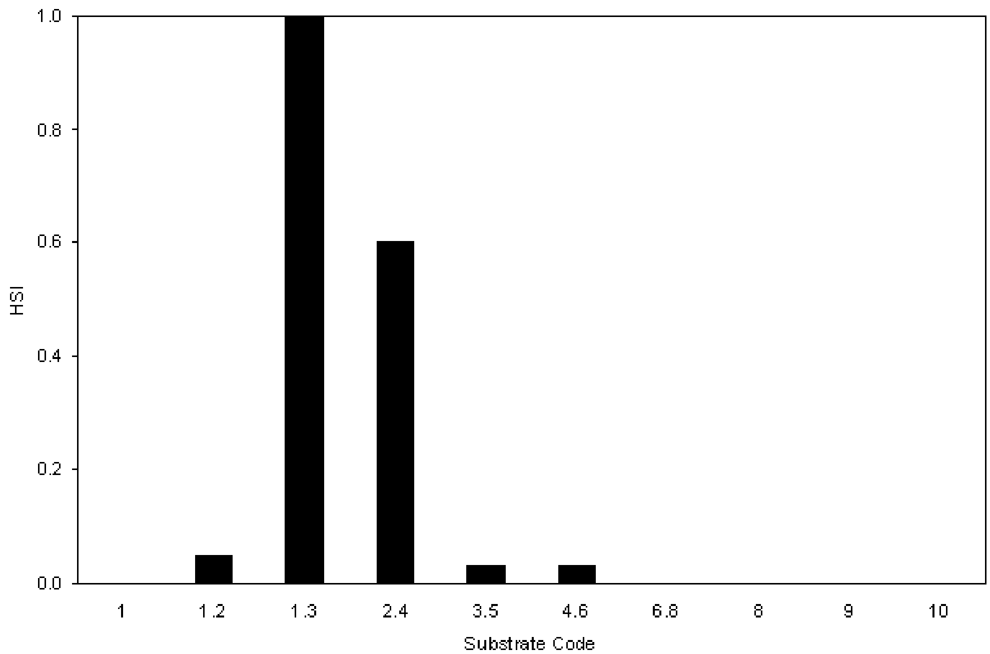


Figure 9. Fall-run Chinook salmon HSC for substrate. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for substrate codes 1.2 to 4.6 and an optimum suitability for substrate code 1.3.

Biological Verification

For fall-run Chinook salmon, the combined habitat suitability predicted by the 2-D model (Figure 10) was significantly higher for locations with redds (median = 0.38, n = 464) than for locations without redds (median = 0.12, n = 1436), based on the Mann-Whitney U test (U = 238843, $p < 0.000001$). A greater number in the suitability index indicates greater suitability. The location of fall-run Chinook salmon redds relative to the distribution of combined suitability is shown in Appendix J. The 2-D model predicted that 55 of the 464 (11.8%) redd locations had a combined suitability of zero. Fifty had a combined suitability of zero due to the predicted substrate being too small (substrate code of 0.1), 3 had a combined suitability of zero due to the predicted substrate being too large (substrate codes of 9 and 10), and 2 had a combined suitability of zero due to the predicted depth being too low (depth less than 0.5 foot (0.15 m).

Habitat Simulation

The WUA values calculated for each site are contained in Appendix K. The ratios of total redds counted in the Lower Alluvial segment, excluding the two-mile restoration reach, to number of redds in the modeling sites for that segment were as follows: fall-run Chinook salmon = 1.92;

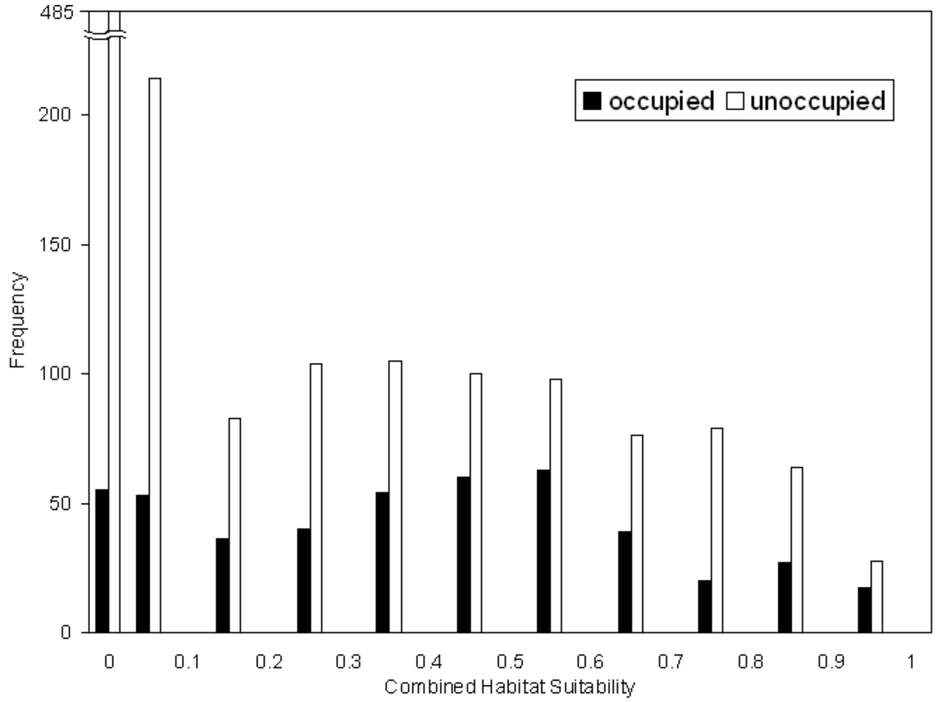


Figure 10. Combined suitability for 2-D model locations with (occupied) and without (unoccupied) fall-run Chinook salmon redds. The median combined suitability for occupied and unoccupied locations was, respectively, 0.41 and 0.03.

steelhead/rainbow trout =1.28. The flow habitat relationships, by species, are depicted in Figures 11 and 12 and Appendix K. The 2-D model predicts the highest total WUA for both fall-run Chinook salmon and steelhead/rainbow trout spawning in the Lower Alluvial segment at 300 cfs.

DISCUSSION

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

For the Upper Renshaw upstream transect and the Lower Renshaw downstream transect, the model, in mass balancing, was decreasing water velocities at high flows so that the known discharge would pass through the increased cross-sectional area. We concluded that this phenomena was caused by channel characteristics which form hydraulic controls at some flows but not others (compound controls), thus affecting upstream water elevations. Accordingly, the performance of IFG4 for these transects was considered adequate despite unusual VAF pattern. We did not regard the deviation in the VAF values for these transects as problematic since RHABSIM was only used to simulate WSELs and not velocities.

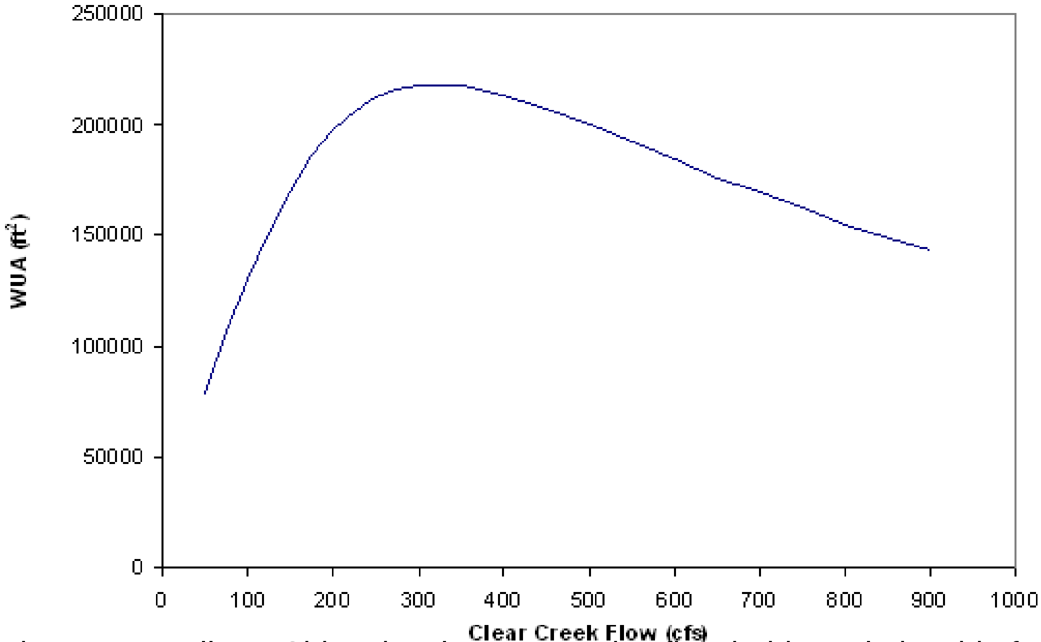


Figure 11. Fall-run Chinook salmon spawning flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum fall-run Chinook salmon spawning habitat was 300 cfs.

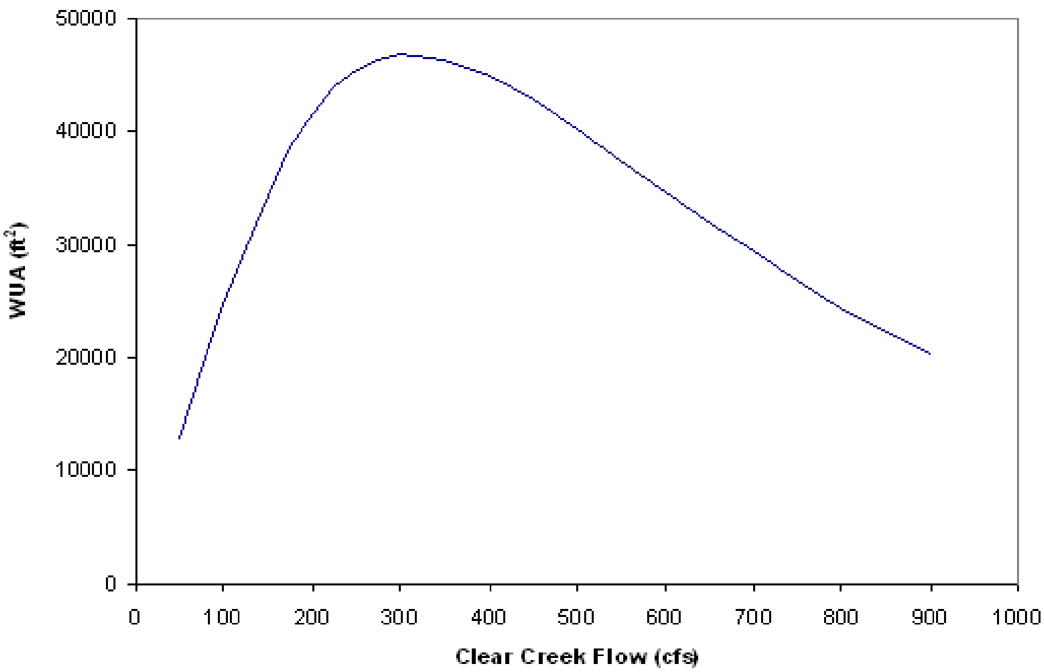


Figure 12. Steelhead/rainbow trout spawning flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum steelhead/rainbow trout spawning habitat was 300 cfs.

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 (0.30 m) horizontally of the bed file location. Given that we had a 1-foot (0.30 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file.

RIVER2D Model Calibration

In general, Lower Gorge and Upper Renshaw sites at the highest simulated flow had WSELs on the two banks that differed by more than 0.1 foot (0.031 m). In both cases, we were uncertain which model was responsible for the discrepancies between the WSELs predicted by RIVER2D and PHABSIM. As a result, we felt that it would be more accurate to calibrate these sites using the measured WSELs for the highest flow within the range of simulated flows. 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. However, when we have concluded, as for these sites, that the simulation of the WSEL at the upstream transect at the highest simulation flow by PHABSIM is potentially inaccurate, it no longer makes sense to calibrate RIVER2D using the WSELs simulated by PHABSIM at the highest simulation flow. In these cases, we use the fall-back option of calibrating RIVER2D using the WSELs measured at the highest flow within the range of simulation flows.

We considered the solution to be acceptable for the study site cdg files which had a maximum Froude Number greater than 1, since the Froude Number only exceeded one at a few nodes, with the vast majority of the site having Froude Numbers less than one. 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. The average and maximum difference between measured and simulated WSELs for Lower Gorge exceeded the 0.1 foot (0.031 m) criterion. However, at the 705 cfs flow at which the WSELs were measured, we were only able to take a measurement next to the right bank due to safety concerns. The WSELs simulated in this portion of the upstream transect were within 0.02 foot (0.01 m) of the measured value. Because of this result and since the simulated left bank WSELs only a short distance (approximately 4 feet (1.22 m)) downstream of the upstream transect were also found to be within 0.1 foot (0.031 m) of the measured, the calibration was considered acceptable.

RIVER2D Model Velocity Validation

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; (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 on the transects 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[16]. As shown in the figures in Appendix G, we attribute most of the differences between measured and predicted velocities to noise in the measured velocity measurements; specifically, for the transects, the simulated velocities typically fell within the range of the measured. 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. For the Lower Gorge downstream transect where RIVER2D over or under-predicted the velocities on both sides of the channel, we attribute this to errors in the bed topography that did not properly characterize features that resulted in faster/slower velocities. There was a long, deep pool and a vertical rock wall on one side of the channel just upstream of the downstream transect. These features may have hindered the collection of the density of points necessary to properly characterize the bed in that area. Further supporting this assessment, the measured discharge at the Lower Gorge downstream transect using the above validation velocities only differed from the actual discharge, based on gage readings, by 0.1 %.

RIVER2D Model Simulation Flow Runs

Two of the three lowest simulation flow run cdg files for Lower Renshaw, 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. In the case of the Lower Renshaw lowest flow production cdg file, where the net Q significantly exceeded the 5% level, we consider that a level of uncertainty applies to results for that production file. We attribute the high net Q in this case to an eddy that the model generated at the downstream boundary (Figure 13). It is likely that we could have reduced the net Q for this file by adding a downstream extension onto the hydraulic model.

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[16] 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.

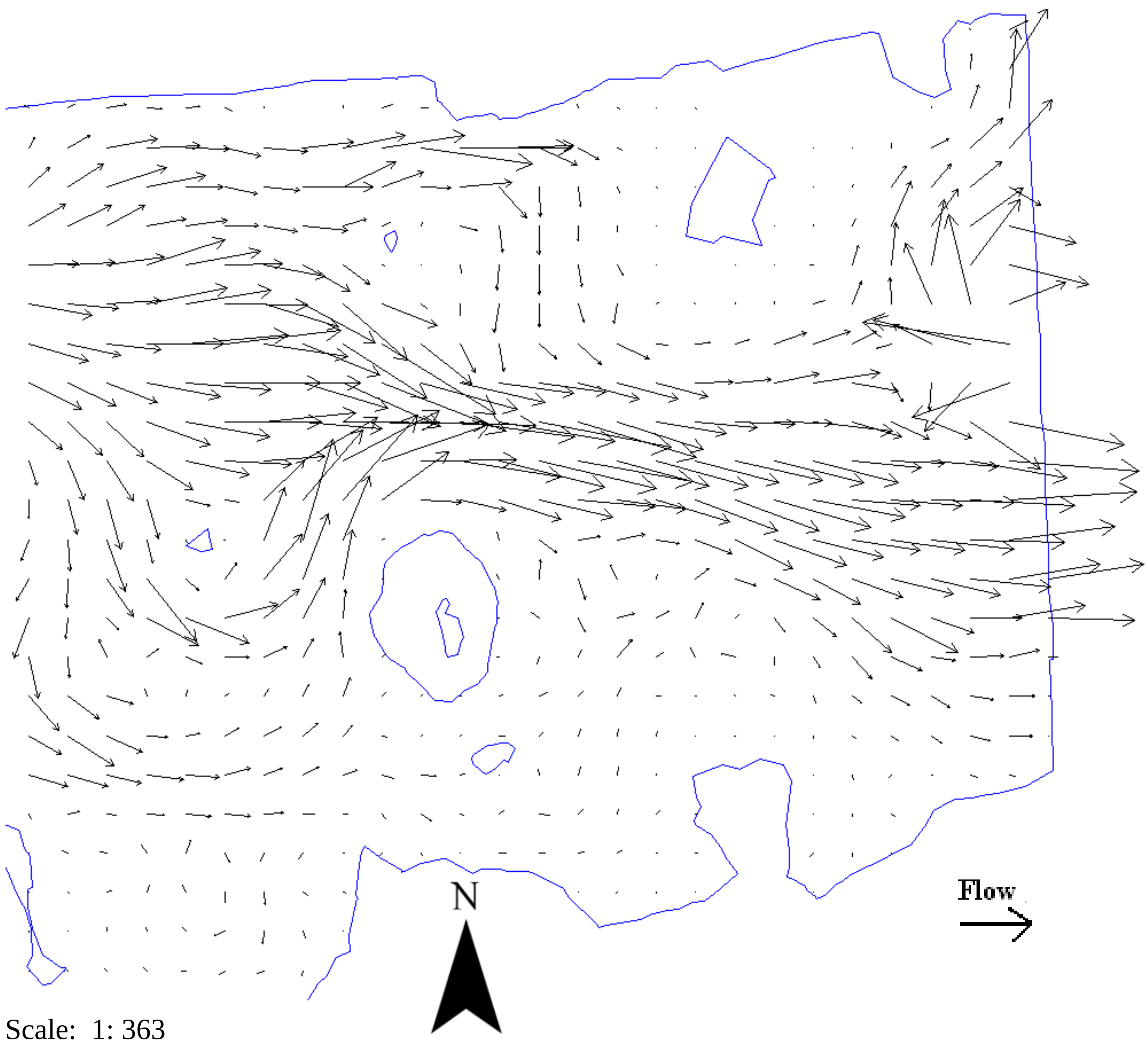


Figure 13. Velocity vectors (black arrows) near the downstream boundary (right side of figure) of Lower Renshaw site at 50 cfs. An eddy (velocity vectors going upstream) is shown in the middle of the boundary. Blue lines denote water's edge – at this flow, there were several exposed gravel/cobble bars in the channel at this location.

Although a majority of the simulation flow files had Max Froude values that exceeded 1, we considered these production runs to be acceptable since the Froude Number was only greater than 1 at a few nodes, with the vast majority of the area within the site having Froude Numbers less than 1. 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.

Habitat Suitability Criteria (HSC) Data Collection

Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. The steady flow conditions increased the likelihood tha the measured depths and velocities were the same as present during redd construction. In addition, for the 2004 and 2005 data, the Red Bluff Office staff were conducting spawning surveys approximately every 2 weeks and thus any redds measured were constructed within the last 2 weeks, further increasing the likelihood tha the measured depths and velocities were the same as those present during redd construction. In 2006, almost all of the redd measurements were made just over 2 weeks after the beginning of the fall-run Chinook salmon spawning period (October 1), again further increasing the likelihood that the measured depths and velocities were the same as those present during redd construction.

Habitat Suitability Criteria (HSC) Development

It should be noted that the regressions for depth and velocity were fit to the raw occupied and unoccupied data, rather than to the frequency histograms shown in Figures 6 to 8. In general, the fall-run Chinook salmon final depth and velocity 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. The R^2 values in Table 9 in general reflect the large degree of overlap in occupied and unoccupied depths and velocities, as shown in Figures 6 to 8. In particular, except for low velocities, the frequency distributions of occupied and unoccupied velocities were almost identical, resulting in the biologically unrealistic logistic regression curve shown in Figure 6. The optimal velocity for spawning should be at intermediate velocities, since bioenergetic considerations and physical abilities of adult salmonids will limit the maximum velocity used for spawning, while requirements of the developing eggs and larvae for sufficient intragravel velocities will set a lower limit on the velocity used for spawning (Gard 1998). Accordingly, criteria that predict optimum suitability at the highest velocities (as shown in Figure 6) are biologically unrealistic. We conclude in this case that the logistic regression technique could not be used to develop velocity criteria because of the almost identical frequency distribution of occupied and unoccupied velocities. However, the logistic regression for velocity clearly demonstrated that the use of higher velocities (greater than 2 ft/sec (0.61 m/sec)) was significantly constrained by the limited availability of these higher velocities. Specifically, the substantial divergence of the logistic regression curve and use data for velocities greater than 2.5 ft/sec (0.76 m/sec) indicates that use was significantly constrained by availability. Accordingly, criteria solely based on use data would significantly underestimate the preference of spawning fall-run Chinook salmon for velocities greater than 2 ft/sec (0.61 m/sec). Since we were unable to use a logistic regression to develop the velocity criteria, modifying the upper end of the use-based criteria to increase the suitability of faster conditions was the only method we had available to correct for the effect of low availability of faster conditions, as shown by the logistic regression.

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 and substrate. 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.

The logistic regressions clearly showed that there was a significant influence of depth and velocity on use or nonuse with the range of overlapping conditions, since the p-values for the logistic regressions and the p-values for the individual terms of the logistic regressions were all less than 0.05. Accordingly, we conclude that depth and velocity do not act as boundary conditions for use given that all other spawning conditions are suitable (i.e., substrate composition, permeability, and intragravel velocities). Binary criteria are generally biologically unrealistic – they either overestimate the habitat value of marginal conditions if the binary criteria are broadly defined (for example, setting suitability equal to 1.0 for any depths and velocities where the original HSI value was greater than 0.1) or completely discount the habitat value of marginal conditions. The latter case would be biologically unrealistic since many redds would be in areas which would be considered completely unsuitable from the binary criteria.

The rapidly decreasing suitability of the initial fall-run depth criteria for depths greater than 1.1 feet (0.34 m) was likely due to the low availability of deeper water with suitable velocities and substrates in Clear Creek at the spawning flows rather than a selection by fall-run Chinook salmon of only shallow depths for spawning.

Figures 14 to 16 compare the two sets of HSC from this study. In general, steelhead/rainbow trout selected deeper conditions with a narrower range of velocities and smaller substrates than fall-run Chinook salmon. We attribute the faster velocities and larger substrates selected by fall-run Chinook salmon to the larger adult size of fall-run Chinook salmon, versus steelhead/rainbow trout. Bioenergetic considerations and physical abilities of adult salmonids will limit the maximum velocity used for spawning, while requirements of the developing eggs and larvae for sufficient intragravel velocities will set a lower limit on the velocity used for spawning (Gard 1998). It is logical that Chinook salmon, with larger body sizes, could construct

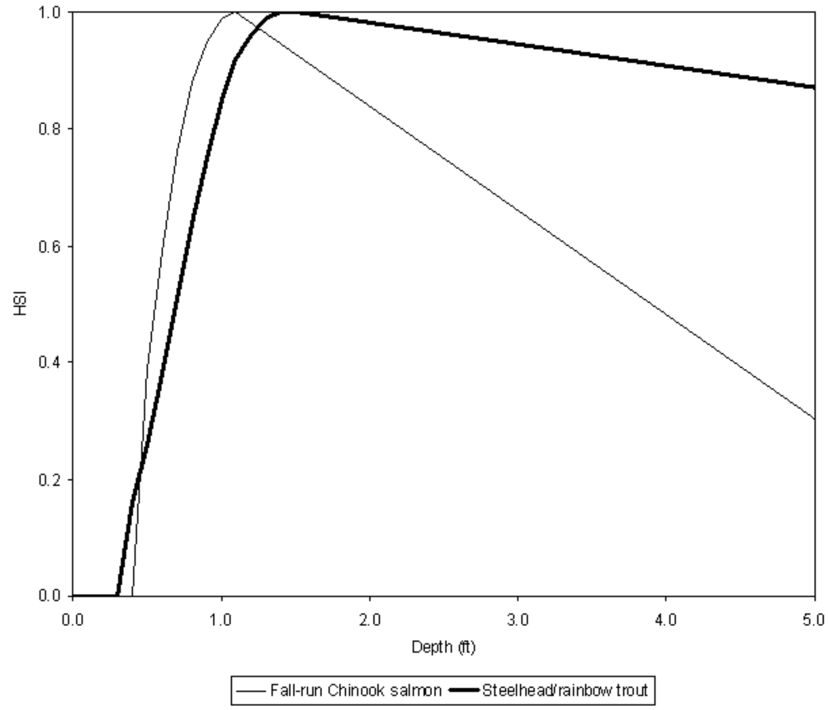


Figure 14. Comparison of depth HSC from this study. These criteria indicate that steelhead/rainbow trout selected deeper conditions than fall-run Chinook salmon.

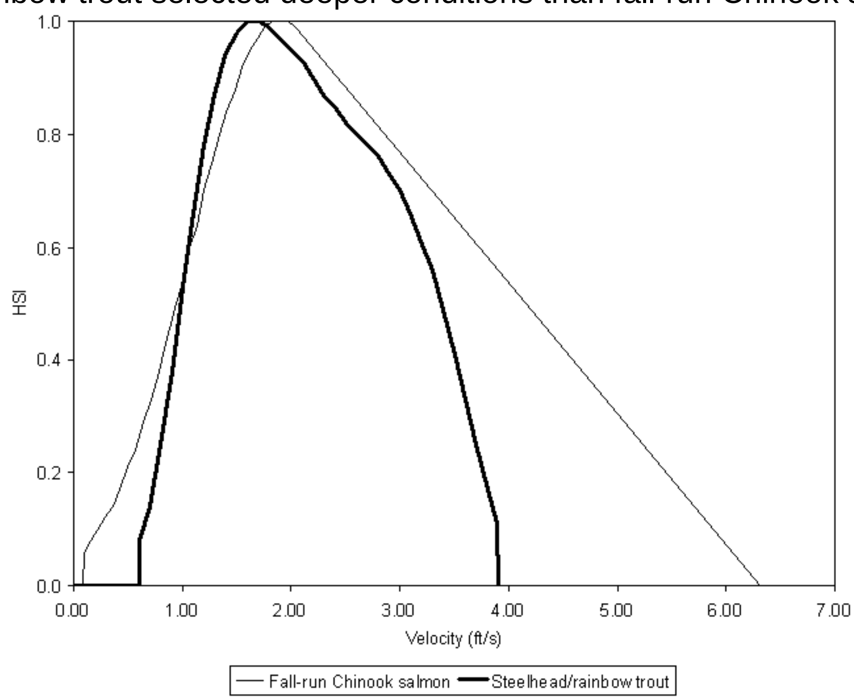


Figure 15. Comparison of velocity HSC from this study. These criteria indicate that fall-run Chinook salmon selected a wider range of velocities than steelhead/rainbow trout.

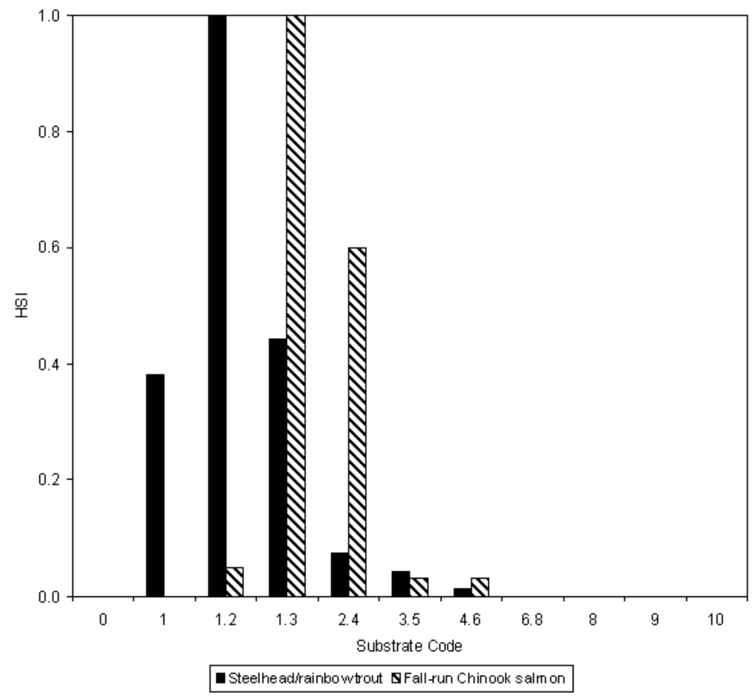


Figure 16. Comparison of substrate HSC from this study. These criteria indicate that steelhead/rainbow trout selected smaller substrates than fall-run Chinook salmon.

redds in faster conditions and with larger substrate sizes, than the smaller steelhead/rainbow trout. Similarly, the larger egg size of Chinook salmon would require higher intragravel velocities, versus the smaller eggs of steelhead/rainbow trout. This would translate to Chinook salmon constructing their redds in faster conditions and with larger substrate sizes than steelhead/rainbow trout. We attribute the wider range of velocities selected by fall-run Chinook salmon also to the larger population size of fall-run Chinook salmon, versus steelhead/rainbow trout; with a larger population size, it is likely that some of the fall-run were forced to use less-optimal conditions, while the steelhead/rainbow trout were able to use only more optimal conditions since there was less competition for spawning habitat.

Figures 17 to 19 compare the fall-run Chinook salmon criteria from this study with fall-run Chinook salmon criteria from other studies. For depth and velocity, we compared the criteria from this study with criteria developed on Battle Creek (Vogel 1982) and those used on the Feather River (California Department of Water Resources 2004); these were the only other criteria we were able to identify, other than those we have developed, which were from the northern portion of the Sacramento Valley. The Vogel (1982) criteria were also used on a previous instream flow study on Clear Creek (California Department of Water Resources 1985). We also compared the depth and velocity criteria with those from Bovee (1978), since these criteria are commonly used in instream flow studies as reference criteria. For substrate, we were limited to comparing the criteria from this study to criteria we had developed on other studies,

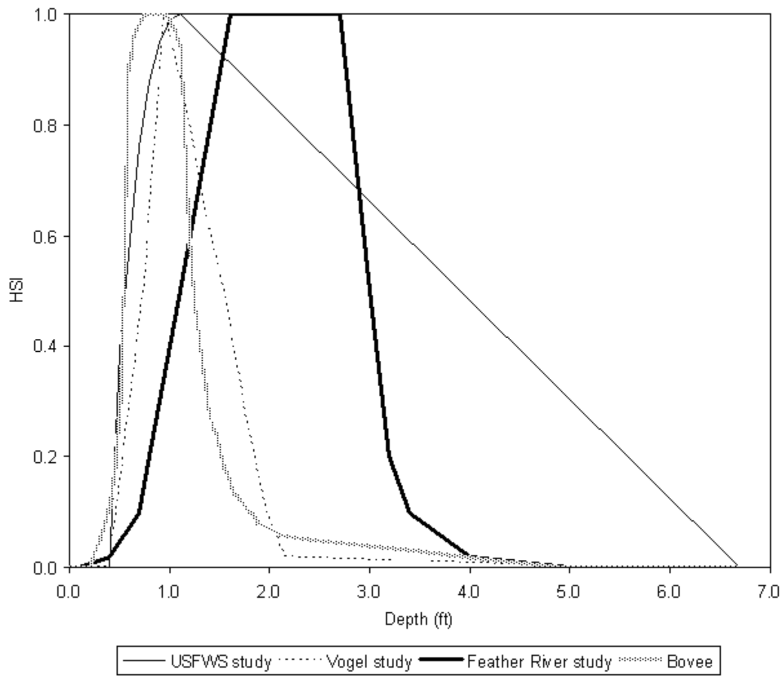


Figure 17. Comparison of fall-run Chinook salmon depth HSC from this study with other fall-run Chinook salmon spawning depth HSC. The criteria from this study show a slower decline in suitability with increasing depth than those from other studies.

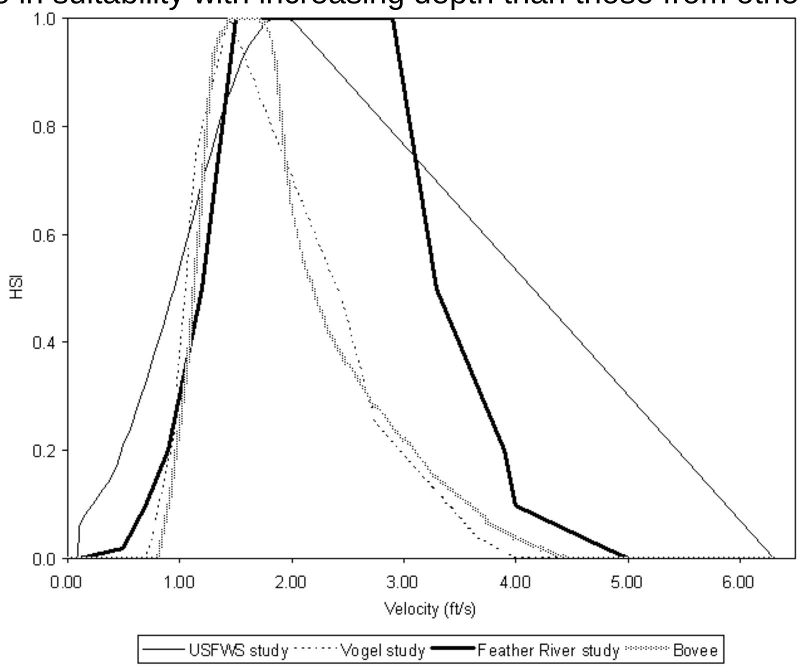


Figure 18. Comparison of fall-run Chinook salmon velocity HSC from this study with other fall-run Chinook salmon spawning velocity HSC. The criteria from this study show non-zero suitability extending to higher velocities than the criteria from other studies.

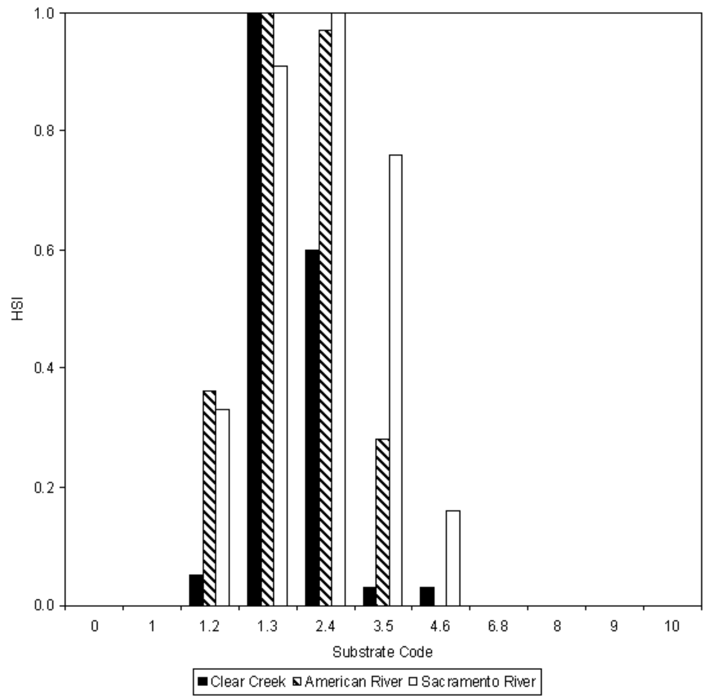


Figure 19. Comparison of fall-run Chinook salmon substrate HSC from this study with other fall-run Chinook salmon spawning substrate HSC.

due to the unique substrate coding system we used. We compared the fall-run Chinook salmon spawning criteria from this study to those we had developed for fall-run Chinook salmon on the Sacramento River (Gard 2006) and on the American River (Gard 1998).

The fall-run Chinook salmon depth criteria from this study show a slower decline in suitability with increasing depth. We attribute this to the use in this study of the Gard (1998) method to correct for availability, and that the other sets of criteria underestimate the suitability of deeper waters. The fall-run Chinook salmon velocity criteria from this study show a non-zero suitability extending to higher velocities than the criteria from other studies. We attribute this to observing fall-run Chinook salmon redds at velocities as high as 6.3 ft/sec (1.92 m/sec), while the other studies must not have had any redds at velocities greater than 5 ft/sec (1.52 m/sesc), the highest velocity with non-zero suitability from any of the other studies. In addition, the Vogel (1982) criteria were based on velocities measured at 0.5 foot (0.15 m) from the substrate, rather than on mean column velocities. The velocity at 0.5 foot (0.15 m) off the bottom would be expected to be less than the mean column velocity for depths greater than 1.2 feet (0.37 m). As a result, the Vogel (1982) velocity criteria are biased towards lower velocities. The fall-run Chinook salmon spawning substrate criteria from this study are relatively similar to the criteria from other studies, although the Clear Creek fall-run Chinook salmon showed a much lower suitability for substrate codes other than 1.3 and 2.4 than the fall-run Chinook salmon in other streams. We conclude that this pattern is likely due to the greater availability of 1 to 3 and 2 to 4 inch (2.5 to 7.5 and 5 to 10 cm) substrate in Clear Creek, versus the Sacramento and American Rivers, allowing the Chinook salmon to minimize their use of other substrate classes.

Biological Verification

The plots of combined suitability of redd locations in Appendix L are similar to the methods used for biological verification in Hardy and Addley (2001). In general, Hardy and Addley (2001) found a better agreement between redd locations and areas with high suitability than we found in this study. We attribute this difference to Hardy and Addley's (2001) use of polygons to map substrate. We feel that our results could have been as good as Hardy and Addley's (2001) if we had mapped substrate polygons using a total station or RTK GPS.

The statistical tests used in this report for biological verification differ from those used in Guay et al. (2000). In Guay et al. (2000), biological verification was accomplished by testing for a statistically significant positive relationship between fish densities, calculated as the number of fish per area of habitat with a given range of habitat suitability (i.e. 0 to 0.1), and habitat quality indexes. We were unable to apply this approach in this study because of the low number of redds and low area of habitat with high values of habitat quality. As a result, the ratio of redd numbers to area of habitat for high habitat quality values exhibits significant variation simply due to chance. Both the number of redds and amount of habitat at high values of habitat quality is quite sensitive to the method used to calculate combined suitability. When combined suitability is calculated as the product of depth, velocity and substrate suitability, as is routinely done in instream flow studies, there will be very low amounts of high habitat quality values. For example, if depth, velocity and substrate all have a high suitability of 0.9, the combined suitability would be only 0.7. In contrast, Guay et al. (2000) calculated combined suitability as the geometric mean of the individual suitabilities; for the above example, the combined suitability calculated as a geometric mean would be 0.9.

We did not use a parametric test to determine whether the combined suitability predicted by River2D was higher at occupied than unoccupied locations because the assumption of normality of parametric tests was violated, as shown in Figure 10, indicating the need to use nonparametric tests. Nonparametric statistical methods were appropriate to use with the large, unbalanced sample size of this study to reduce type II errors, since unoccupied depths, velocities and substrates have a much greater range of values than occupied depths, velocities and substrates. Analogously, Thomas and Bovee (1993) found that a minimum of 55 occupied and 200 unoccupied locations were required to reduce type II errors. We view the biological verification as successful because there was a greater suitability for occupied versus unoccupied locations, which has the biological significance that fish are preferentially selecting locations with higher suitability. The successful biological verification in this study increases the confidence in the use of the flow-habitat relationships from this study for fisheries management in Clear Creek.

Habitat Simulation

There was some variation from site to site in the flow-habitat relationships shown in Appendix K. For example, the maximum habitat for fall-run Chinook salmon spawning ranged from 250 cfs for Shooting Gallery to 450 cfs for Lower Gorge. We attribute these differences to variations in the cross-sectional profiles at the study sites. Shooting Gallery, which was relatively shallow, had the smallest cross-sectional profile and thus had optimal velocities at a lower flow than Lower Gorge, which was much deeper and thus had the largest cross-sectional profile. The overall flow-habitat relationships, as shown in Figures 11 and 12, capture the inter-site variability in flow-habitat relationships by summing the amount of habitat for all of the sites within the Lower Alluvial segment.

An earlier study (California Department of Water Resources 1985) also modeled fall-run Chinook salmon and steelhead spawning habitat in Clear Creek between Whiskeytown Dam and the confluence with the Sacramento River for flows of 40 to 500 cfs. A representative reach approach was used to place transects, instead of only placing sites for spawning in heavy spawning-use areas. PHABSIM was used to model habitat, instead of two-dimensional models. As shown in Figures 20 and 21, the results from this study predict smaller amounts of habitat at all flows and a peak amount of habitat at the same or slightly higher flows than the California Department of Water Resources (1985) study. The difference between studies in the flow with the peak amount of habitat varied by species. 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 apply the method used in this report for correcting depth HSC for availability; 3) sites for the California Department of Water Resources (1985) study were placed using a representative reach approach, as opposed to only placing sites in high-spawning-use areas, as was employed in this study; and 4) 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 slightly biased towards lower flows, since the HSC, generated only from use data and without correcting depth HSC for availability, were biased towards slower and shallower conditions. We conclude that the difference in criteria are responsible for most of the differences between the two studies. We attribute the remainder of the difference between the two studies to a combination of using 2-D versus PHABSIM and modeling only high-use spawning areas. Using a representative reach-based approach for modeling spawning habitat fails to take into account salmonids' preference for spawning in areas with high gravel permeability (Vyverberg et al 1996), while having sites only in high-use spawning areas indirectly takes into account preference for high gravel permeability (Gallagher and Gard 1999). The assumption is that high-use spawning areas have high gravel permeability since salmonids are selecting these areas for spawning. We attribute the difference in magnitude of the results from this study versus California Department of Water

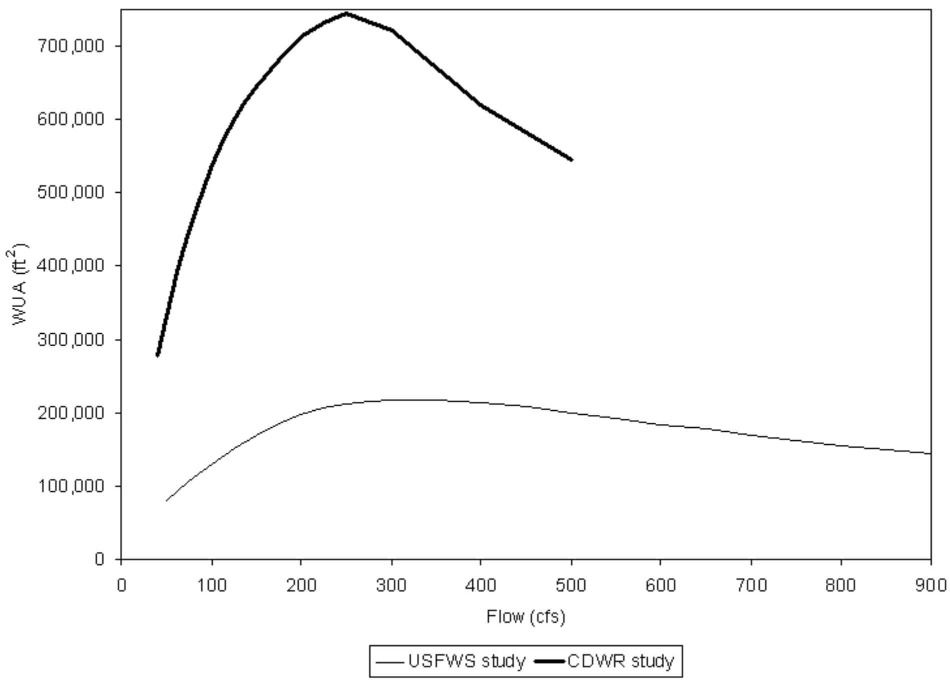


Figure 20. Comparison of fall-run Chinook salmon flow-habitat relationship from this study and the CDWR (1985) study. This study predicted less habitat at all flows and the peak habitat at a slightly higher flow than the CDWR (1985) study.

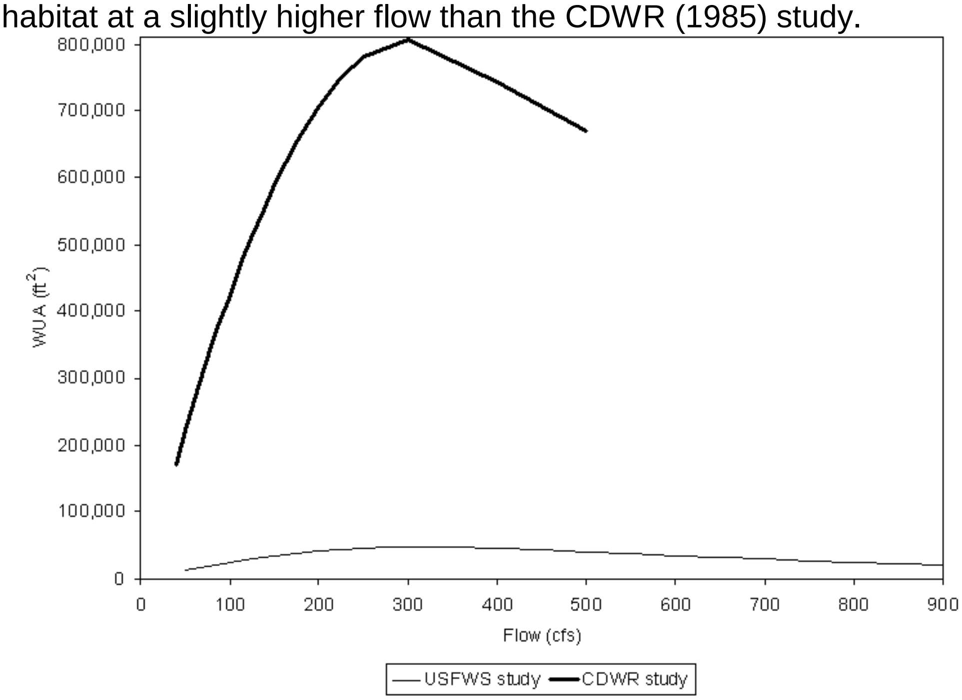


Figure 21. Comparison of steelhead/rainbow trout flow-habitat relationship from this study and the CDWR (1985) study. This study predicted less habitat at all flows and the peak habitat at the same flow as the CDWR (1985) study.

Resources (1985) to our extrapolation to the entire segment based on the percentage of the reach's spawning that was in the study sites, versus California Department of Water Resources (1985) extrapolation based on use of a representative reach. We consider extrapolation based on the percentage of the reach's spawning that was in the study sites to be more accurate based on considerations of salmonids' preference for high gravel permeability, which is taken into account by the extrapolation approach used in this study, but not with a representative reach-based extrapolation approach.

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 161 different hydrograph management scenarios (each of the 23 simulation flows in each of the 7 spawning months –October to December for fall-run, and January to April for steelhead/rainbow trout). For example, increasing flows from 200 cfs to 300 cfs in October would result in an increase of 10.2% of habitat during this month for fall-run Chinook salmon spawning in the Lower Alluvial segment. Based on the conceptual model presented in the introduction, this increase in spawning habitat could decrease redd superimposition, increasing reproductive success which could result in an increase in fall-run Chinook salmon 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, which will be addressed in future reports. We do not feel that there are any significant limitations of the model. This study supported and achieved the objective of producing models predicting the availability of physical habitat in the Lower Alluvial segment of Clear Creek for fall-run Chinook salmon and steelhead/rainbow trout spawning over a range of stream flows. The results of this study are intended to support or revise the flow recommendations in the introduction (i.e., a release from Whiskeytown Dam of 200 cfs from October through June and a release of 150 cfs or less from July through October). The results of this study suggest that the flow recommendations in the introduction during the fall-run Chinook salmon and steelhead/rainbow trout spawning and incubation period of October-June (200 cfs) may be close to achieving maximum habitat availability and productivity for spawning fall-run Chinook salmon and steelhead/rainbow trout in Clear Creek (greater than 89 % of maximum WUA).

REFERENCES

Annear, T., I. Chirholm, H. Beecher, A. Locke, P. Aarestad, N. Burkhart, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, C. Stalnaker and R. Wentworth. 2002. Instream Flows for Riverine Resource Stewardship. Instream Flow Council, Cheyenne, Wyoming.

Bartholow, J.M. 1996. Sensitivity of a salmon population model to alternative formulations and initial conditions. Ecological Modeling 88:215-226.

Bartholow, J.M., J.L. Laake, C.B. Stalnaker and S.C. Williamson. A salmonid population model with emphasis on habitat limitations. Rivers 4(4):265-279.

Bovee, K.D. 1978. Probability of use criteria for the family salmonidae. Instream Flow Information Paper 4. U.S. Fish and Wildlife Service FWS/OBS-78/07. 80 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U.S. Fish and Wildlife Service Biological Report 86(7). 235 pp.

Bovee, K.D., editor. 1996. The Complete IFIM: A Coursebook for IF 250. U.S. Geological Survey, Fort Collins, CO.

California Department of Water Resources. 1985. Clear Creek fishery study appendix, instream flow needs data, June 1985. California Department of Water Resources, Northern District, Red Bluff, CA.

California Department of Water Resources. 2004. Phase 2 report evaluation of project effects on instream flows and fish habitat, SP F-16, Oroville Facilities Relicensing FERC Project No. 2100. California Department of Water Resources, Sacramento, CA.

Clackamas Instream Flow/Geomorphology Subgroup (CIFGS). 2003. Estimating salmonid habitat availability in the lower oak grove fork using expert habitat mapping, summary of methods and preliminary results. Report prepared by McBain and Trush Inc., Arcata, California, for Clackamas Instream Flow/Geomorphology Subgroup, March 5, 2003.

Cohen, J. 1992. Quantitative methods in psychology: A power primer. Psychological Bulletin 112(1): 155-159.

Crowder, D.W. and P. Diplas. 2000. Using two-dimensional hydrodynamic models at scales of ecological importance. Journal of Hydrology. 230: 172-191.

Gallagher, S. P. and M. F. Gard. 1999. Relation between Chinook salmon (Oncorhynchus tshawtscha) redd densities and PHABSIM predicted habitat in the Merced and Lower American Rivers, CA. Canadian Journal of Fisheries and Aquatic Sciences 56: 570-577.

Gard, M. 1998. Technique for adjusting spawning depth habitat utilization curves for availability. Rivers: 6: 94-102.

Gard, M. 2006. Changes in salmon spawning and rearing habitat associated with river channel restoration. International Journal of River Basin Management 4: 201-211.

Gard, M. 2009a. Demonstration flow assessment and 2-D modeling: perspectives based on instream flow studies and evaluation of restoration projects. Fisheries 34(7): 320-329.

Gard, M. 2009b. Comparison of spawning habitat predictions of PHABSIM and River2D models. International Journal of River Basin Management 7:55-71.

Geist, D.R., J. Jones, C.J. Murray and D.D. Dauble. 2000. Suitability criteria analyzed at the spatial scale of redd clusters improved estimates of fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning habitat use in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57: 1636-1646.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1995. Two-dimensional modeling of flow in aquatic habitats. Water Resources Engineering Report 95-S1, Department of Civil Engineering, University of Alberta, Edmonton, Alberta. March 1995.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1996. Two-dimensional hydraulic simulation of physical habitat conditions in flowing streams. Regulated Rivers: Research and Management. 12: 185-200.

Guay, J.C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57: 2065-2075.

Hamilton, A. 1998. FLOMANN program. U.S. Fish and Wildlife Service: Sacramento, CA.

Hardy, T.B. and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River, phase II, final report. Prepared for U.S. Department of the Interior. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah.

Hosmer, D.W. and S. Lemeshow. 2000. Applied Logistic Regression, Second Edition. John Wiley and Sons, Inc, New York.

Knapp, R.A. and H.K. Preisler. 1999. Is it possible to predict habitat use by spawning salmonids? A test using California golden trout (*Oncorhynchus mykiss aguabonita*). Canadian Journal of Fisheries and Aquatic Sciences 56: 1576-1584.

Leclerc M., Boudreault A., Bechara J.A. and Corfa G. 1995. Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology. Transactions of the American Fisheries Society. 124: 645-662.

McHugh, P. and P. Budy. 2004. Patterns of spawning habitat selection and suitability for two populations of spring Chinook salmon, with an evaluation of generic verses site-specific suitability criteria. Transactions of the American Fisheries Society 133: 89-97.

Milhous, R.T., M.A. Updike and D.M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U. S. Fish and Wildlife Service Biological Report 89(16).

Pampel, F.C. 2000. Logistic regression: a primer. Quantitative Applications in the Social Sciences 132.

Parasiewicz, P. 1999. A hybrid model – assessment of physical habitat conditions combining various modeling tools. In: Proceedings of the Third International Symposium on Ecohydraulics, Salt Lake City, Utah.

Pasternack G.B., C.L. Wang and J.E. Merz. 2004. Application of a 2D hydrodynamic model to design of reach-scale spawning gravel replenishment on the Mokelumne River, California. River Research and Applications. 20: 202-225.

Payne and Associates. 1998. RHABSIM 2.0 for DOS and Window's User's Manual. Arcata, CA: Thomas R. Payne and Associates.

Snider, B., K. Vyverberg and S. Whiteman. 1996. Chinook salmon redd survey lower American river fall 1994. California Department of Fish and Game, Environmental Services Division, Stream Flow and Habitat Evaluation Program, Sacramento, CA. 55 pp.

Steffler, P. 2002. River2D_Bed. Bed Topography File Editor. User's manual. University of Alberta, Edmonton, Alberta. 32 pp. http://www.river2d.ualberta.ca/download.htm

Steffler, P. and J. Blackburn. 2002. River2D: Two-dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat. Introduction to Depth Averaged Modeling and User's Manual. University of Alberta, Edmonton, Alberta. 120 pp. http://www.river2d.ualberta.ca/download.htm

SYSTAT. 2002. SYSTAT 10.2 Statistical Software. SYSTAT Software Inc., Richmond, CA.

Thielke, J. 1985. A logistic regression approach for developing suitability-of-use functions for fish habitat. Pages 32-38 in F.W. Olson, R.G. White, and R.H. Hamre, editors. Proceedings of the symposium on small hydropower and fisheries. American Fisheries Society, Western Division and Bioengineering Section, Bethesda, Maryland.

Thomas, J.A. and K.D. Bovee. 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. Regulated Rivers: Research & Management 8: 285-294.

Tiffan, K.E., R.D. Garland and D.W. Rondorf. 2002. Quantifying flow-dependent changes in subyearling fall Chinook salmon rearing habitat using two-dimensional spatially explicit modeling. North American Journal of Fisheries Management 22: 713-726.

U.S. Fish and Wildlife Service. 1994. Using the computer based physical habitat simulation system (PHABSIM). Fort Collins, CO: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 2000. Effects of the January 1997 flood on flow-habitat relationships for steelhead and fall-run Chinook salmon in the Lower American River. U.S. Fish and Wildlife Service, Sacramento, CA.

U.S. Fish and Wildlife Service. 2001. Final restoration plan for the anadromous fish restoration program. A plan to increase natural production of anadromous fish in the Central Valley of California. January 9, 2001. Prepared for the U. S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. U.S. Fish and Wildlife Service, Stockton, CA.

U.S. Fish and Wildlife Service. 2005. Monitoring of restoration projects in Clear Creek using 2-dimensional modeling methodology. U.S. Fish and Wildlife Service: Sacramento, CA.

U.S. Fish and Wildlife Service. 2007. Flow-habitat relationships for spring-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Whiskeytown Dam and Clear Creek Road. U.S. Fish and Wildlife Service: Sacramento, CA.

Vogel, D.A. 1982. Preferred spawning velocities, depths, and substrates for fall chinook salmon in Battle Creek, California. U.S. Fish & Wildlife Service, Red bluff, California.

Vyverberg, K., B. Snider and R.G. Titus. 1996. Lower American river Chinook salmon spawning habitat evaluation October 1994. California Department of Fish and Game, Environmental Services Division, Stream Flow and Habitat Evaluation Program, Sacramento, CA. 120 pp.

Waddle, T. and P. Steffler. 2002. R2D_Mesh - Mesh Generation Program for River2D Two Dimensional Depth Averaged Finite Element. Introduction to Mesh Generation and User's manual. U.S. Geological Survey, Fort Collins, CO. 32 pp. http://www.river2d.ualberta.ca/download.htm

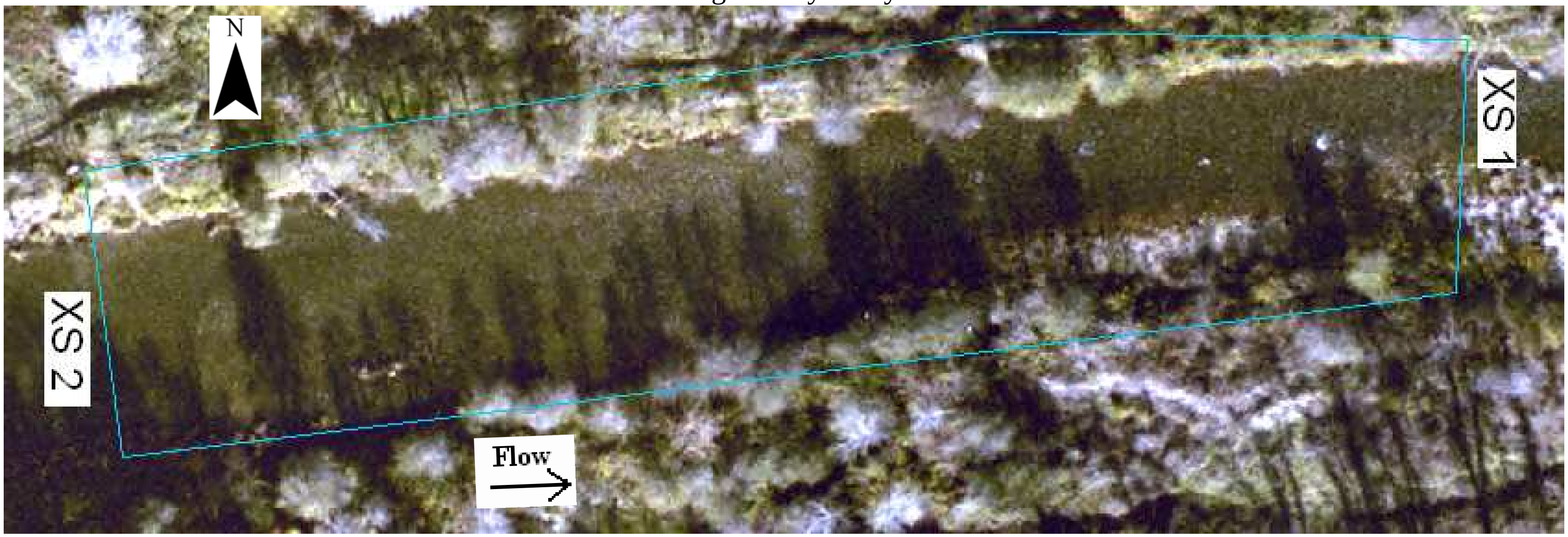
Williamson, S.C., J.M. Bartholow and C.B. Stalnaker. 1993. Conceptual model for quantifying pre-smolt production from flow-dependent physical habitat and water temperature. Regulated Rivers: Research and Management 8:15-28.

Yalin, M.S. 1977. Mechanics of Sediment Transport. Pergamon Press, New York.

Zar, J.H. 1984. Biostatistical Analysis, Second Edition. Prentice-Hall, Inc, Englewood Cliffs, NJ.

APPENDIX A
STUDY SITE AND TRANSECT LOCATIONS

Shooting Gallery Study Site



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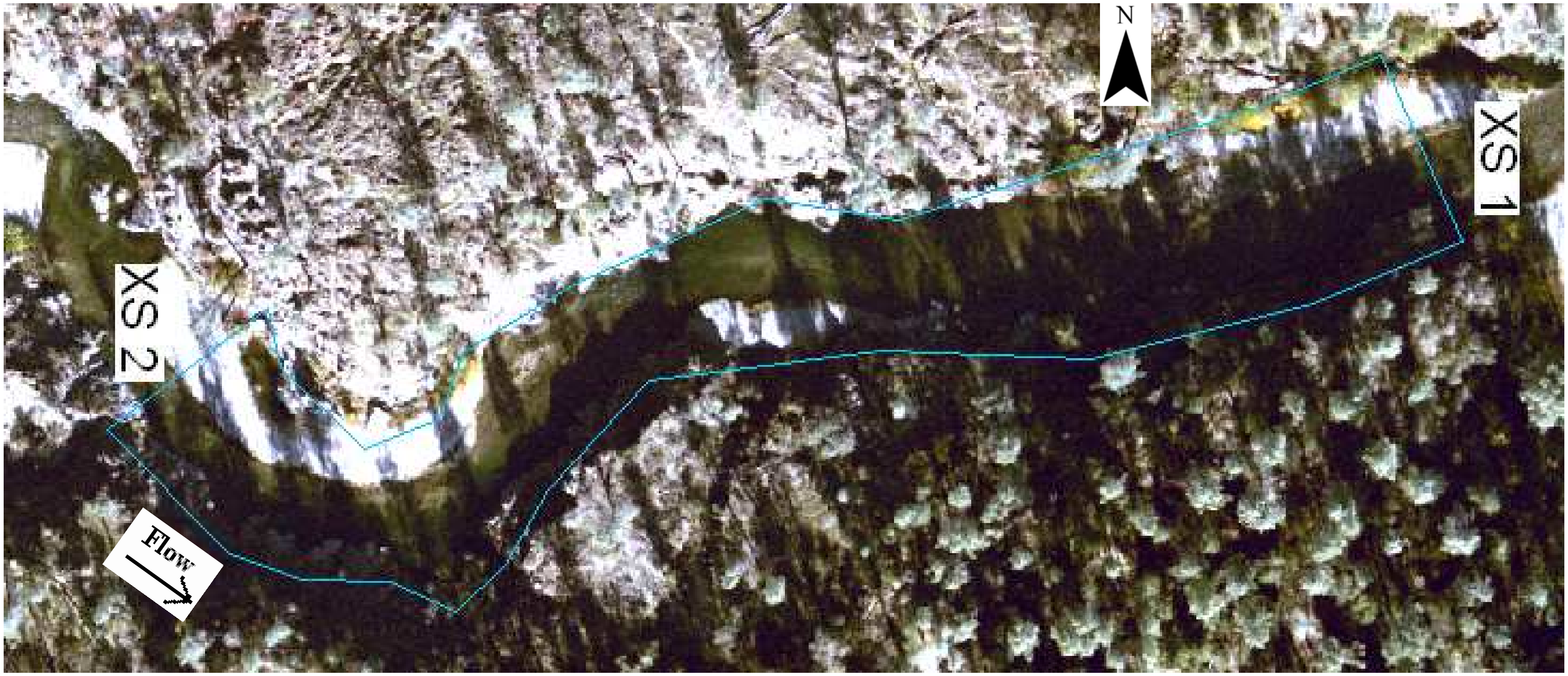
Lower Gorge Study Site



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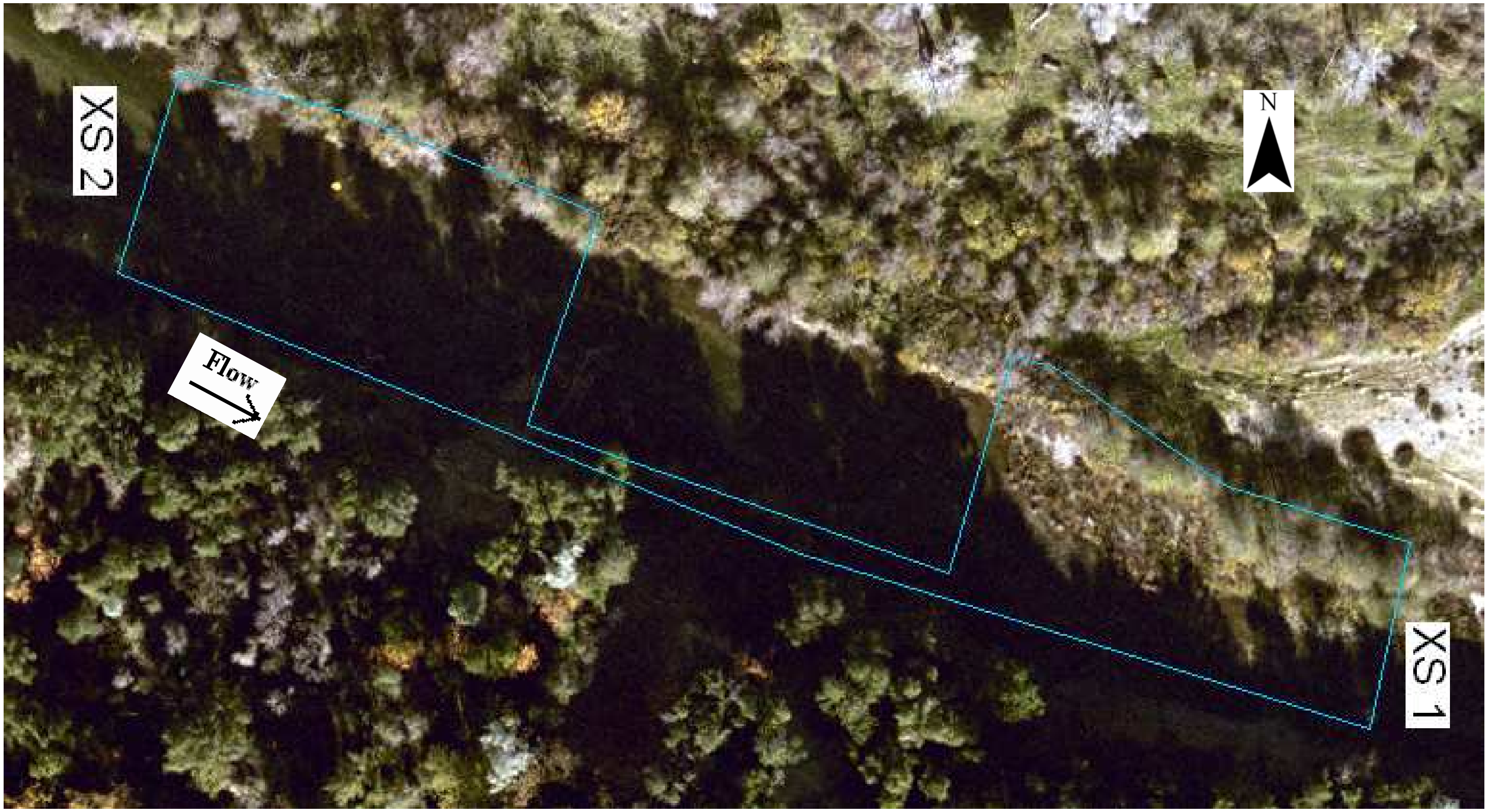
Upper Renshaw

Scale: 1: 1273

Lower Renshaw

Scale: 1: 2112

Upper Isolation



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APPENDIX B
RHABSIM WSEL CALBRATION

Stage of Zero Flow Values

Study Site	XS # 1 SZF	XS # 2 SZF
Shooting Gallery	94.21	98.40
Lower Gorge	95.00	95.70
Upper Renshaw	93.73	95.00
Lower Renshaw	95.30	98.20
Upper Isolation	94.20	96.70

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range	Calibration Flows	Method	Parameters
Shooting Gallery	1	50-900	82, 208, 440, 739	IFG4	- - -
Shooting Gallery	2	50-900	82, 208, 440, 740	IFG4	- - -
Lower Gorge	1	50-900	83, 200, 429, 711	IFG4	- - -
Lower Gorge	2	50-900	83, 200, 430, 705	IFG4	- - -
Upper Renshaw	1	50-900	83.1, 196, 259, 426, 687	IFG4	- - -
Upper Renshaw	2	50-900	83.1, 196, 259, 426, 689	IFG4	- - -
Lower Renshaw	1	50-900	151, 424, 678	IFG4	- - -
Lower Renshaw	2	50-900	151, 425, 678	IFG4	- - -
Upper Isolation	1, 2	50-900	92.5, 156, 189, 419, 654	IFG4	- - -

Shooting Gallery Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	82	208	440	739	82	208	440	739
1	2.65	0.9	0.2	1.0	1.7	0.9	0.00	0.01	0.02	0.01

	BETA	%MEAN								
XS	COEFF.	ERROR	82	208	440	740	82	208	440	740
2	3.35	5.9	5.3	5.9	6.3	6.3	0.02	0.03	0.04	0.05

Lower Gorge Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	83	200	429	711	83	200	429	711
1	3.19	5.87	5.6	6.8	5.3	5.8	0.03	0.05	0.05	0.07

	BETA	%MEAN								
XS	COEFF.	ERROR	83	200	430	705	83	200	430	705
2	3.73	4.69	3.2	1.8	7.8	5.8	0.03	0.02	0.09	0.09

Upper Renshaw Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)					Difference (measured vs. pred. WSELs)				
XS	COEFF.	ERROR	83.1	196	259	426	687	83.1	196	259	426	687
1	3.28	3.61	2.1	7.6	6.5	1.8	0.2	0.02	0.07	0.07	0.02	0.00

	BETA	%MEAN	Calculated vs Given Discharge (%)					Difference (measured vs. pred. WSELs)				
XS	COEFF.	ERROR	83.1	196	259	426	689	83.1	196	259	426	689
2	2.17	3.75	2.6	1.6	7.4	1.6	5.3	0.02	0.02	0.09	0.02	0.10

Lower Renshaw Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	151	424	678	151	424	678
1	2.45	4.29	2.4	6.7	3.9	0.02	0.06	0.05

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	151	425	678	151	425	678
2	3.82	4.56	2.6	7.1	4.2	0.02	0.06	0.04

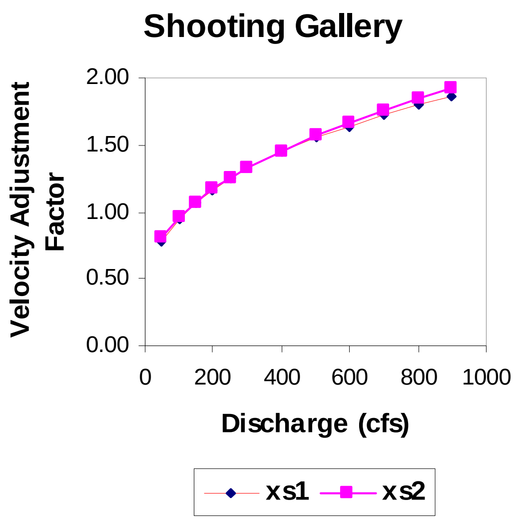
Upper Isolation Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)					Difference (measured vs. pred. WSELs)				
XS	COEFF.	ERROR	92.5	156	189	419	654	92.5	156	189	419	654
1	3.44	3.00	1.11	3.18	3.87	4.48	2.42	0.01	0.02	0.03	0.05	0.03
2	3.95	5.31	1.76	7.83	1.67	10.38	4.99	0.01	0.06	0.01	0.06	0.05

APPENDIX C
VELOCITY ADJUSTMENT FACTORS

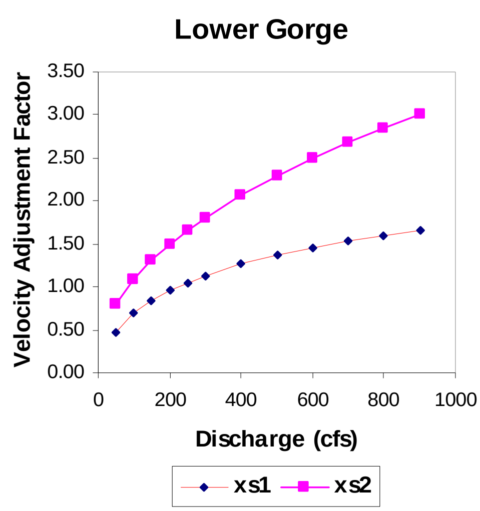
Shooting Gallery Study Site

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.78	0.81
100	0.95	0.96
150	1.07	1.08
200	1.17	1.17
250	1.25	1.25
300	1.32	1.33
400	1.45	1.46
500	1.55	1.57
600	1.64	1.67
700	1.72	1.76
800	1.80	1.85
900	1.86	1.93



Lower Gorge Study Site

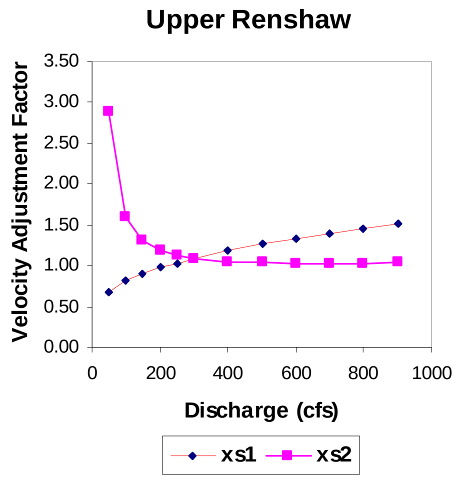
	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.48	0.79
100	0.69	1.09
150	0.84	1.31
200	0.95	1.49
250	1.05	1.66
300	1.13	1.80
400	1.26	2.06
500	1.37	2.29
600	1.46	2.49
700	1.53	2.68
800	1.60	2.85
900	1.66	3.01



Upper Renshaw Study Site

Velocity Adjustment Factors

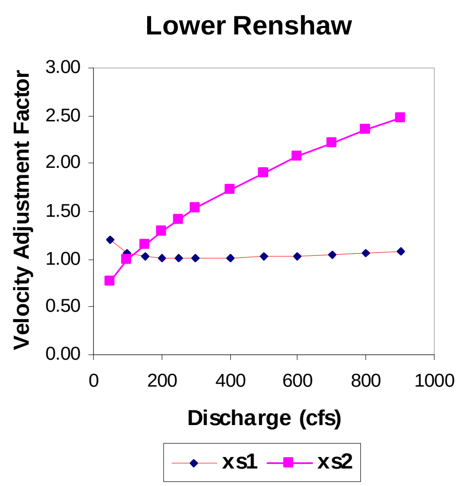
Discharge	Xsec 1	Xsec 2
50	0.68	2.88
100	0.82	1.60
150	0.91	1.31
200	0.97	1.19
250	1.03	1.13
300	1.09	1.09
400	1.18	1.05
500	1.26	1.04
600	1.33	1.03
700	1.40	1.03
800	1.46	1.03
900	1.51	1.03



Lower Renshaw Study Site

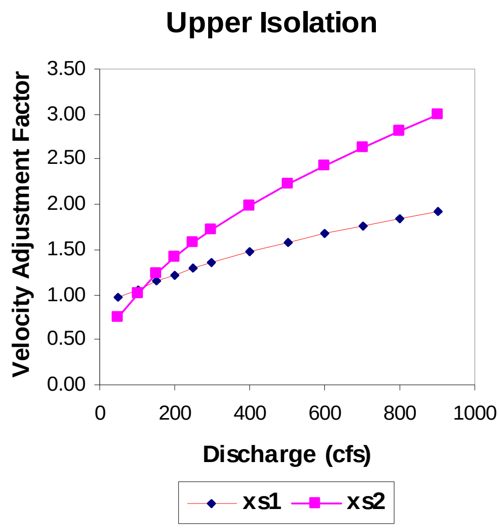
Velocity Adjustment Factors

Discharge	Xsec 1	Xsec 2
50	1.20	0.77
100	1.06	0.99
150	1.02	1.15
200	1.01	1.29
250	1.00	1.42
300	1.01	1.53
400	1.01	1.73
500	1.02	1.91
600	1.04	2.07
700	1.05	2.22
800	1.06	2.36
900	1.07	2.48



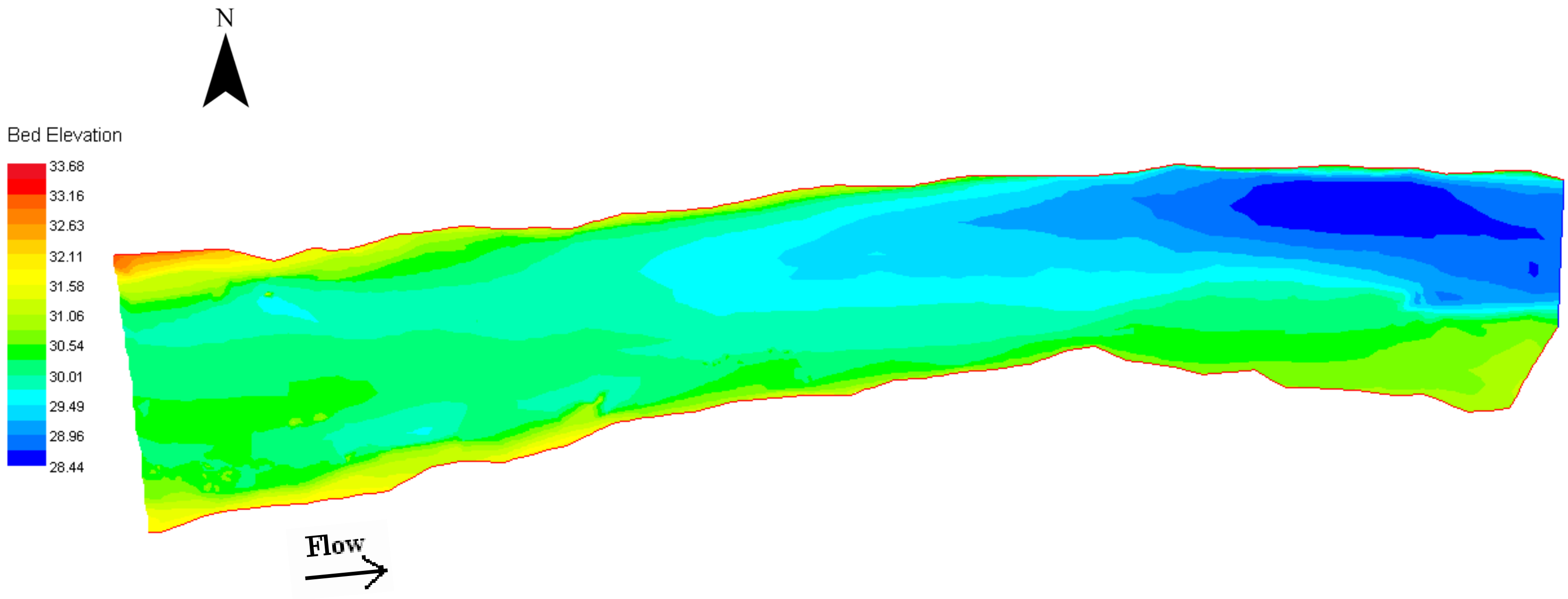
Upper Isolation Study Site

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.96	0.75
100	1.06	1.02
150	1.14	1.23
200	1.22	1.42
250	1.29	1.58
300	1.36	1.72
400	1.47	1.99
500	1.58	2.22
600	1.67	2.43
700	1.76	2.63
800	1.84	2.82
900	1.92	2.99



APPENDIX D
BED TOPOGRAPHY OF STUDY SITES

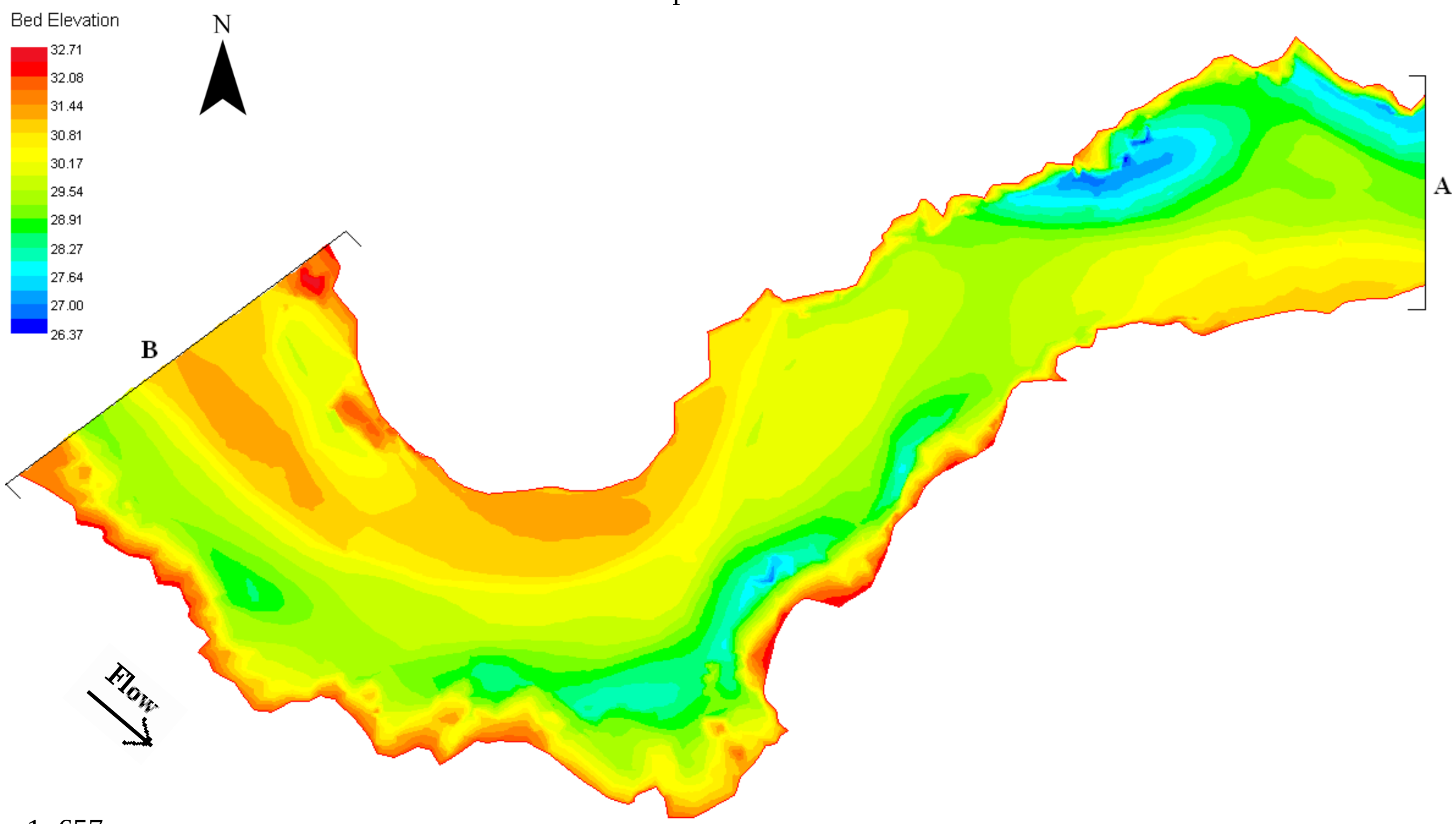
Shooting Gallery Study Site



Scale: 1: 1078

Units of bed elevation are meters

Lower Gorge Study Site
Upstream Section



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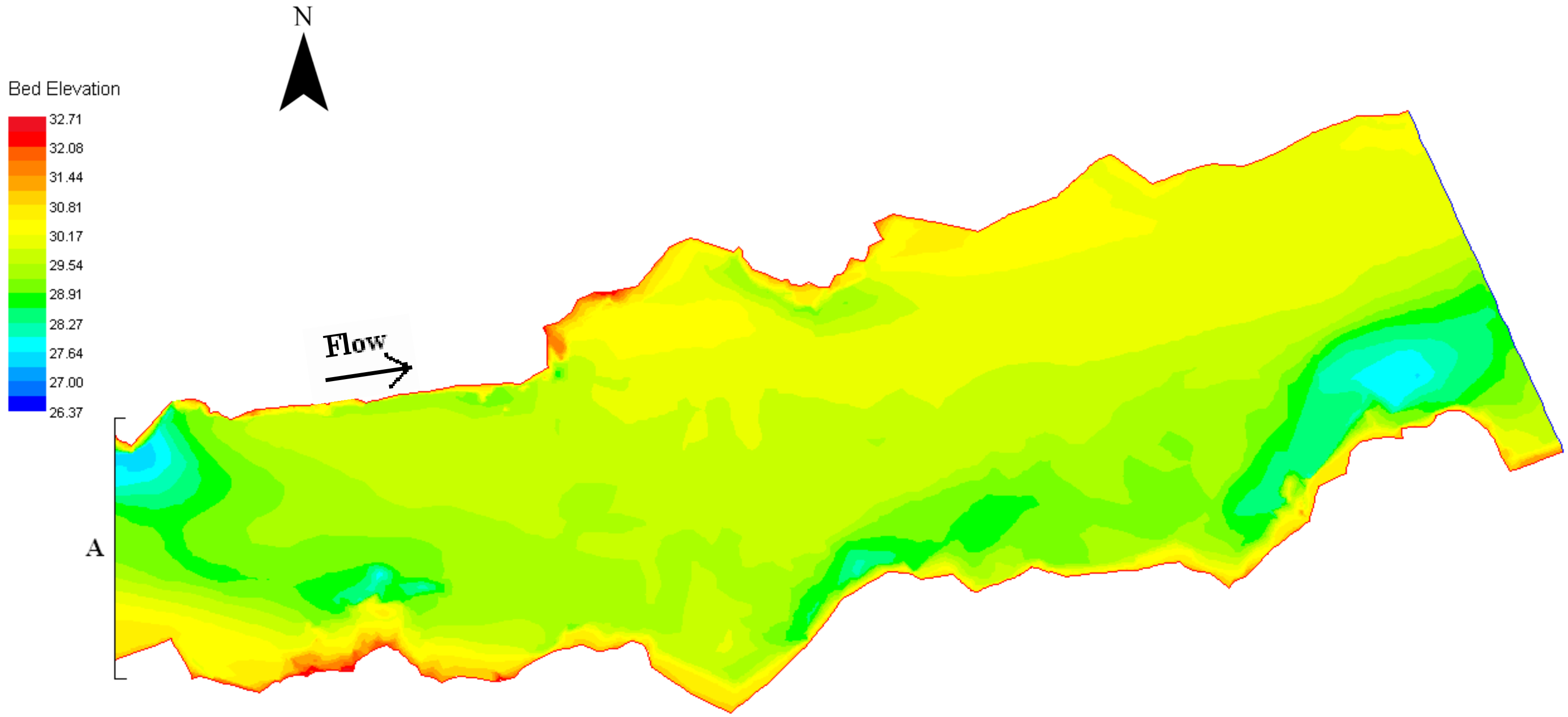
Units of bed elevation are meters.

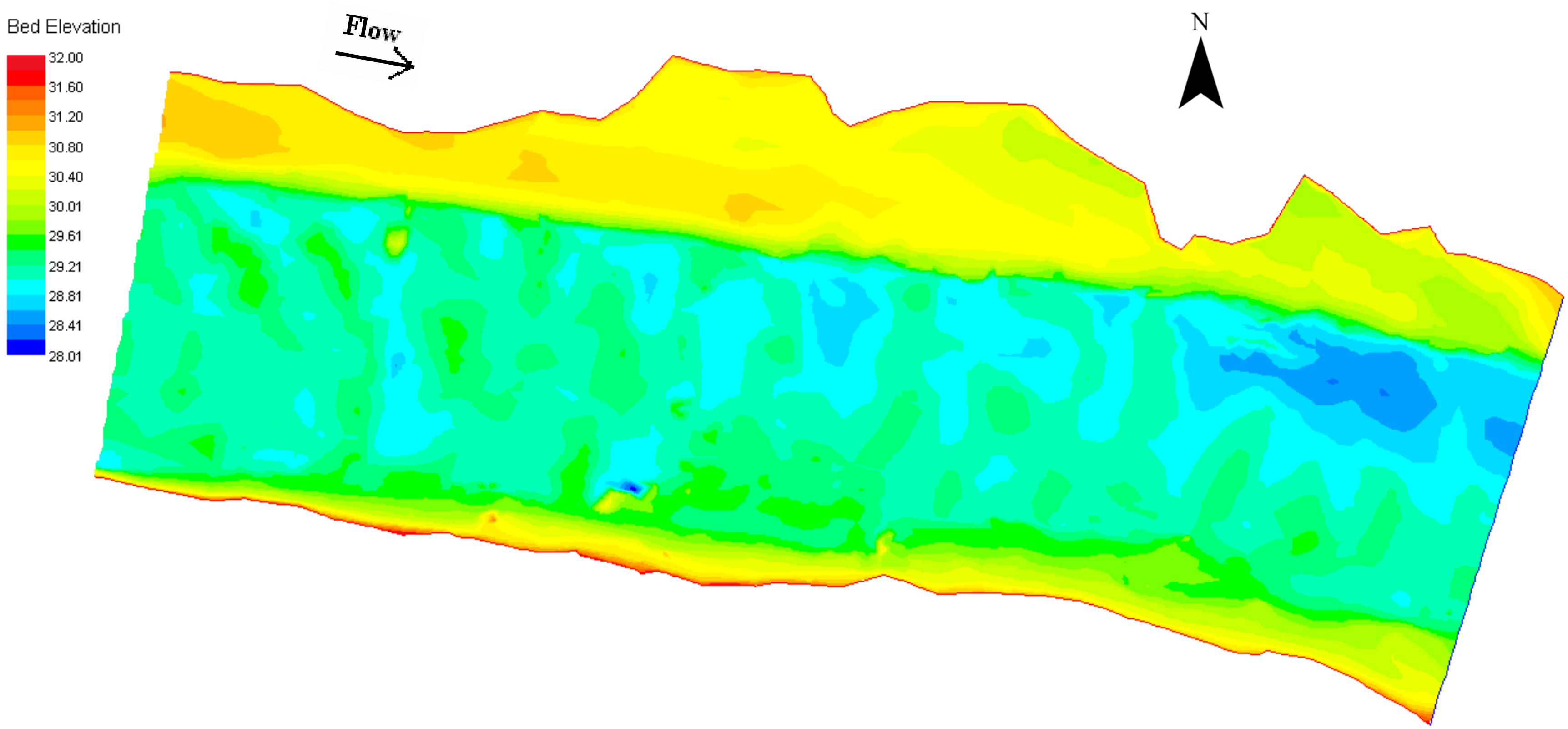
Lower Gorge Study Site
Downstream Section



Scale: 1: 910

Units of bed elevation are meters.

Upper Renshaw



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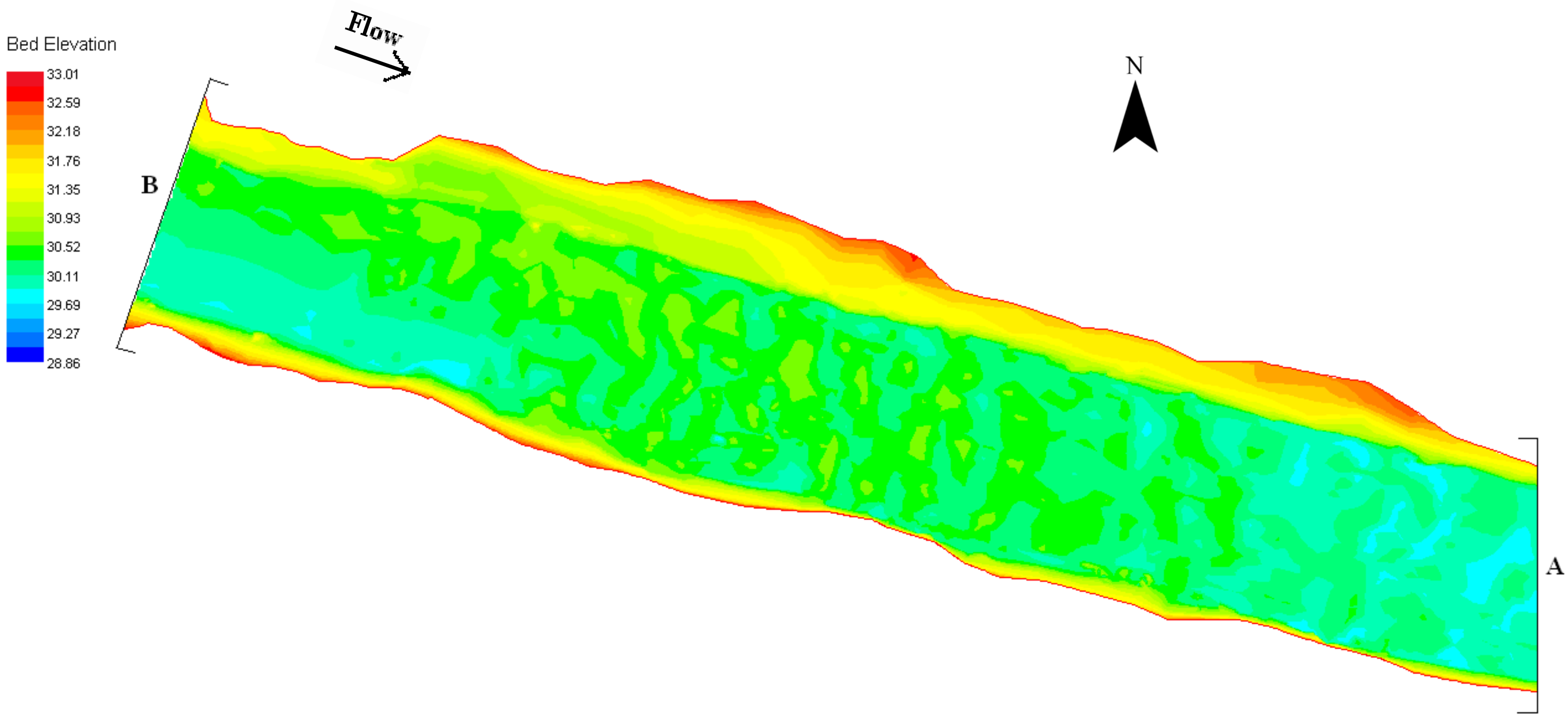
Units of bed elevation are meters.

Lower Renshaw
Upstream Section



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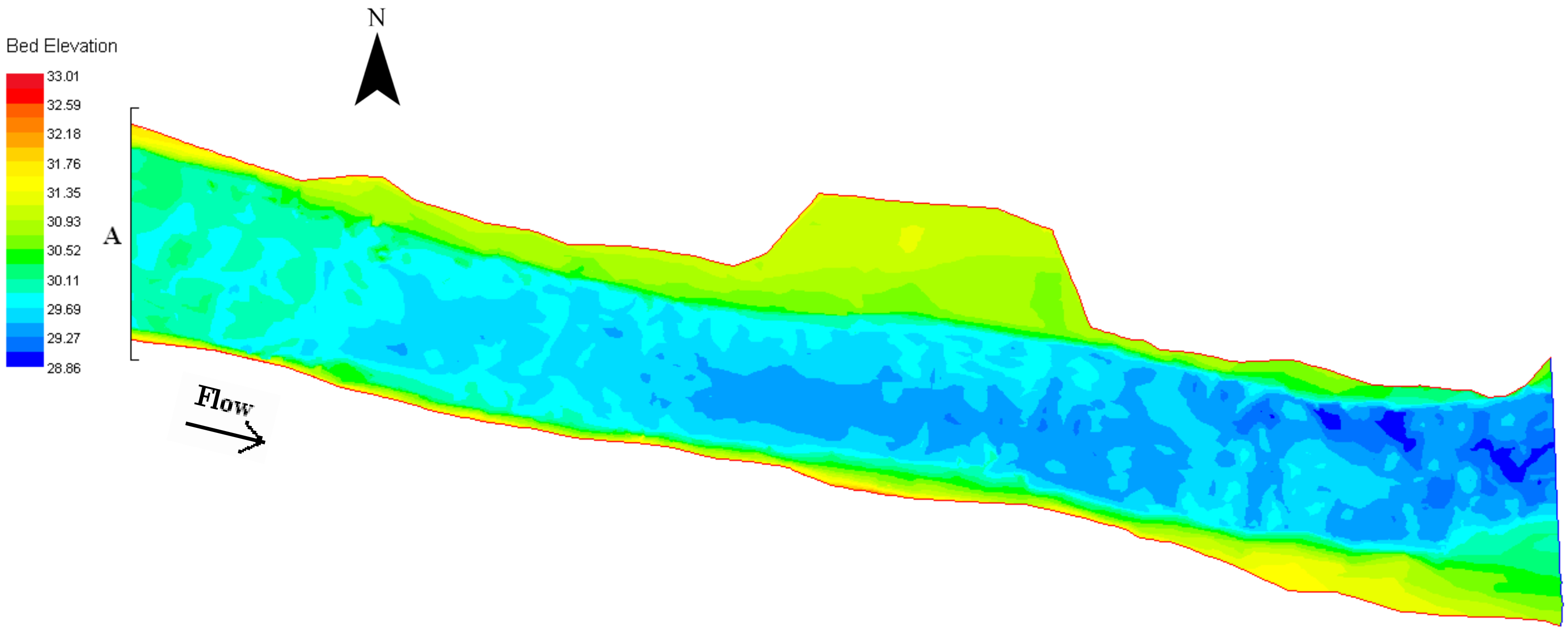
Units of bed elevation are meters.

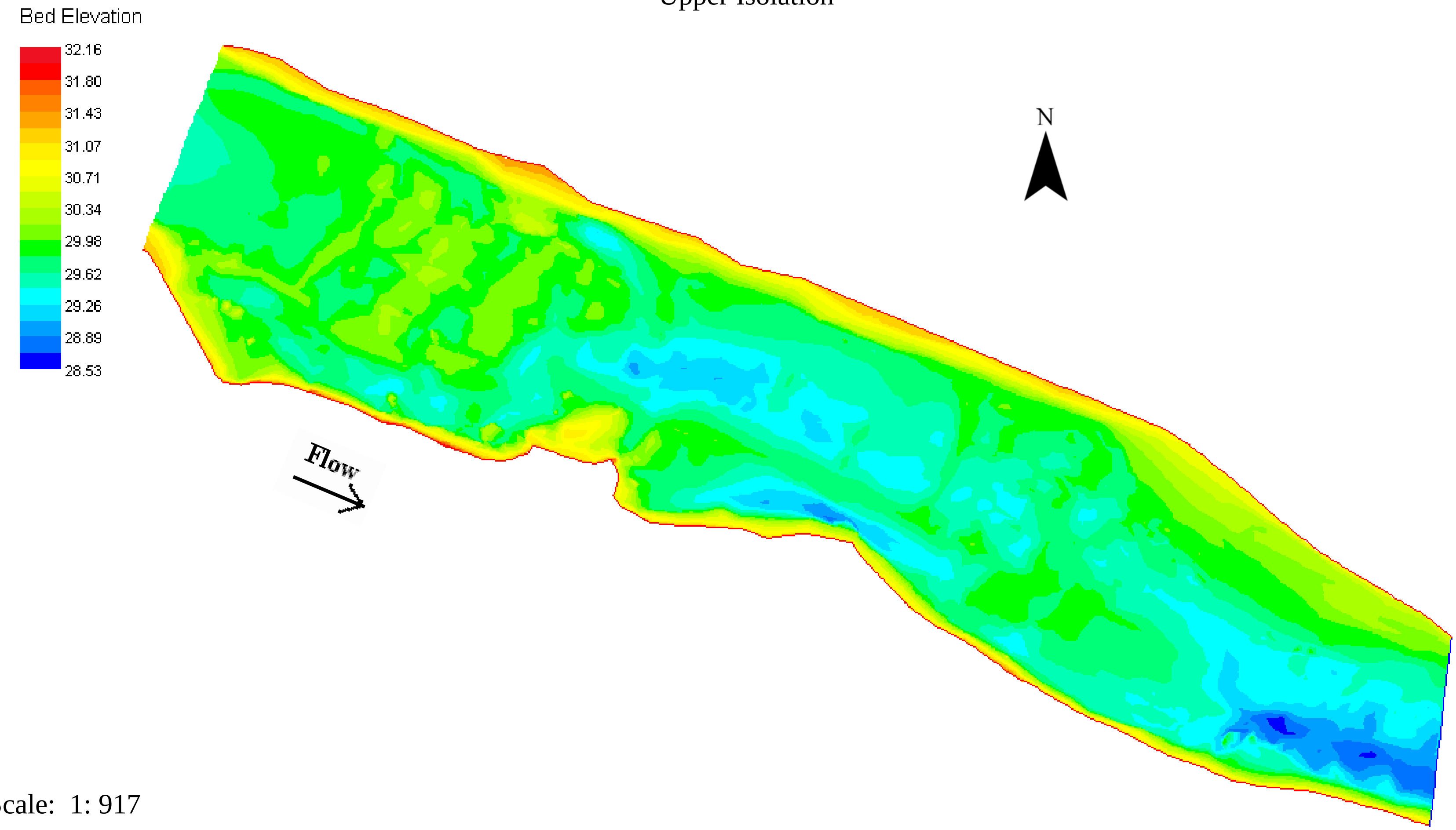
Lower Renshaw
Downstream Section



Scale: 1: 968

Units of bed elevation are meters.

Upper Isolation



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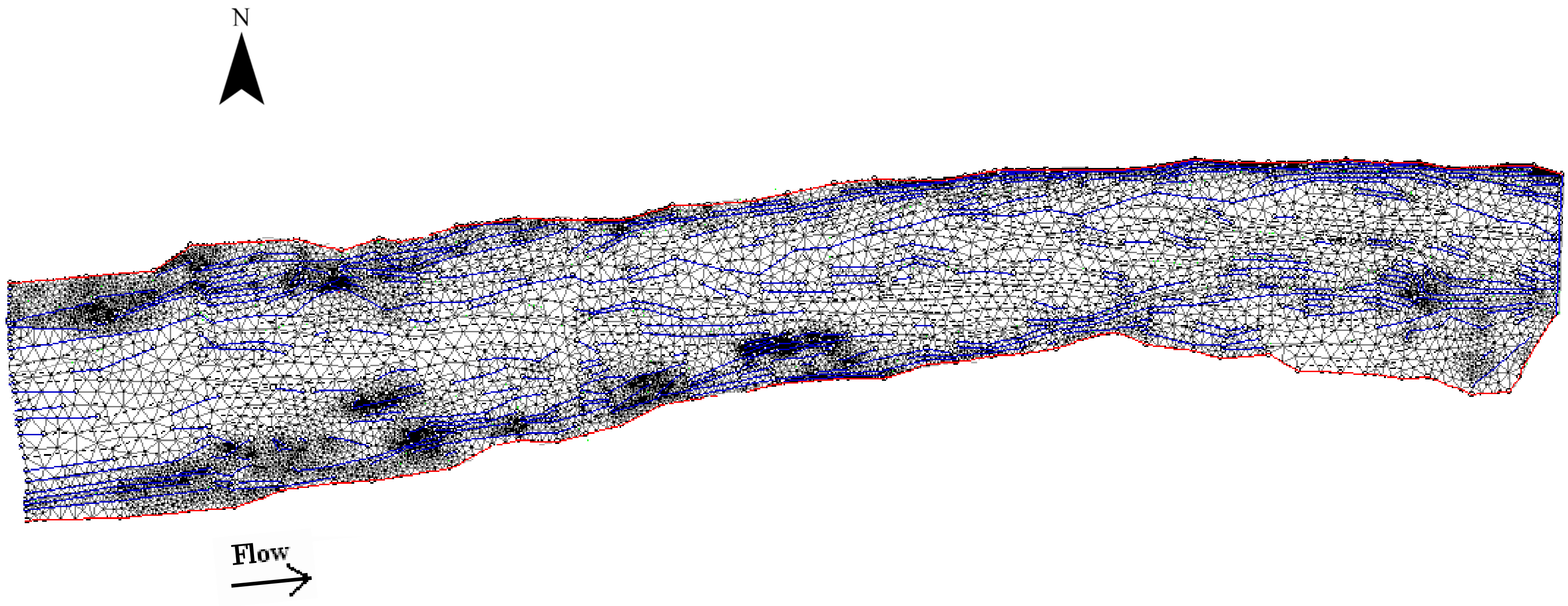
Units of bed elevation are meters.

APPENDIX E
COMPUTATIONAL MESHES OF STUDY SITES

Shooting Gallery Study Site



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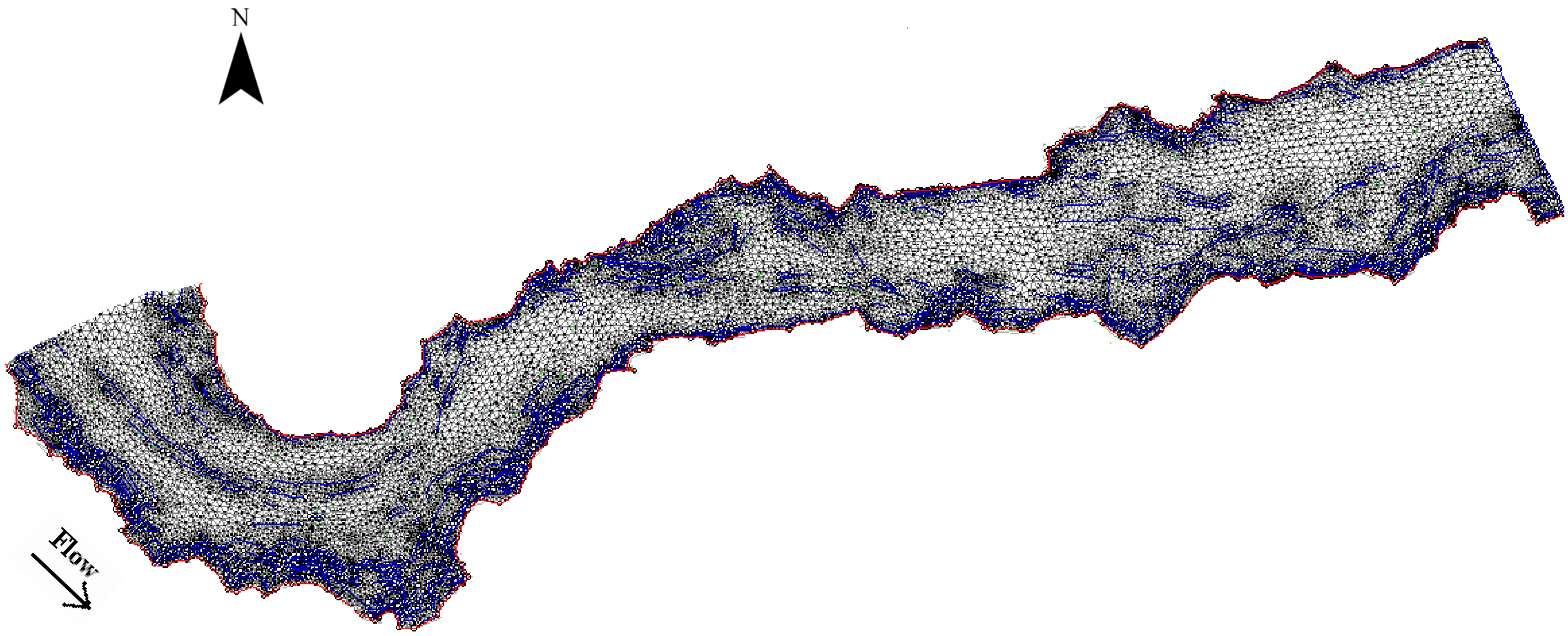
Lower Gorge Study Site



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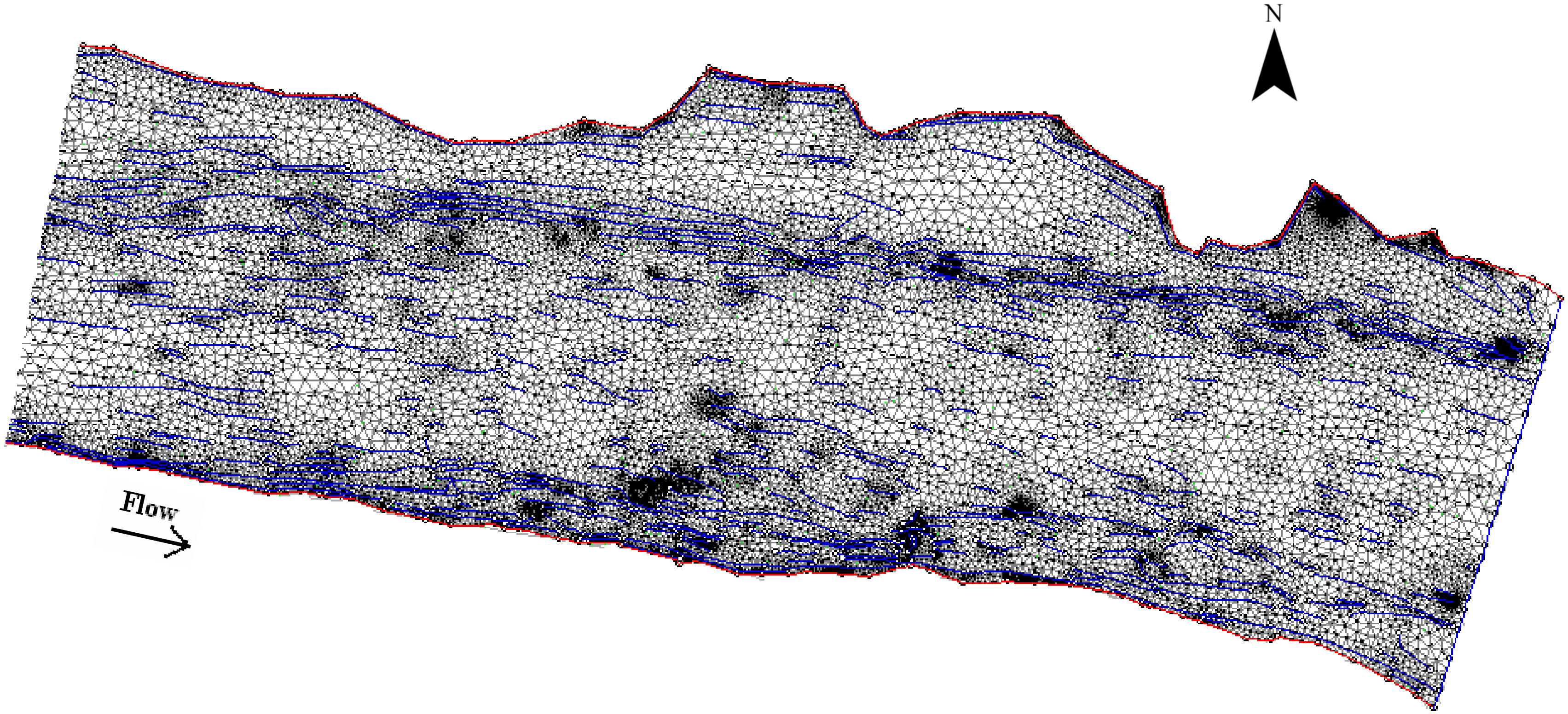
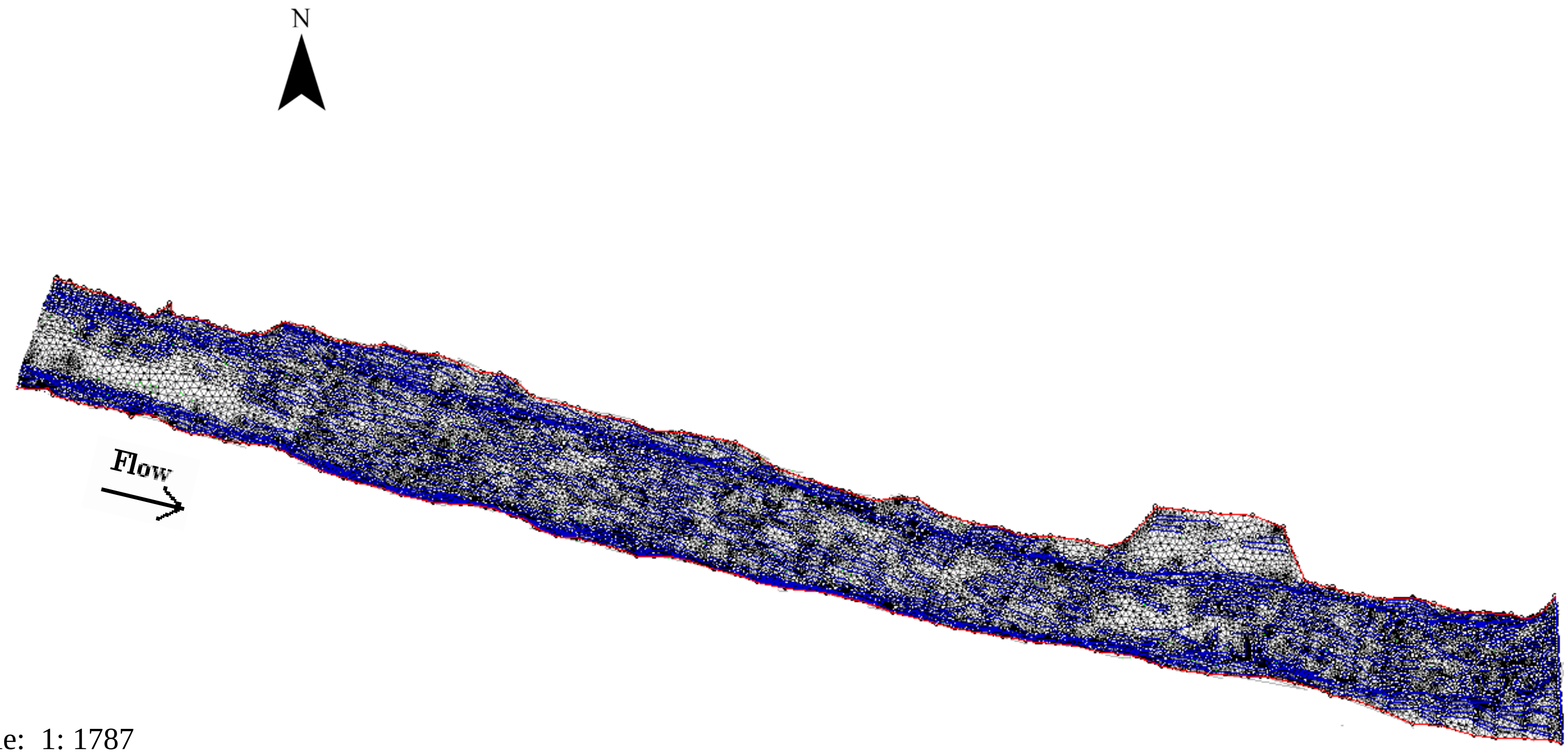
Upper Renshaw Study Site



Scale: 1: 620

Lower Renshaw



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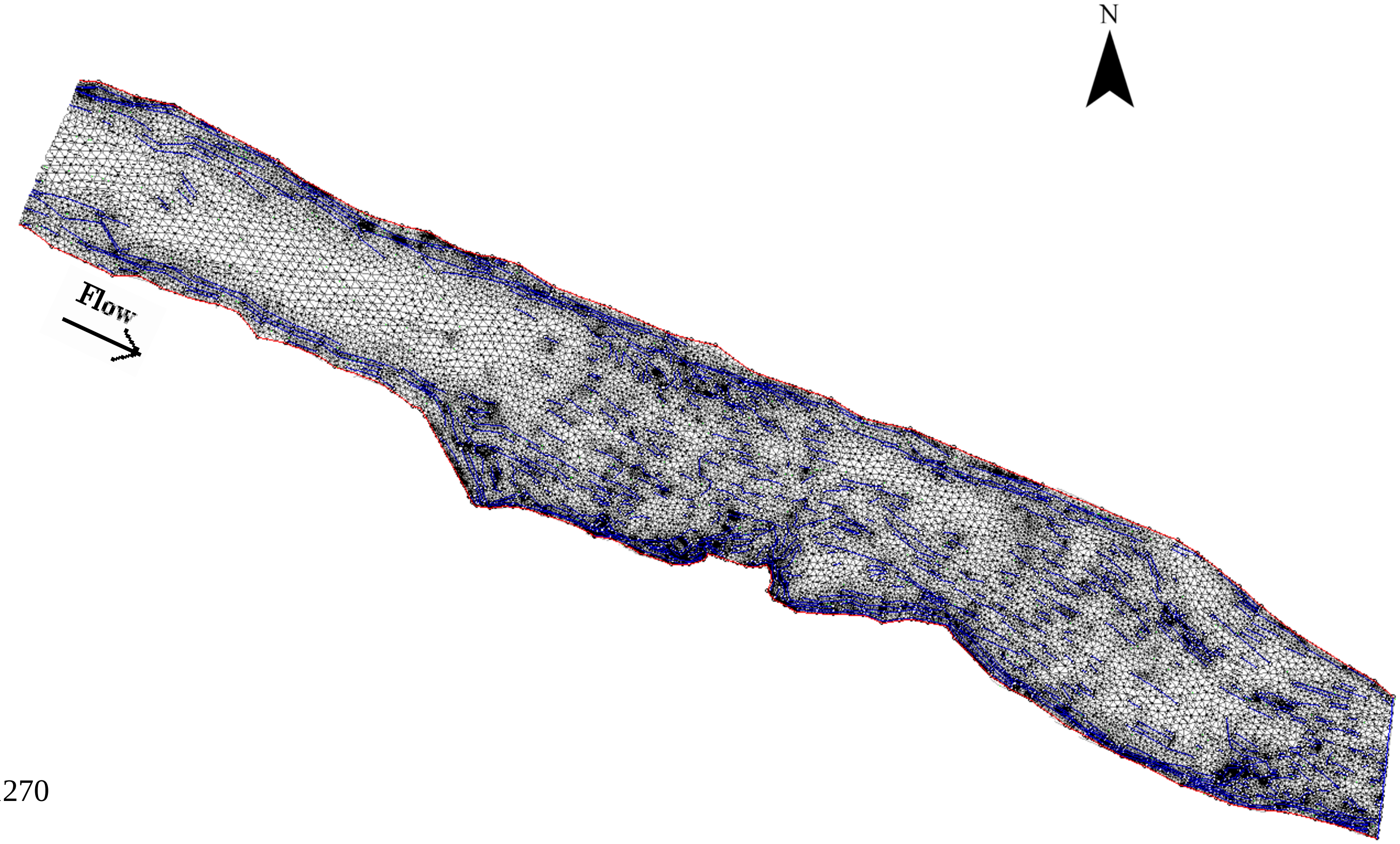
Upper Isolation



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APPENDIX F
2-D WSEL CALIBRATION

Calibration Statistics

Site Name	**% Nodes within 0.1'**	**Nodes**	**QI**	**Net Q**	**Sol Δ**	**Max F**
Shooting Gallery	90.1 %	12181	0.30	0.007%	< .000001	3.47
Lower Gorge	79.7%	23601	0.30	0.030%	.000001	7.28
Upper Renshaw	92.1 %	19174	0.30	0.021%	< .000001	0.91
Lower Renshaw	89.2%	29911	0.30	0.050%	< .000001	3.11
Upper Isolation	92.7%	23763	0.30	0.36%	< .000001	2.44

Shooting Gallery

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2	0.3	0.05	0.03	0.10

Lower Gorge

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	2.0	0.13	0.08	0.33

Upper Renshaw

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	3.0	0.02	0.01	0.03

Lower Renshaw

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	0.6	0.04	0.01	0.04

Upper Isolation

XSEC	BR Mult	Difference (measured vs. pred. WSELs) Average	Standard Deviation	Maximum
2	1.5	0.03	0.02	0.05

APPENDIX G
VELOCITY VALIDATION STATISTICS

Site Name	Number of Observations	Correlation Between Measured and Simulated Velocities
Shooting Gallery	96	0.77
Lower Gorge	92	0.85
Upper Renshaw	94	0.78
Lower Renshaw	102	0.70
Upper Isolation	90	0.90

Measured Velocities less than 3 ft/s

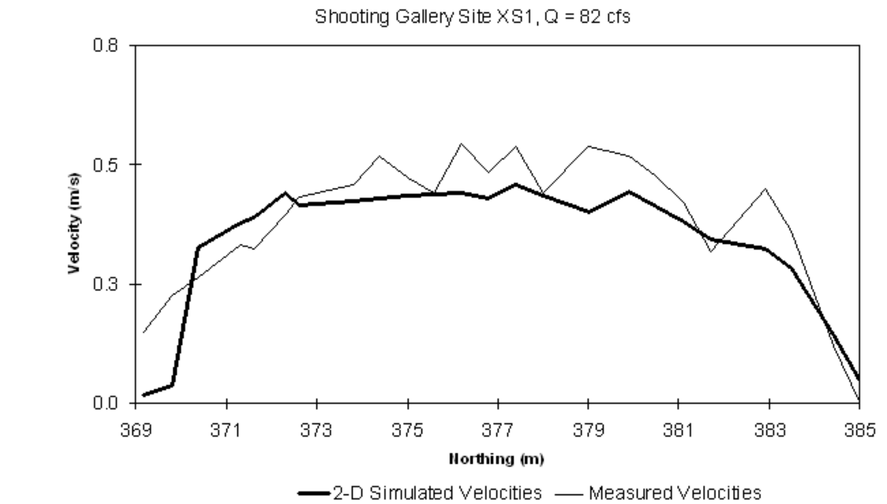
Difference (measured vs. pred. velocities, ft/s)

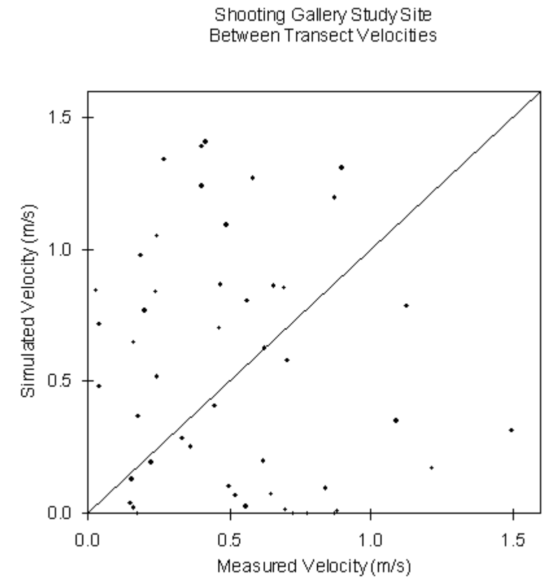
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Shooting Gallery	92	0.56	0.52	2.43
Lower Gorge	85	0.34	0.25	1.15
Upper Renshaw	94	0.38	0.33	1.50
Lower Renshaw	92	0.59	0.63	2.47
Upper Isolation	78	0.2	0.32	1.37

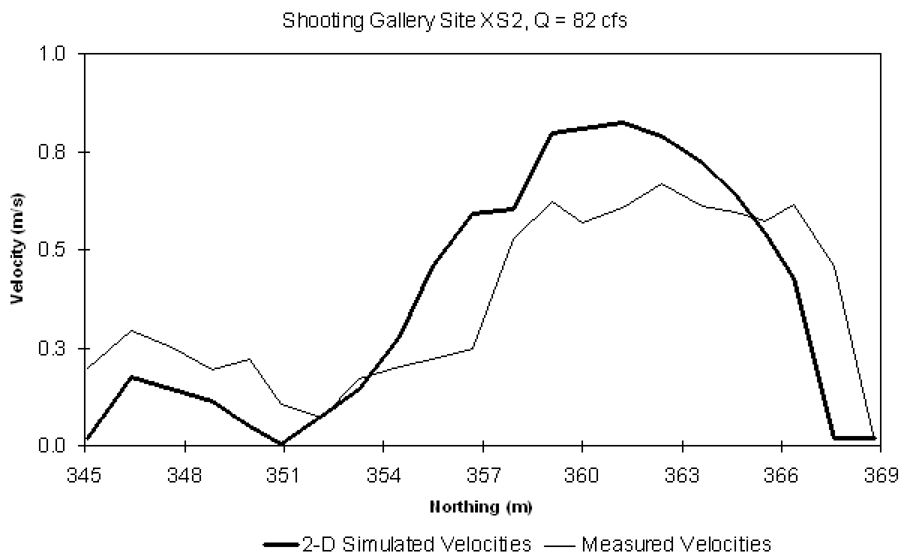
Measured Velocities greater than 3 ft/s

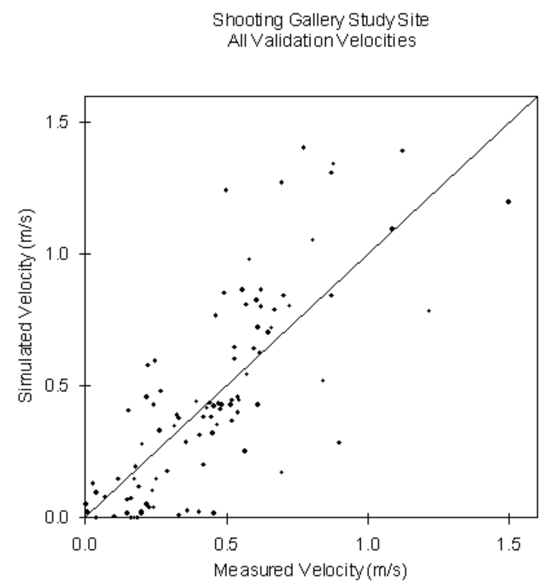
Percent difference (measured vs. pred. velocities)

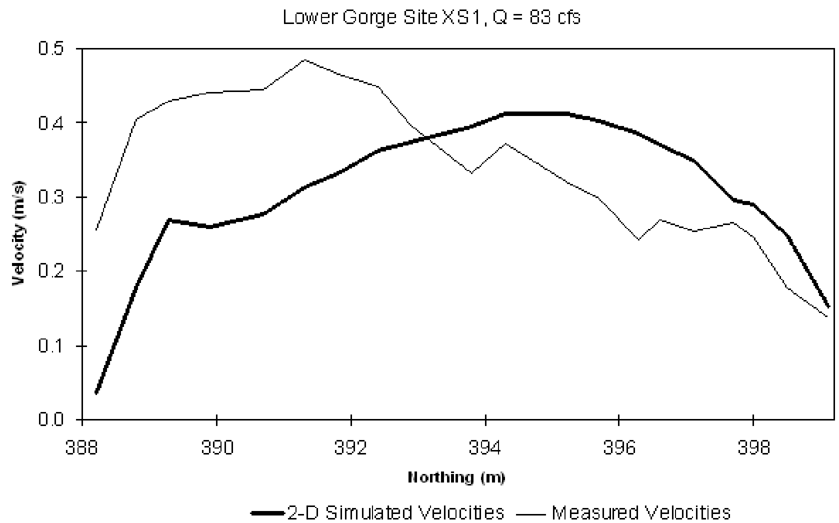
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Shooting Gallery	4	20%	14%	35%
Lower Gorge	7	24%	15%	51%
Upper Renshaw	--	--	--	--
Lower Renshaw	10	10%	7%	21%
Upper Isolation	12	16%	8%	26%

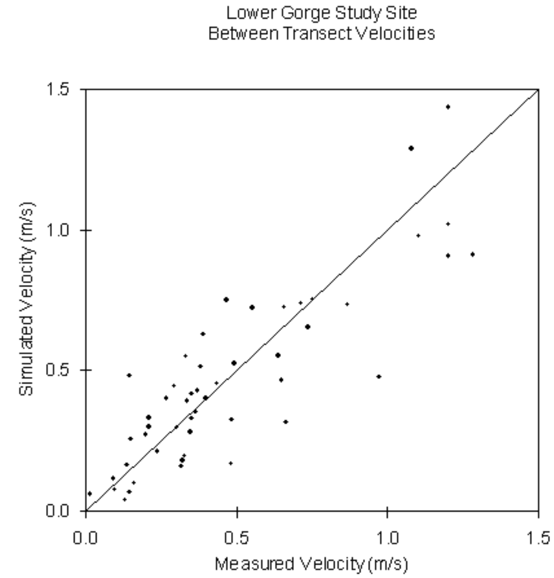

Shooting Gallery Site XS1, Q = 82 cfs
Velocity (m/s)
0.8
0.5
0.3
0.0
369
371
373
375
377
379
381
383
385
Northing (m)
2-D Simulated Velocities
Measured Velocities

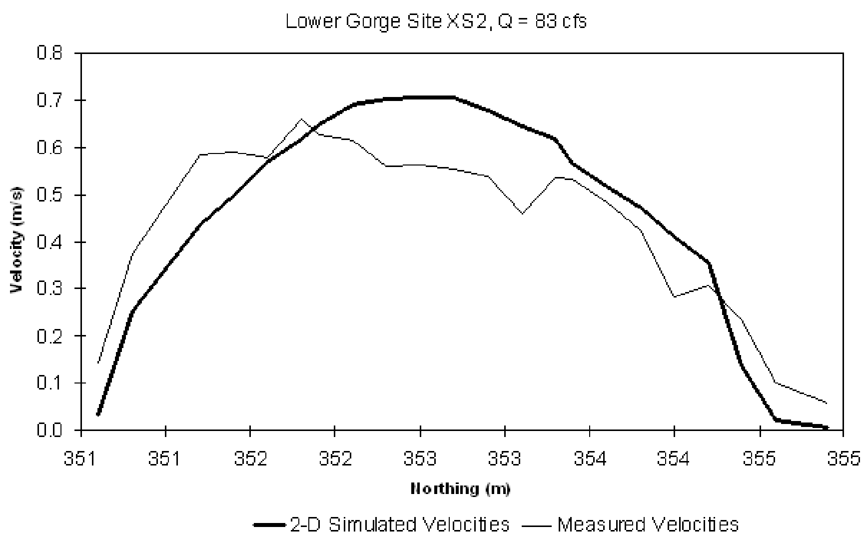

Shooting Gallery Study Site
Between Transect Velocities
Simulated Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Measured Velocity (m/s)

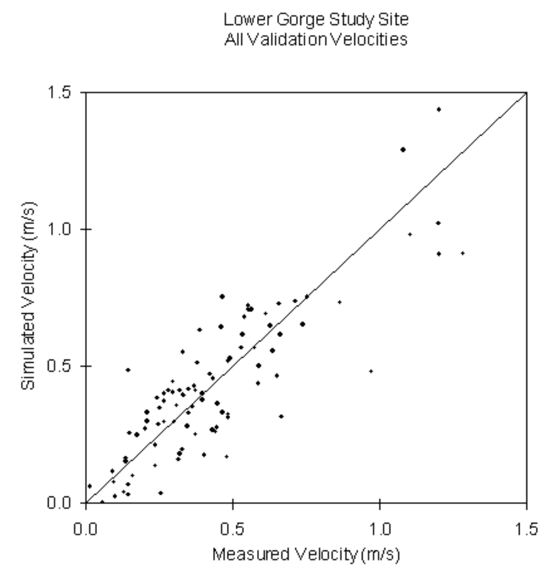

Shooting Gallery Site XS2, Q = 82 cfs
Velocity (m/s)
1.0
0.8
0.5
0.3
0.0
345
348
351
354
357
360
363
366
369
Northing (m)
2-D Simulated Velocities
Measured Velocities

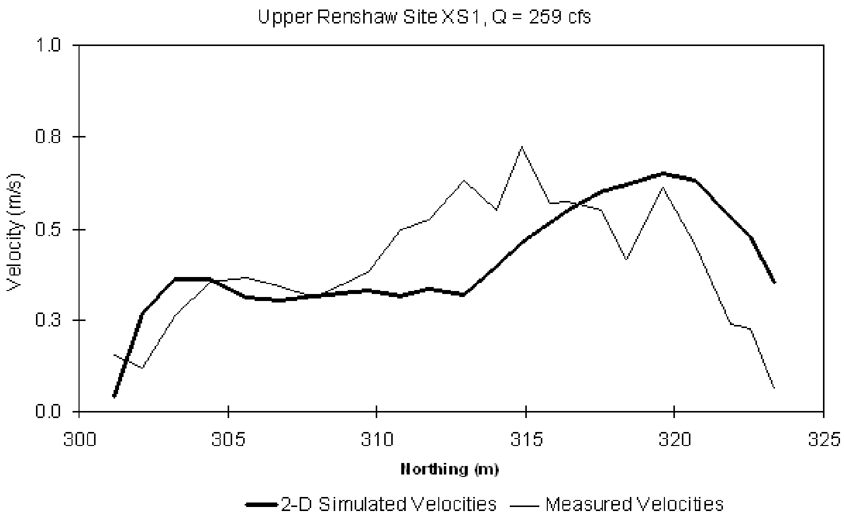

Shooting Gallery Study Site
All Validation Velocities
Simulated Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Measured Velocity (m/s)

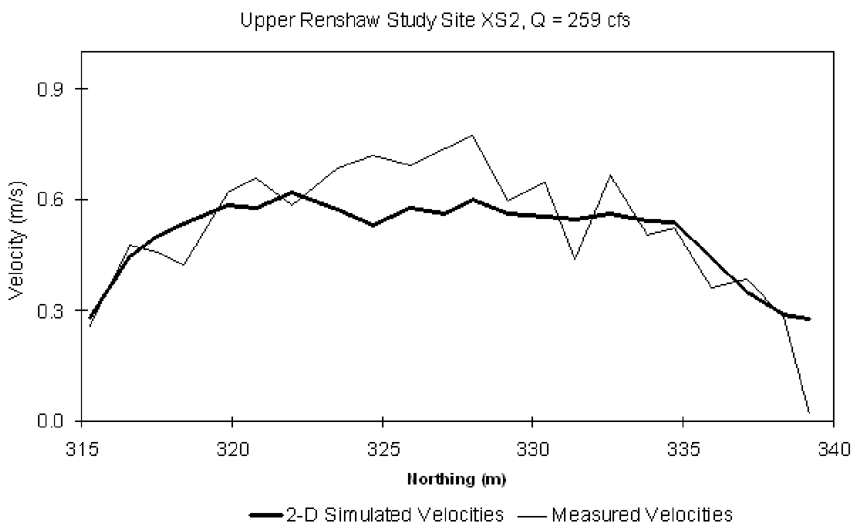

Lower Gorge Site XS1, Q = 83 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities

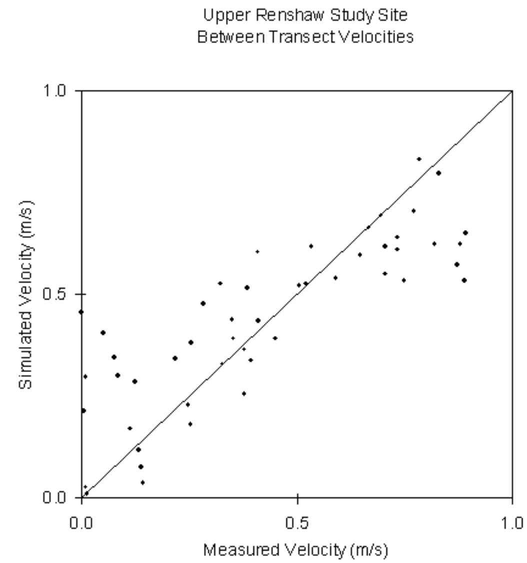

Lower Gorge Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

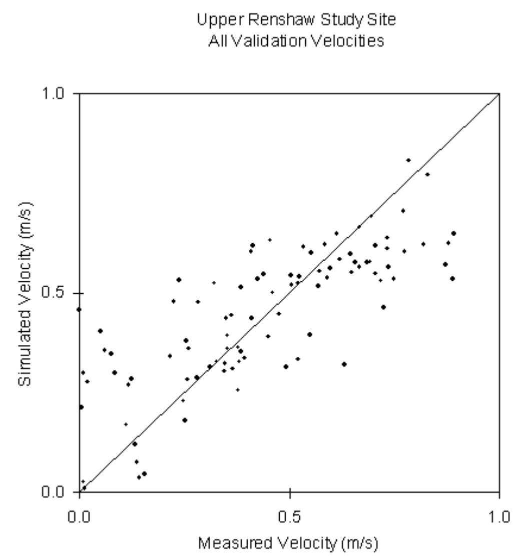

Lower Gorge Site XS2, Q = 83 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities


Lower Gorge Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

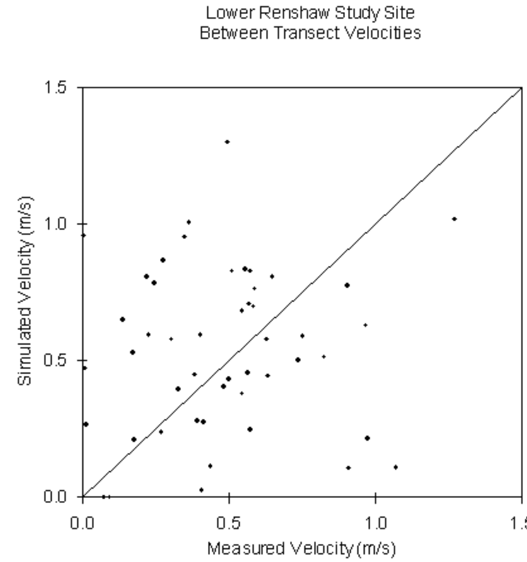

Upper Renshaw Site XS1, Q = 259 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities


Upper Renshaw Study Site XS2, Q = 259 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities

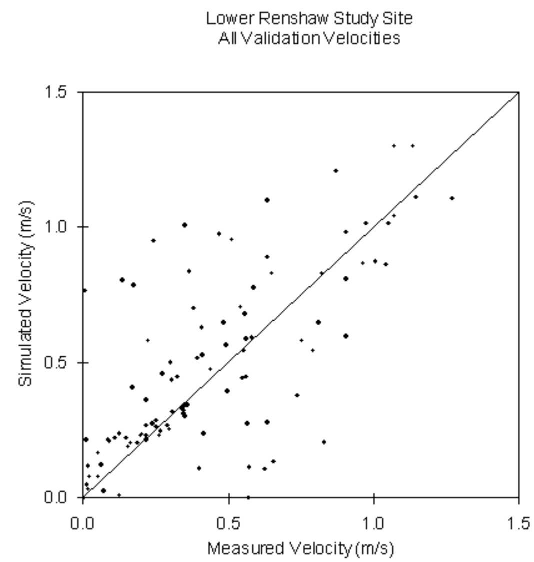

Upper Renshaw Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

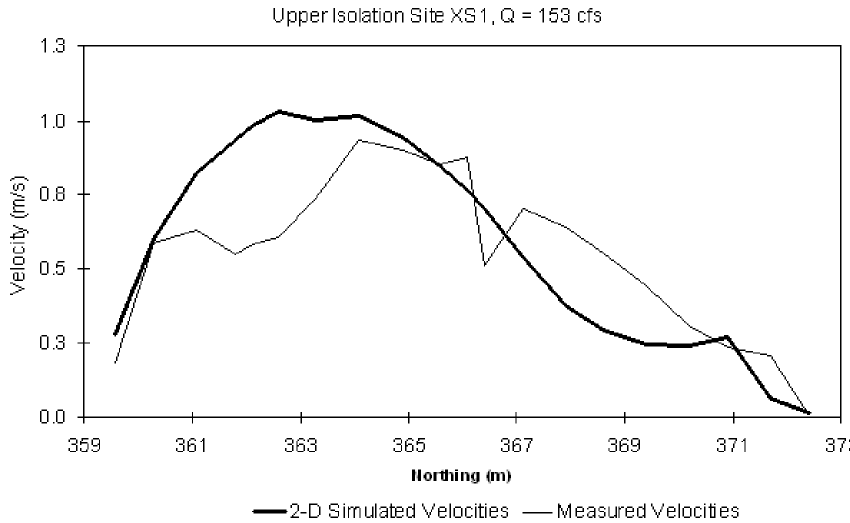

Upper Renshaw Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

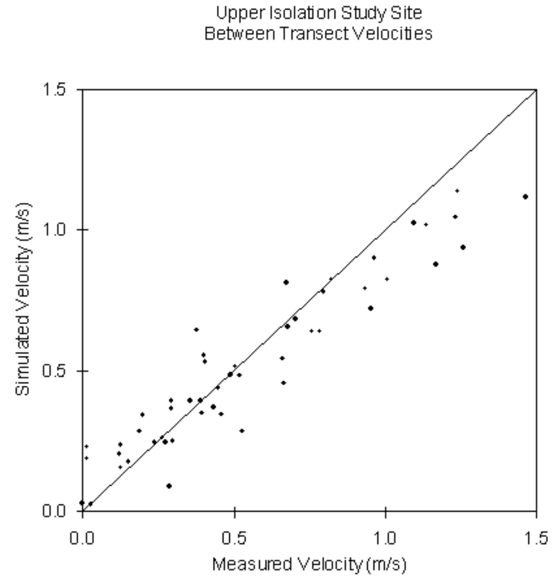

Lower Renshaw Site XS1, Q = 151 cfs
Velocity (m/s)
1.3
1.0
0.8
0.5
0.3
0.0
481
486
491
496
Northing (m)
2-D Simulated Velocities
Measured Velocities


Lower Renshaw Study Site
Between Transect Velocities
Simulated Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Measured Velocity (m/s)

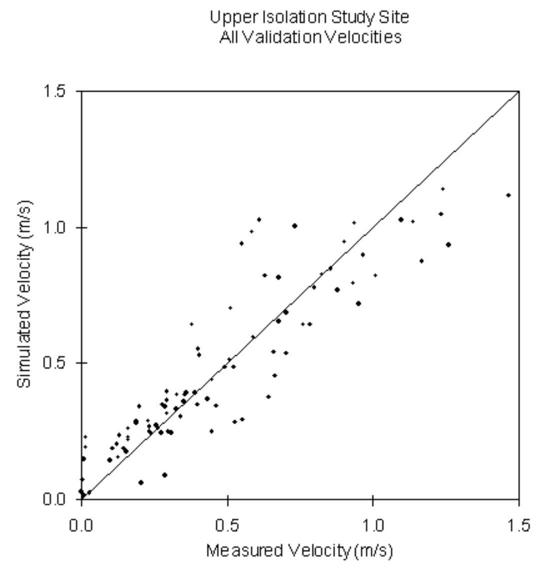

Lower Renshaw Site XS2, Q = 151 cfs
Velocity (m/s)
0.4
0.3
0.2
0.1
0.0
573
578
583
588
593
Northing (m)
2-D Simulated Velocities
Measured Velocities


Lower Renshaw Study Site
All Validation Velocities
Simulated Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Measured Velocity (m/s)


Upper Isolation Site XS1, Q = 153 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities


Upper Isolation Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)


Upper Isolation Site XS2, Q = 153 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities


Upper Isolation Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

APPENDIX H
SIMULATION STATISTICS

Shooting Gallery

Flow (cfs)	Net Q	Sol	Max F
50	0.14%	< .000001	1.08
75	0.19%	< .000001	1.12
100	0.14%	< .000001	1.28
125	0.06%	< .000001	1.26
150	0.07%	< .000001	1.20
175	0.06%	< .000001	1.19
200	0.05%	< .000001	1.14
225	0.03%	< .000001	1.08
250	0.01%	< .000001	3.13
275	0.01%	< .000001	3.46
300	0.01%	< .000001	3.71
350	0.23%	< .000001	3.83
400	0.02%	.000005	4.43
450	0.02%	< .000001	1.92
500	0.00%	< .000001	1.81
550	0.00%	< .000001	1.52
600	0.02%	< .000001	1.58
650	0.01%	< .000001	2.54
700	0.01%	< .000001	2.61
750	0.01%	< .000001	3.60
800	0.01%	< .000001	2.82
850	0.01%	< .000001	2.93
900	0.01%	< .000001	3.47

Lower Gorge

Flow (cfs)	**Net Q**	**Sol**	**Max F**
50	0.57%	< .000001	1.76
75	0.38%	< .000001	1.46
100	0.36%	< .000001	1.20
125	0.29%	< .000001	0.98
150	0.17%	< .000001	1.02
175	0.18%	< .000001	1.04
200	0.14%	< .000001	2.55
225	0.13%	< .000001	2.46
250	0.14%	< .000001	2.15
275	0.09%	< .000001	1.78
300	0.09%	< .000001	2.66
350	0.11%	< .000001	2.52
400	0.04%	.000001	2.33
450	0.05%	< .000001	5.38
500	0.06%	< .000001	2.25
550	0.06%	.000002	5.58
600	0.01%	.000002	8.41
650	0.04%	< .000001	9.08
700	0.04%	.000002	7.53
750	0.02%	< .000001	6.84
800	0.02%	< .000001	17.66
850	0.28%	.000008	6.75
900	0.02%	.000005	11.39

Upper Renshaw

Flow (cfs)	Net Q	Sol	Max F
50	0.43%	< .000001	1.02
75	0.29%	< .000001	0.75
100	0.14%	< .000001	0.86
125	0.14%	< .000001	0.75
150	0.05%	< .000001	2.82
175	0.04%	< .000001	2.06
200	0.05%	< .000001	1.50
225	0.02%	< .000001	1.28
250	0.03%	< .000001	1.19
275	0.04%	< .000001	1.31
300	0.04%	< .000001	1.67
350	0.03%	< .000001	1.26
400	0.03%	< .000001	0.97
450	0.02%	< .000001	1.76
500	0.02%	< .000001	1.65
550	0.01%	< .000001	1.62
600	0.01%	< .000001	1.28
650	0.02%	< .000001	1.14
700	0.02%	< .000001	1.04
750	0.03%	< .000001	0.97
800	0.03%	< .000001	0.91
850	0.02%	< .000001	0.98
900	0.02%	< .000001	0.99

Lower Renshaw

Flow (cfs)	Net Q	Sol	Max F
50	14.71%	< .000001	1.40
75	4.29%	< .000001	1.33
100	2.14%	< .000001	2.43
125	0.66%	< .000001	2.06
150	0.45%	< .000001	1.98
175	0.28%	< .000001	1.92
200	0.16%	< .000001	1.83
225	0.08%	< .000001	2.16
250	0.01%	< .000001	2.58
275	0.01%	< .000001	2.17
300	.05%	< .000001	2.55
350	0.15%	< .000001	2.39
400	0.13%	< .000001	3.21
450	0.13%	< .000001	3.42
500	0.11%	< .000001	4.37
550	0.11%	< .000001	3.57
600	0.11%	< .000001	2.68
650	0.10%	< .000001	2.37
700	0.09%	< .000001	1.91
750	0.09%	< .000001	4.85
800	0.07%	< .000001	4.59
850	0.07%	< .000001	4.13
900	0.05%	< .000001	3.11

Upper Isolation

Flow (cfs)	Net Q	Sol	Max F
50	0.17%	< .000001	1.33
75	0.43%	< .000001	1.03
100	0.50%	< .000001	1.16
125	0.29%	< .000001	1.01
150	0.24%	< .000001	1.02
175	0.19%	< .000001	1.02
200	0.24%	< .000001	1.24
225	0.17%	< .000001	1.00
250	0.14%	< .000001	1.67
275	0.14%	< .000001	2.00
300	0.18%	< .000001	2.72
350	0.10%	< .000001	2.07
400	0.10%	< .000001	3.64
450	0.08%	< .000001	3.56
500	0.02%	< .000001	2.25
550	0.01%	< .000001	1.91
600	0.04%	< .000001	1.60
650	0.07%	< .000001	1.64
700	0.11%	< .000001	1.96
750	0.10%	< .000001	6.00
800	0.14%	< .000001	3.86
850	0.35%	< .000001	2.88
900	0.36%	< .000001	2.44

APPENDIX I
HABITAT SUITABILITY CRITERIA

Fall-run Chinook Salmon Spawning HSC

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Substrate Code	SI Value
0.00	0.00	0.0	0	0	0
0.09	0.00	0.4	0	1	0
0.10	0.06	0.5	0.39	1.2	0.05
0.15	0.08	0.6	0.59	1.3	1
0.22	0.10	0.7	0.76	2.4	0.6
0.29	0.12	0.8	0.88	3.5	0.03
0.36	0.14	0.9	0.95	4.6	0.03
0.43	0.17	1.0	0.99	6.8	0
0.50	0.21	1.1	1	100	0.00
0.57	0.24	6.7	0		
0.64	0.29	100.0	0		
0.71	0.33				
0.78	0.38				
0.85	0.43				
0.92	0.48				
0.95	0.50				
0.99	0.53				
1.06	0.59				
1.13	0.64				
1.20	0.70				
1.27	0.75				
1.34	0.80				
1.41	0.84				
1.48	0.88				
1.55	0.92				
1.62	0.95				
1.69	0.97				
1.76	0.99				
1.83	1.00				
1.97	1.00				
2.04	0.99				
4.15	0.50				
6.31	0.00				
100.00	0.00				

Steelhead/rainbow Trout Spawning HSC

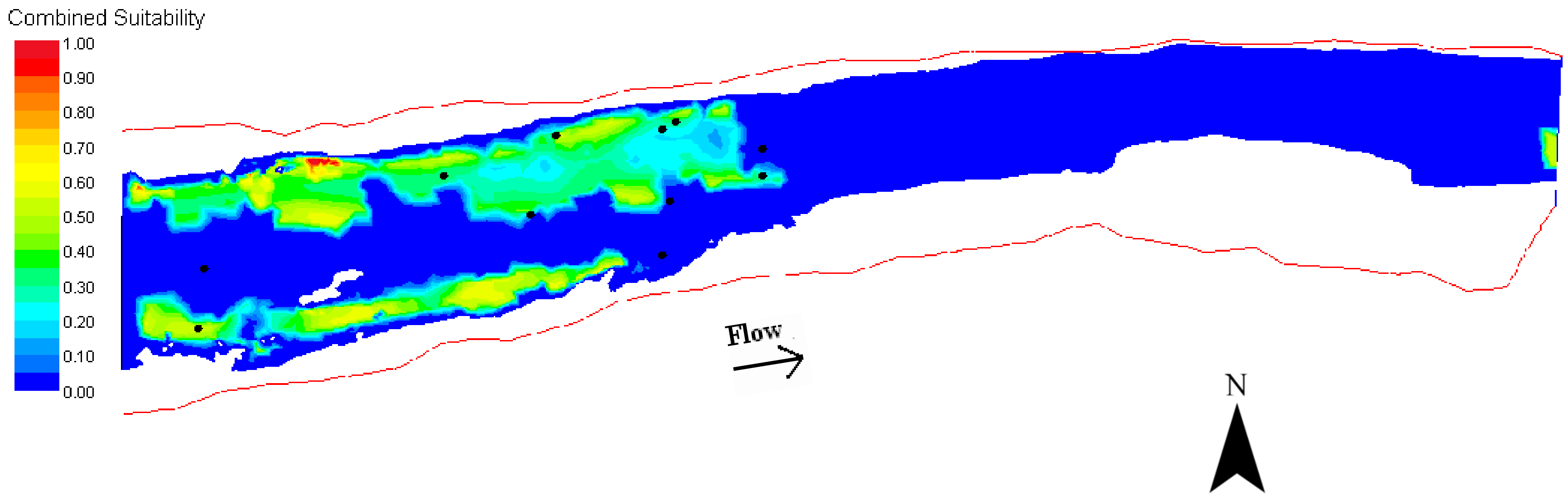
Water Depth (ft)	SI Value
0.00	0
0.3	0
0.4	0.16
0.5	0.26
0.6	0.38
0.7	0.51
0.8	0.64
0.9	0.75
1.0	0.85
1.1	0.92
1.2	0.96
1.3	0.99
1.4	1
1.5	1
28.6	0
100	0

Water Velocity (ft/s)	SI Value
0.00	0
0.60	0
0.61	0.08
0.70	0.14
0.80	0.25
0.90	0.38
1.00	0.53
1.10	0.66
1.20	0.78
1.30	0.87
1.40	0.94
1.50	0.98
1.60	1.00
1.70	1.00
1.80	0.99
1.90	0.97
2.00	0.95
2.10	0.93
2.20	0.90
2.30	0.87
2.40	0.85
2.50	0.82
2.60	0.80
2.70	0.78
2.80	0.76
2.90	0.73
3.00	0.70
3.10	0.66
3.20	0.61
3.30	0.56
3.40	0.49
3.50	0.41
3.60	0.33
3.70	0.25
3.80	0.17
3.89	0.11
3.90	0
100	0

Substrate Code	SI Value
0	0
0.1	0
1	0.38
1.2	1.00
1.3	0.44
2.3	0.26
2.4	0.07
3.4	0.06
3.5	0.04
4.6	0.01
6.8	0
10	0
100	0

APPENDIX J
RIVER2D COMBINED SUITABILITY OF REDD LOCATIONS

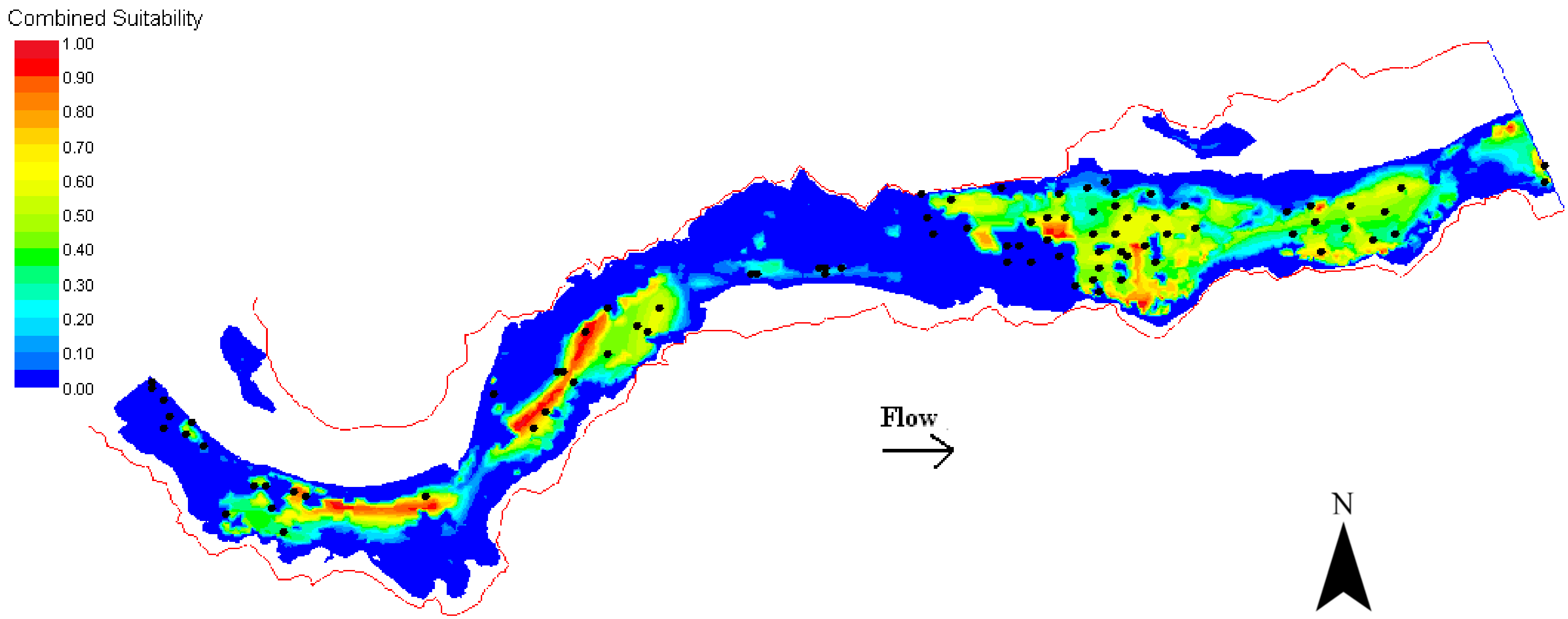
SHOOTING GALLERY STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 202 CFS



Scale: 1: 1001

Redd locations: ●

LOWER GORGE STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 195 CFS

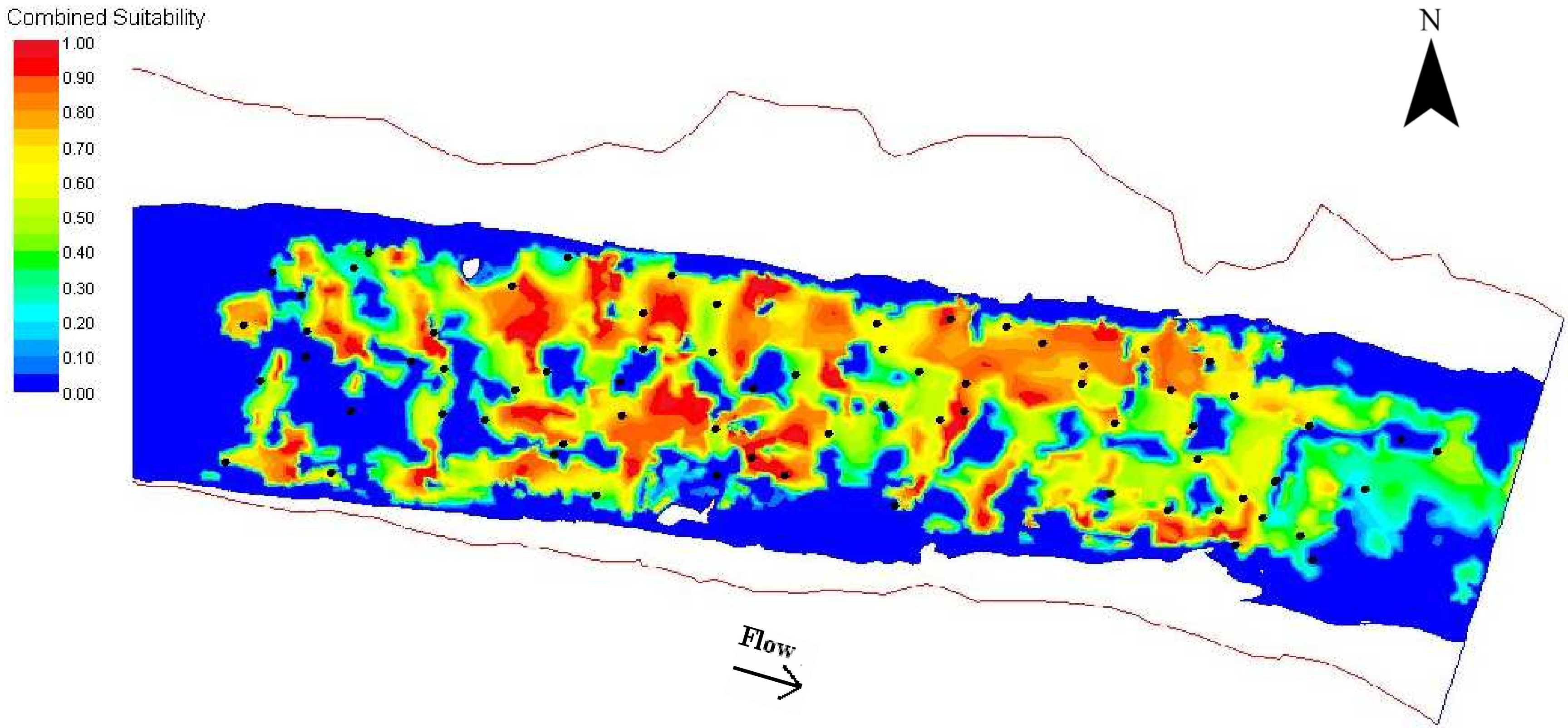


Scale: 1: 1660

Redd locations: ●

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Spawning Report
January 21, 2011

UPPER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 187 CFS

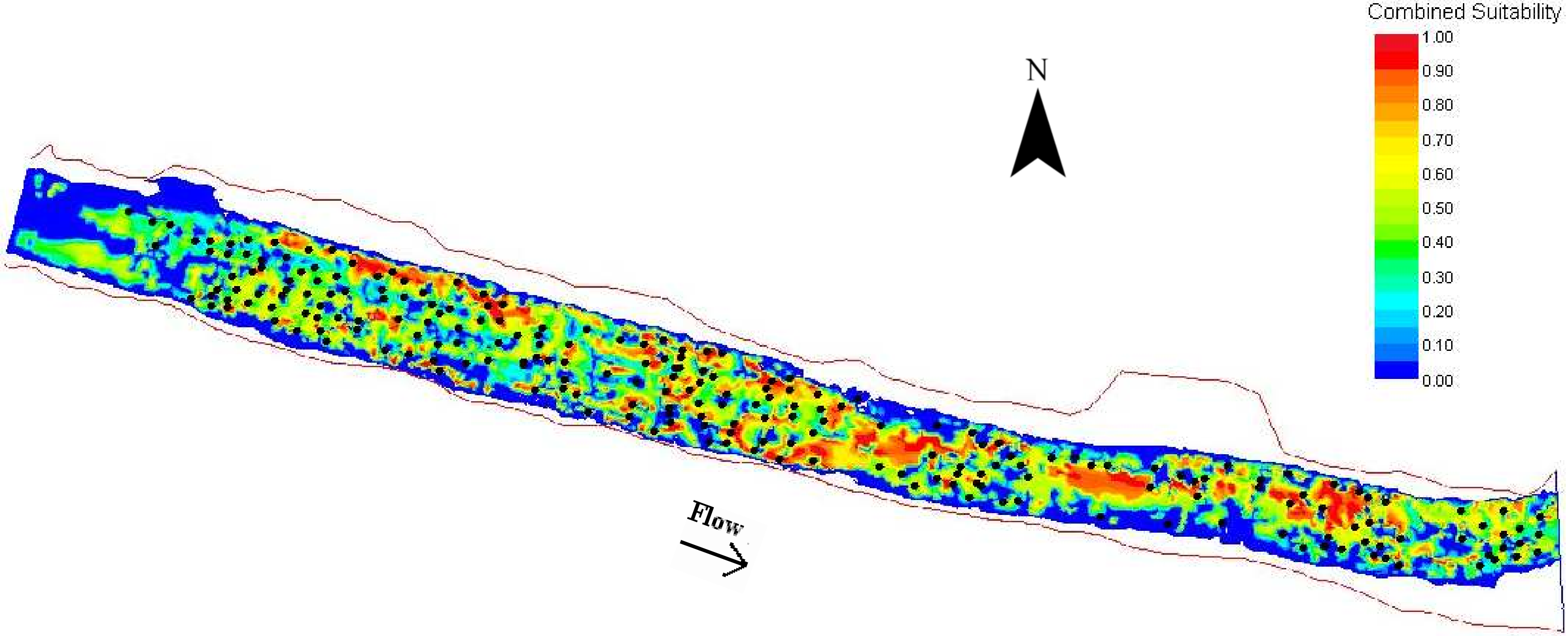


Scale: 1: 515

Redd locations: ●

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Spawning Report
January 21, 2011

LOWER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 186 CFS

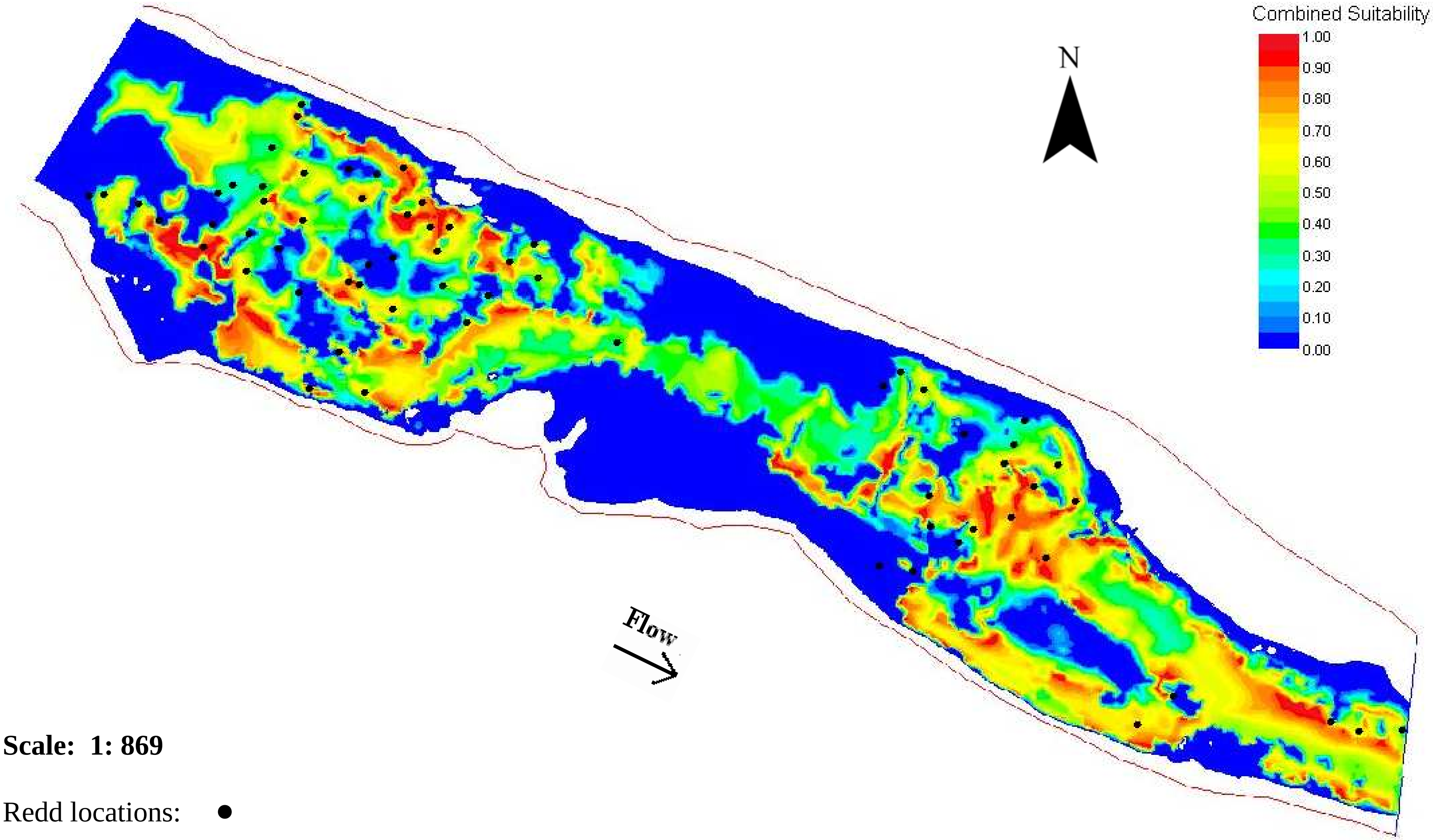


Scale: 1: 1787

Redd locations: ●

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Spawning Report
January 21, 2011

UPPER ISOLATION STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 184 CFS



Scale: 1: 869

Redd locations: ●

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Spawning Report
January 21, 2011

APPENDIX K
HABITAT MODELING RESULTS

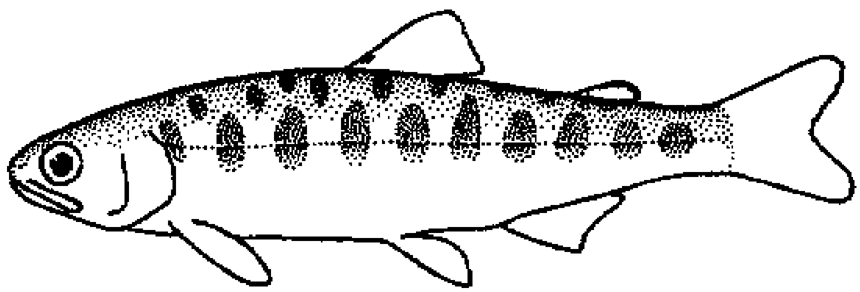
Fall-run Chinook Salmon spawning WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation	Total
50	2,583	3,909	5,032	21,851	7,325	78,145
75	3,067	5,608	6,783	30,376	9,900	107,008
100	3,477	6,915	8,270	37,254	11,894	130,194
125	3,861	7,866	9,513	43,561	13,885	151,079
150	4,171	8,630	10,492	48,933	15,769	168,950
175	4,473	9,356	11,324	53,862	17,793	185,871
200	4,663	9,969	11,883	57,038	19,418	197,705
225	4,754	10,466	12,239	59,287	20,742	206,377
250	4,757	10,861	12,475	60,730	21,808	212,410
275	4,724	11,141	12,583	61,516	22,550	216,026
300	4,667	11,377	12,604	61,828	23,002	217,880
350	4,540	11,700	12,465	61,343	23,261	217,553
400	4,440	11,808	12,131	59,901	22,938	213,538
450	4,294	11,862	11,743	57,963	22,270	207,615
500	4,038	11,851	11,248	55,520	21,334	199,662
550	3,804	11,808	10,764	53,141	20,419	191,877
600	3,582	11,733	10,321	50,784	19,483	184,133
650	3,370	11,614	9,878	48,448	18,589	176,448
700	3,181	11,496	9,454	46,231	17,728	169,132
750	3,010	11,388	9,055	44,046	16,932	162,105
800	2,841	11,248	8,649	41,915	16,081	155,008
850	2,751	11,141	8,298	39,988	15,392	148,934
900	2,652	11,130	7,964	38,222	14,703	143,371

Steelhead/rainbow Trout Spawning WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation	Total
50	320	955	1,536	5,214	2,102	12,963
75	361	1,553	2,285	8,019	3,030	19,518
100	396	2,004	2,935	10,278	3,762	24,801
125	420	2,336	3,522	12,475	4,555	29,834
150	434	2,620	4,011	14,445	5,350	34,380
175	448	2,891	4,456	16,221	6,188	38,663
200	452	3,111	4,745	17,416	6,839	41,681
225	447	3,277	4,957	18,309	7,355	43,962
250	432	3,399	5,088	18,891	7,744	45,508
275	417	3,462	5,158	19,203	7,977	46,357
300	406	3,515	5,186	19,343	8,107	46,793
350	402	3,528	5,137	19,063	8,104	46,379
400	404	3,435	5,026	18,374	7,878	44,949
450	391	3,294	4,894	17,405	7,514	42,878
500	368	3,108	4,710	16,167	7,015	40,151
550	340	2,920	4,519	14,897	6,526	37,379
600	317	2,756	4,354	13,606	6,031	34,641
650	301	2,609	4,158	12,325	5,558	31,937
700	286	2,488	3,952	11,065	5,110	29,314
750	274	2,382	3,735	9,873	4,686	26,814
800	266	2,290	3,483	8,719	4,250	24,330
850	286	2,213	3,255	7,724	3,879	22,218
900	287	2,162	3,022	6,901	3,507	20,325

FLOW-HABITAT RELATIONSHIPS FOR JUVENILE SPRING-RUN AND FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT REARING IN CLEAR CREEK BETWEEN CLEAR CREEK ROAD AND THE SACRAMENTO RIVER



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CVPIA INSTREAM FLOW INVESTIGATIONS CLEAR CREEK JUVENILE SPRING-RUN AND FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT REARING

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 Clear Creek Road and the Sacramento River. These investigations are part of the Central Valley Project Improvement Act (CVPIA) Instream Flow 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 (CDFG). The purpose of these investigations is to provide scientific data to the U. S. Fish and Wildlife Service Central Valley Project Improvement Act 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 Flow Investigations, which ran from February 1995 through September 2001.

ABSTRACT

Flow-habitat relationships were derived for spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing in Clear Creek between Clear Creek Road Bridge and the Sacramento River. A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this study to model available habitat. Habitat was modeled for ten sites in the Lower Alluvial segment, which were representative of the mesohabitat types available in that segment for spring-run and fall-run Chinook salmon and steelhead/rainbow trout. Bed topography was collected for these sites using a total station and a survey-grade Real-Time Kinematic Global Positioning System (RTK GPS). 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 in 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 roughness heights 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. Fall-run Chinook salmon habitat suitability criteria (HSC) were developed from depth, velocity, adjacent velocity, and cover measurements collected at the locations of 326 fall-run Chinook salmon fry and 184 fall-run Chinook salmon juvenile. Logistic regression was used to develop the HSC. The horizontal locations of a separate set of fall-run Chinook salmon observations, located in nine of the ten study sites, were measured with a total station to use in biological validation of the habitat models. The spring-run Chinook salmon and steelhead/rainbow trout HSC used in this study were those developed in a previous study of the Upper Alluvial and Canyon segments. No biological validation was performed for spring-run Chinook salmon and steelhead/rainbow trout in the Lower Alluvial segment. The biological validation showed a significant difference between the suitability of occupied and unoccupied locations for both fry and juvenile fall-run Chinook salmon. The 2-D model predicts the highest total weighted usable area values (WUA) for: 1) spring-run Chinook salmon fry rearing at 900 cfs; 2) spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing at 850 cfs; 3) fall-run Chinook salmon and steelhead/rainbow trout fry rearing at 50 cfs; and 4) fall-run Chinook salmon juvenile rearing at 350 cfs. The results of this study suggest that the flow recommendations in the CVPIA Anadromous Fish Restoration Program during the spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing period of October-September (150-200 cfs) may be close to achieving maximum habitat availability and productivity for rearing fall-run Chinook salmon fry and juveniles and steelhead/rainbow trout fry in the Lower Alluvial Segment of Clear Creek (79 to 94 % of maximum WUA), but is substantially lower than the maximum habitat availability for rearing spring-run Chinook salmon fry and juveniles and steelhead/rainbow trout juveniles (51 to 61 % of maximum WUA). Given the much large population size of fall-run Chinook salmon, versus spring-run Chinook salmon and steelhead, habitat is much more likely to be limiting for this race/species.

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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. For Clear Creek, the Central Valley Project Improvement Act Anadromous Fish Restoration Plan (AFRP) 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). The Clear Creek study was planned to be a 5-year effort, the goals of which are 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]. The rearing habitat study sites for the fourth phase of the study were selected that encompassed the Lower Alluvial segment of the creek, including the restored portion of a two-mile restoration reach (U.S. Fish and Wildlife Service 2005a). The goal of this report was to produce models predicting the availability of physical habitat in Clear Creek between Clear Creek Road and the Sacramento River, including the restored portion of the two-mile restoration reach, for spring-run and fall-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. 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 spawning) 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 the hydraulic and structural conditions (depth, velocity, substrate or cover)

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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 areal extent of study segments
habitat mapping	delineate the areal 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 fall-run Chinook salmon 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

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.

Conceptual models are essential for establishing theoretical or commonly-accepted frameworks, upon which data collection and scientific testing can be interpreted meaningfully. A conceptual model of the link between rearing habitat and population change may be described as follows (Bartholow 1996, Bartholow et al. 1993, Williamson et al. 1993). 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 2009a). 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 the Lower Alluvial segment of Clear Creek.

The results of this study are intended to support or revise the flow recommendations above. The range of Clear Creek flows to be evaluated for management generally falls within the range of 50 cfs (the minimum required release from Whiskeytown Dam) to 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 to be evaluated for management. The assumptions of this study are: 1) that physical habitat is the limiting factor for salmonid populations in Clear Creek; 2) that rearing habitat quality can be characterized by depth, velocity, adjacent velocity and cover; 3) that the ten study sites are representative of anadromous salmonid rearing habitat in Clear Creek between Clear Creek Road and the Sacramento River, including the restored portion of the two-mile restoration reach; 4) theoretical equations of physical processes along with a description of stream bathymetry and roughness height and a stage-discharge relationship provide sufficient input to simulate velocity distributions through a study site; and 5) that Clear Creek is in a state of dynamic equilibrium.

METHODS

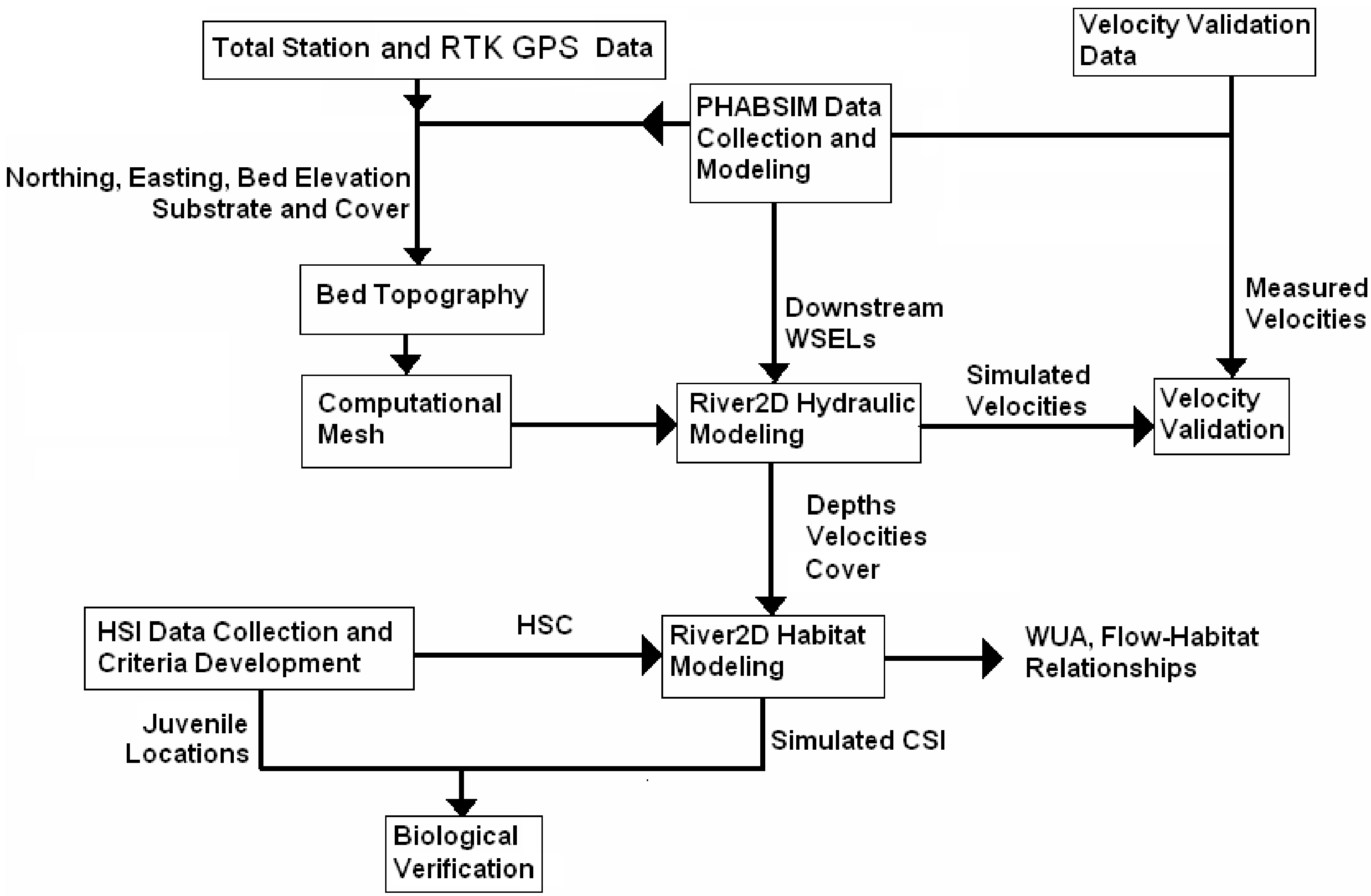
Approach

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]) component of IFIM. River2D inputs include the bed topography and bed roughness height, 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 (Gard 2009b). 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 height, 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 PHABSIM 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

[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.



PHABSIM using the collected calibration water surface elevations (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.

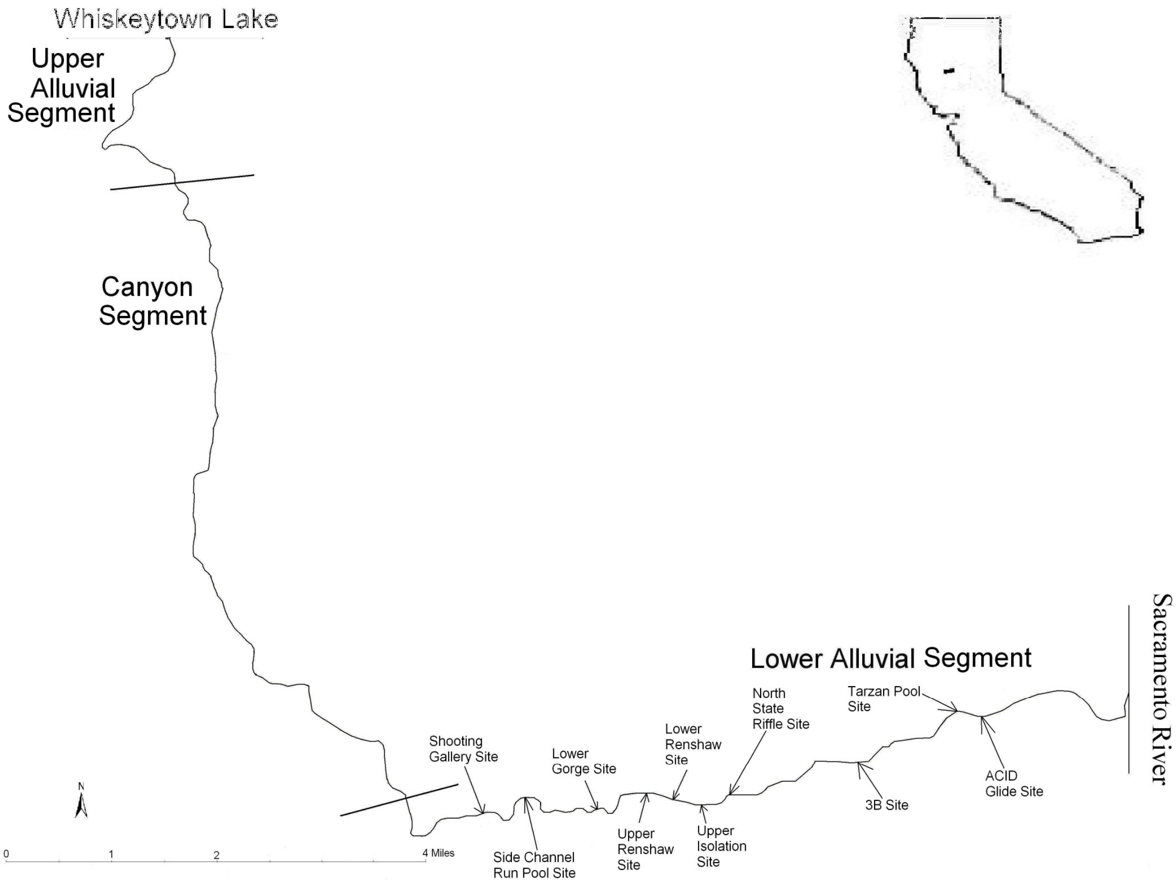
Study Segment Selection

Study segments were delineated within the study reach of Clear Creek between Whiskeytown Dam and the Sacramento River (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 of the lower alluvial segment, excluding the two-mile restoration reach, was performed February 4-7, 2008. This work consisted of hiking and wading downstream from Clear Creek Road bridge to the confluence with the Sacramento River, 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: bar complex glides, bar complex pools, bar complex riffles, bar complex 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 “bar complex” and “flatwater” 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 2007 flown at 1:4200 were used in conjunction with direct observations to determine the aerial extent of each habitat unit. The location of the upstream and downstream boundaries of habitat units was recorded with a Global Positioning System (GPS) unit. The habitat units were also delineated on the aerial photos. Following the completion of the mesohabitat mapping on February 7, 2008, the mesohabitat types and number of habitat units of each habitat type 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 habitat mapping, we used a stratified random sampling design to select five juvenile habitat study sites that, together with five previously selected spawning sites (U.S. Fish and Wildlife Service 2011a), adequately represent the mesohabitat types present in each segment. The five new study sites were randomly selected out of all of the mesohabitat units of the mesohabitat types that were not adequately represented in the five previously selected study sites. Mesohabitat types were considered adequately represented by at least one mesohabitat unit of less common mesohabitat types and multiple mesohabitat units of more common mesohabitat types. As a result, the mesohabitat composition of the study sites, taken together, were roughly proportional to the mesohabitat composition of the entire segment. The five new study sites were randomly selected, stratified by mesohabitat type, to ensure unbiased selection of the study sites. 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.

Table 2. Mesohabitat 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, 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.

Transect Placement (study site setup)

The study sites were established between February and July 2008. 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 roughness heights 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 900 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 Data Collection

Vertical benchmarks were established at each site to serve as the vertical elevations to which all elevations (streambed and water surface) were referenced. Vertical benchmarks consisted of lag bolts driven into trees and fence posts or painted bedrock points. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site to serve as the horizontal locations to which all horizontal locations (northings and eastings) were referenced.

Hydraulic and structural data collection began in February 2008 and was completed in March 2009. 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 bank-full 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 a short way downstream of the site that was higher than that measured at the downstream transect thalweg simply due to natural variation in topography (Figure 3). This stage of zero flow downstream of the site acts as a control on the water surface elevations at the downstream transect, and could cause errors in the WSELs. Because the true stage of zero flow is needed to

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[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
Total Station	Slope Distance	± (5ppm + 5) mm	
Total Station	Angle		4 sec
Survey-Grade RTK GPS	Northing, Easting, Bed Elevation		0.3 cm
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)

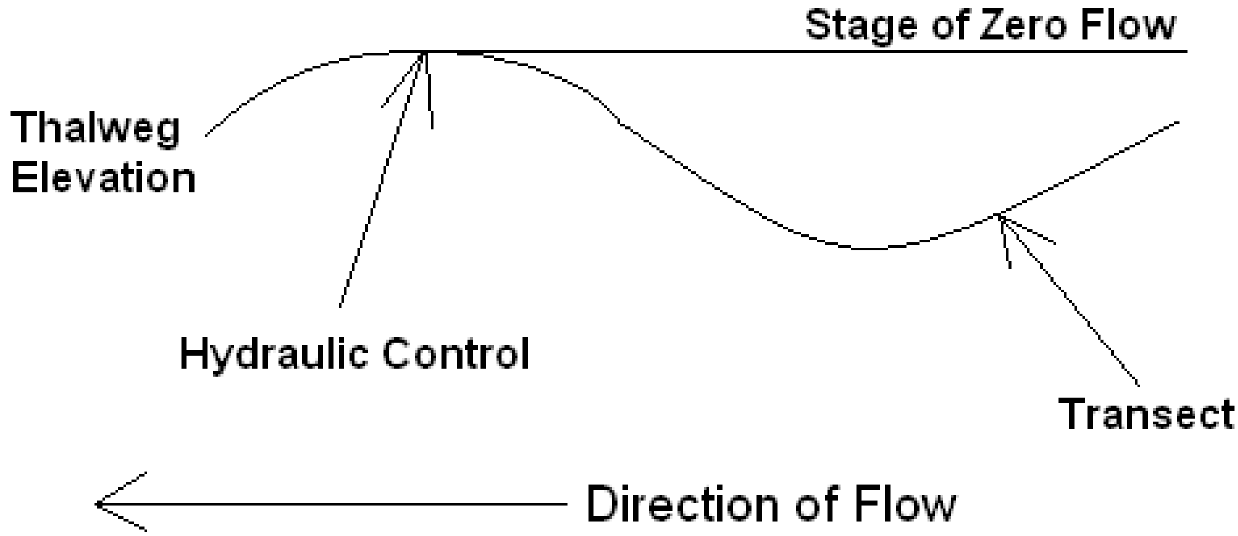
Table 5. Cover coding system.

Cover Category	Cover Code
No cover	0
Cobble	1
Boulder	2
Fine woody vegetation (< 1" [2.5 cm] diameter)	3
Fine woody vegetation + overhead	3.7
Branches	4
Branches + overhead	4.7
Log (> 1' [0.3 m] diameter)	5
Log + overhead	5.7
Overhead cover (> 2' [0.6 m] above substrate)	7
Undercut bank	8
Aquatic vegetation	9
Aquatic vegetation + overhead	9.7
Rip-rap	10

accurately calibrate the water surface elevations on the downstream transect, this stage of zero flow in the thalweg downstream of the downstream transect was surveyed in using differential leveling. If the true stage of zero flow was not measured as described above, the default stage of zero flow would be the thalweg elevation at the transect. Depth and velocity measurements were made using a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter. 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]. For sites that did not include the total

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

Figure 3. Stage of zero flow diagram.



flow of Clear Creek, we measured the flow of a side channel that carried the remaining flow of Clear Creek at four different flows, to use in developing a regression relationship between the side channel flow and the total Clear Creek flow.

We collected the data between the upstream and downstream transects by obtaining the bed elevation and horizontal location of individual points with a total station or survey-grade Real Time Kinematic (RTK) GPS, while the cover and substrate were visually assessed at each point. Topography data, including substrate and cover data, were also collected for a minimum of a half-channel width upstream of the upstream transect to improve the accuracy of the flow distribution at the upstream end of the sites. Substrate and cover along the transects were also determined visually. At each change in substrate size class or cover type, the distance from the headpin or tailpin was measured using a hand held laser range finder or measuring tape.

To validate the velocities predicted by the 2-D model, depth, velocity, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter. These 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 per 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[6] files. A separate PHABSIM file was constructed for each study site. A total of four or five WSEL sets at low, medium, and high flows were used. 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 data files. Flow/flow regressions were performed for sites which did not include the entire Clear Creek flow, using the flows measured with a wading rod and Marsh-McBirney flow meter in the side channel adjacent to the site and the corresponding gage total flows for the dates that the side channel flows were measured. The regressions were developed from four sets of flows. Calibration flows in the PHABSIM files were the flows calculated from gage readings[7] or from the above flow/flow regressions. The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. 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.

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

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

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 each dataset 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 condition 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 given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs[8]. *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[9] 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*.

Velocity Adjustment Factors (VAFs)[10] 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 were 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

[8] The first three criteria are from U.S. Fish and Wildlife Service (1994), while the fourth criterion is our own criterion.

[9] The reach multiplier is used to vary Manning's n as a function of discharge.

[10] VAFs are used in PHABSIM to adjust velocities (see Milhous et al. (1989)), but in this study are only used as an indicator of potential problems with the stage-discharge relationship.

program. An artificial extension one channel-width-long was added upstream of the topography data collected upstream of the study 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 upsteam transect and within the study site.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness height value for each point, while the cover files contain the horizontal location, bed elevation and cover code for each point. The initial bed roughness height value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness height values in Table 6, with the bed roughness height value for each point computed as the sum of the substrate bed roughness height value and the cover bed roughness height value for the point. The resulting initial bed roughness height value for each point was therefore a combined matrix of the substrate and cover roughness height values. The bed roughness height values for substrate in Table 6 were computed as five times the average particle size[11]. The bed roughness height 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 the spreadsheet 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[12] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. The first step in refining the TIN was to conduct a quality assurance/quality control process, consisting of a point-by-point inspection to eliminate quantitatively wrong points, and a qualitative process where we checked the features constructed in the TIN against aerial photographs to make sure we had represented landforms correctly. 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 and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final bed file as an input. The first stage in creating the

[11] 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).

[12] 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 fall on the breaklines (Steffler 2002).

Table 6. Initial bed roughness height 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[13]	9	0.29
10	1.4	9.7	0.57
		10	3.05

[13] 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 0.1, 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

computational mesh was to define mesh breaklines[14] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and then additional nodes were added as needed 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) 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.

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 roughness heights 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 roughness heights of the computational mesh elements were then modified by multiplying them by a constant bed roughness height 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 $\varepsilon_3 = 0.1$).

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[14] Mesh breaklines are a feature of the R2D_MESH program which force edges of the computation mesh elements to fall on the mesh breaklines and force the TIN of the computational mesh to linearly interpolate the bed elevation and bed roughness values of mesh nodes between the nodes at the end of each breakline segment (Waddle and Steffler 2002). A better fit between the bed and mesh TINs is achieved by having the mesh and bed breaklines coincide.

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[15]. 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[16].

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 (for intercept equals zero) 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 cover values into

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[15] 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).

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

habitat quality (HSI). HSI refers to the dependent 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[17].

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 selecting areas without that cover type. Guay et al. (2000) proposed a modification of this 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 is employed in this study.

HSC data collection for fall-run Chinook salmon YOY (fry and juvenile) rearing was conducted January 2007 - September 2007. Data were collected by snorkeling upstream through the habitat units. We also collected depth, velocity, adjacent velocity and cover data on locations which were not occupied by YOY Chinook salmon (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 out 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, with a range of 0.5 to 10 feet (0.15 to 3.05 m) by 0.5 foot (0.15 m) increments, with the values produced by a random number generator.

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[17] 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. The adjacent velocity was measured within 2 feet (0.61 m) on either side of the location where the velocity was the highest. Two feet (0.61 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 median 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 (1.22 m) (i.e., 4 feet [1.22 m] x ½ = 2 feet [0.61 m]).

When conducting snorkel surveys adjacent to the bank, one person snorkeled upstream along each bank and placed a weighted, numbered tag at each location where YOY Chinook salmon were observed. The snorkeler recorded the tag number, 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 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 300-foot-long [91m] tape) were also recorded. The cover coding system used is shown in Table 5. A 300-foot-long (91 m) tape was put out with one end at the location where the snorkeler finished and the other end where the snorkeler began. Three people went up the tape, one with a stadia rod and data book and the other two with wading rods and velocity meters. 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 (1 m) of the location, "tag within 3" was recorded on that line in the data book and the people proceeded to the next 20-foot (6 m) mark on the tape, using the distance from the bank on the next line. If there was no tag within 3 feet (1 m) of that location, one of the people with the wading rod measured the depth, velocity, adjacent velocity and cover at that location. Depth was recorded to the nearest 0.1 ft (0.03 m) and average water column velocity and adjacent velocity were recorded to the nearest 0.01 ft/s (0.003 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. The same procedures were used for sampling mid-channel, except that distance was measured from the edge of the width of channel sampled rather than from water's edge.

HSC data collection for spring-run Chinook salmon and steelhead/rainbow trout was not conducted for the Lower Alluvial segment. HSC developed for the Upper Alluvial and Canyon segments of Clear Creek were used (U.S. Fish and Wildlife 2011b).

Biological Validation Data Collection

Biological validation data were collected to test the hypothesis that the compound suitability predicted by the River2D model is higher at locations where fry or juveniles were present than in locations where fry or juveniles were absent. The biological validation dataset was a separate dataset which was not used to develop the habitat suitability criteria. The compound suitability is the product of the depth suitability, the velocity suitability, the adjacent velocity suitability and the cover suitability. The collected biological validation data were the horizontal locations of fry and juveniles. The horizontal locations of fall-run Chinook salmon fry and juveniles found

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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).

during surveys were recorded by sighting from the total station to a stadia rod and prism. Depth, velocity, adjacent velocity, and cover type as described in the previous section on habitat suitability criteria data collection were also measured. The horizontal locations of where fry or juveniles were not present (unoccupied locations) were also recorded with the total station. The hypothesis that the compound suitability predicted by the River2D model is higher at locations where fry and juveniles were present than in locations where fry and juveniles were absent was statistically tested with a Mann-Whitney U test. No biological validation data were collected for spring-run Chinook salmon and steelhead/rainbow trout in the Lower Alluvial segment.

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.

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.

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 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:

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

We computed values of equation (3) for the range of occupied adjacent velocities, and rescaled the values so that the largest value was 1.0. We 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}.

To evaluate whether we 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 3.7, 4, 4.7, 5.7, 7 and 9.7), and Cover Group 0 (all other cover codes). In U.S. Fish and Wildlife Service (2005b), which describes the derivation of these two cover groups, we had addressed the availability of cover in developing the Sacramento River criteria 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. We were unable to use this process for the Lower Alluvial segment of Clear Creek because of the low amount of cover group 1 present in the Lower Alluvial segment of Clear Creek. Instead, we developed the Clear Creek fall-run Chinook salmon cover criteria using a logistic regression analysis. For a categorical independent variable, the result of a logistic regression is the percentage of occupied locations (number of occupied locations / (number of occupied locations + number of unoccupied locations)) for each category of the independent variable.

The first step in the development of the cover criteria was to group cover codes, so that there were no significant differences within the groups and a significant difference between the groups, using Pearson's test for association. We excluded cover codes from this analysis that had a total (occupied plus unoccupied) of two or less observations. We combined together the occupied and unoccupied observations in each group of cover types and calculated the percentage of occupied locations for each group. The HSI for each group was calculated by dividing the percent of occupied locations in each group by the percent of occupied locations in the group with the highest percent of occupied locations. This procedure normalized the HSI, so that the maximum HSI value was 1.0. The HSI for cover codes that had a total of two or less observations was determined based on Sacramento River cover criteria (U.S. Fish and Wildlife Service 2005b).

The spring-run Chinook salmon and steelhead/rainbow trout HSC utilized in this study were those developed for the rearing study of the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2011b).

Biological Validation

We determined the combined habitat suitability predicted by River2D at each fry and juvenile observation location in the sites where fall-run Chinook salmon fry and juvenile locations were recorded with total station and prism. We ran the River2D cdg files at the flows present in the study sites for the dates that the biological validation data were collected. We used the horizontal location measured for each observation to determine the location of each observation in the

River2D sites. We used the horizontal locations recorded with the total station where fry or juveniles were not present for the unoccupied points. We used Mann-Whitney U tests (Zar 1984) to determine whether the combined suitability predicted by River2D was higher at fry or juveniles were present versus locations where fry or juveniles were absent.

Habitat Simulation

The final step was to simulate available habitat for each site. Preference curve files were created containing the digitized fry and juvenile rearing HSC developed for the spring-run and fall-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 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 to calculate the WUA values for each mesohabitat type in each site over the desired range of flows for all ten sites. The total WUA for the Lower Alluvial segment was calculated using the following equation:

$$\text{Segment WUA} = \Sigma\,(\text{Ratio}_i * \Sigma\ \text{Mesohabitat Unit}_{i,j}\ \text{WUA}), \qquad (4)$$

where Ratio_i is the ratio of the total area of habitat type_i present in the Lower Alluvial segment to the area of habitat type_i that was modeled in the Lower Alluvial segment and Mesohabitat $\text{Unit}_{i,j}$ WUA is the WUA for mesohabitat unit_j of habitat type_i that was modeled in the Lower Alluvial segment. For purposes of this analysis, the restored habitat was considered another mesohabitat type, with the ratio based on the area of study site 3B and the total area of restored habitat (the sum of the areas of restoration sites 3A and 3B).

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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.

RESULTS

Study Segment Selection

We 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 addressed spring-run Chinook salmon and steelhead/rainbow trout rearing while the last segment where this study occurred addresses spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing.

Habitat Mapping

A total of 166 mesohabitat units were mapped for the Lower Alluvial 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.

Study Site Selection

After reviewing the field reconnaissance notes and considering time and manpower constraints, five additional study sites (Table 8, Appendix B) were selected for modeling in the Lower Alluvial segment: 1) Side-Channel Run Pool; 2) North State Riffle; 3) Restoration Site 3B; 4) Tarzan Pool; and 5) ACID Glide. The mesohabitat composition of the study sites versus the entire Lower Alluvial segment is given in Table 9.

Hydraulic and Structural Habitat Data Collection

Water surface elevations were measured at all sites at the following flow ranges: 79-95 cfs, 201-246 cfs, 378-445 cfs, and 568-650 cfs. Depth and velocity measurements on the transects were collected at the Side-Channel Pool-Run transects at 246 cfs, North State Riffle transects at 208 cfs, Restoration Site 3B transects at 226 and 86.9 cfs, Tarzan Pool transects at 94 cfs, and ACID Glide transects at 95 cfs. The number and density of points collected for each site are given in Table 10.

No validation velocities, other than those measured at the transects, were collected for the Side-Channel Pool-Run site due to an oversight in the data collection efforts for this site. As a result, we used the 22 velocities collected during biological validation at a flow of 173 cfs for velocity validation for this site, in addition to the transect data. North State Riffle validation velocities were collected at a flow of 204 cfs, Restoration Site 3B validation velocities were collected at a flow of 233 cfs, Tarzan Pool validation velocities were collected at a flow of 217 cfs, and ACID Glide validation velocities were collected at a flow of 261 cfs.

Table 7. Clear Creek Lower Alluvial segment mesohabitat mapping results.

Mesohabitat Type	Lower Alluvial Segment	
	Area (1000 m^2)	Number of Units
Main Channel Riffle (MCRi)	98.3	11
Main Channel Run (MCRu)	1,159.2	45
Main Channel Glide (MCG)	512.8	21
Main Channel Pool (MCP)	792.3	36
Side Channel Riffle (SCRi)	4.1	4
Side Channel Run (SCRu)	60.1	22
Side Channel Glide (SCG)	3.6	3
Side Channel Pool (SCP)	52.2	21
Cascade (C)	25.0	2

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

No problems with water appearing to flow uphill due to measurement error or inaccuracies were found for any of the five study sites. A total of five WSEL sets at low, medium, and high flows were used for the Side Channel Run Pool site, and four WSEL sets were used for North State Riffle, 3B, Tarzan Pool and ACID Glide sites. For total Clear Creek flows less than 125 cfs, the flow for North State Riffle was the same as the total Clear Creek flow. The flow/flow regression equation for North State Riffle for higher flows
(R^2 = 0.97) was as follows:

North State Riffle site flow = 16.3 + 0.861 x total Clear Creek flow (5)

Calibration flows for the PHABSIM calibration were interpolated based on river mile between the gage flows for the Renshaw and P4 gages operated by Graham Matthews and Associates. Calibration flows in the PHABSIM data files and the SZFs used for each transect are given in Appendix C.

Table 8. Sites selected for modeling spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing in the Clear Creek Lower Alluvial segment. Lack of a number in parenthesis indicates one unit for that mesohabitat type in the site.

Site Name	Site Mesohabitat Types
Shooting Gallery	MCRu
Side Channel Run Pool	MCG, MCP (2), MCRu, SCP, SCRu
Lower Gorge	MCG, MCP (2), MCRi, MCRu (2)
Upper Renshaw	MCG
Lower Renshaw	MCG, MCRu
Upper Isolation	MCG, MCRi (2), MCRu (2)
North State Riffle	MCRi
Restoration Site 3B	Restored Habitat
Tarzan Pool	MCP
ACID Glide	MCG

For seven of the ten transects, *IFG4* met the criteria described in the methods for *IFG4* (Appendix C). For both transects at Site 3B, we used only the right bank WSELs in calibration, since these transects would not calibrate using the average of the measured WSELs. For Side Channel Run Pool transect 1 and both transects at ACID Glide, we needed to split the calibration into two flow ranges. For all three transects, using the highest three flows, *IFG4* met the criteria described in the methods for *IFG4*. For Side Channel Run Pool transect 1, using the lowest three flows, *IFG4* did not meet the criteria described in the methods for IFG4; as a result, we used *MANSQ*, which met the criteria described in the methods for *MANSQ*. We were unable to calibrate either transect at ACID Glide using the lowest three flows with either *IFG4* or *MANSQ*. As a result, we had to use IFG4 with the lowest two flows, since there appeared to be a change in the stage-discharge relationship for these transects above versus below 230 cfs. Even with two

Table 9. Clear Creek Lower Alluvial segment and study site mesohabitat composition.

Mesohabitat Type	Lower Alluvial Segment	
	Segment	Sites
Main Channel Riffle (MCRi)	3.6%	6.1%
Main Channel Run (MCRu)	42.9%	48.3%
Main Channel Glide (MCG)	18.9%	30.8%
Main Channel Pool (MCP)	29.3%	14.2%
Side Channel Riffle (SCRi)	0.2%	0%
Side Channel Run (SCRu)	2.2%	0.3%
Side Channel Glide (SCG)	0.1%	0%
Side Channel Pool (SCP)	1.9%	0.3%
Cascade (C)	0.9%	0%

Table 10. Number and density of data points collected for each study site.

Site Name	Number of Points		Density of Points (points/100 m^2)
	Points on Transects	Points Between Transects	
Side Channel Run Pool	90	6,081	127
North State Riffle	89	2,044	100
Restoration Site 3B	84	15,364	39
Tarzan Pool	72	6,383	171
ACID Glide	55	3,853	120

flows, where only the beta value parameter could be evaluated[20], IFG4 did not meet the criteria described in the methods for IFG4, since both beta values were greater than 7. None of the transects deviated significantly from the expected pattern of VAFs (Appendix D). A minor deviation in the expected pattern was observed with the Site 3B upstream transect. VAF values for all transects (ranging from 0.41 to 4.86) were all within an acceptable range for all transects.

RIVER2D Model Construction

For the Side-Channel Run-Pool site, we put a longitudinal high elevation artificial barrier in the lowest-most portion of the south bank of the site to exclude an off channel area from the site. We also put a longitudinal high elevation artificial barrier in the north bank of the upstream extension of the North State Riffle site. The bed topography of the sites is shown in Appendix E. The finite element computational mesh (TIN) for each of the study sites is shown in Appendix F. As shown in Appendix G, the meshes for all sites had QI values of 0.30. The percentage of the original bed nodes for which the mesh differed by less than 0.1 foot (0.03 m) from the elevation of the original bed nodes ranged from 74.2% to 95.0 % (Appendix G).

RIVER2D Model Calibration

The North State Riffle and Tarzan Pool sites were calibrated at 900 cfs, the highest simulation flow. In the cases of the Side Channel Run Pool, 3B and ACID Glide sites, we used the highest measured flow within the range of simulated flows because the simulated WSELs at the highest simulation flow of 900 cfs varied across the channel by more than 0.1 foot (0.031 m), thus resulting in the RIVER2D simulated WSELs differing from the PHABSIM simulated WSELs by more than 0.1 foot (0.031 m). The calibrated cdg files all had a solution change of less than 0.00001, 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 of greater than 1 (Appendix G). All three study sites calibrated at the highest measured flow had calibrated cdg files with WSELs that were within 0.1 foot (0.031 m) of the PHABSIM predicted WSELs (Appendix G), although for Site 3B, this was only true on the banks, where WSEL measurements were made. Of the two study sites calibrated at 900 cfs, ACID Glide had a calibrated cdg file with WSELs that were within 0.1 foot (0.031 m) of the PHABSIM simulated WSEL at 900 cfs. In the case of North State Riffle, the calibrated cdg file had WSELs that were, on average, within 0.1 foot (0.031 m) of the PHABSIM simulated WSEL at 900 cfs, although the maximum WSEL difference exceeded the 0.1 foot (0.031 m) criterion.

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[20] With only two flows, the mean error, differences in calculated versus measured discharges, and differences in simulated versus measured WSELs from a linear regression procedure, such as *IFG4*, are by definition zero.

RIVER2D Model Velocity Validation

For all of the sites, there was a strong to very strong correlation between predicted and measured velocities (Appendix H). However, there were significant differences between individual measured and predicted velocities. The models for four of the five study sites (the exception being 3B Restoration site) were validated, since the correlation between the predicted and measured velocities was greater than 0.6 for those sites. In general, the simulated and measured cross-channel velocity profiles at the upstream and downstream transects (Appendix H[21]) were relatively similar in shape, with some differences in magnitude that fall within the amount of variation in the Marsh-McBirney velocities. For Side Channel Run Pool downstream transect, River2D overpredicted the velocities on the south side and underpredicted the velocities on the north side of the transect. For 3B Restoration Site, River2D overpredicted the velocities on both the north and south sides of the downstream transect. Tarzan Pool had simulated velocities that were low on the south side and high on the north side of the downstream transect. With ACID Glide, the model over-predicted the velocities on the north and south sides of the downstream transect, and over-predicted the velocities on the south side and under-predicted the velocities on the north side of the upstream transect.

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. The net Q was less than 1% for all of the simulation flows for two of the five sites. The Side Channel Run Pool site had two flows that had net Qs exceeding 1%, North State Riffle had three flows with net Qs that exceeded 1%, and Restoration Site 3B had 17 flows with net Qs that exceeded 1%, (Appendix H). The maximum Froude Number was greater than one for all of the simulated flows for Restoration Site 3B, 18 of the 23 simulated flows for Side Channel Run Pool, 20 of the 23 simulated flows for North State Riffle, 15 of the 23 simulated flows for Tarzan Pool, and 8 of the 23 simulated flows for ACID Glide (Appendix H).

Habitat Suitability Criteria (HSC) Data Collection

The sampling dates and Clear Creek flows are shown in Table 11. There were 495 measurements of depth, velocity and adjacent velocity and 481 observations of cover at locations where YOY Chinook salmon were observed. All but one of these measurements was made near the stream banks. There were 18 observations of fish less than 40 mm, 313 observations of 40-60 mm fish, 160 observations of 60-80 mm fish and 47 observations of fish greater than 80 mm.

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[21] 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.

Table 11. Fall-run Chinook salmon YOY HSC sampling dates and flows.

Sampling Dates	Clear Creek Flows[22] (cfs)
January 22-25, 2007	216
March 19-22, 2007	230
May 14-17, 2007	226
Jul 9-12, 2007	112
Sep 4-6, 2007	82

A total of 58 mesohabitat units were surveyed. A total of 2.4 miles (3.9 km) 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 10,536 feet (3,211 m) of Cover Group 0 and 2,263 feet (690 m) of Cover Group 1 were sampled. The spring-run Chinook salmon and steelhead/rainbow trout HSC utilized in this study were those developed for the rearing study of the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2011b).

Biological Validation Data Collection

We conducted snorkeling surveys of four of the five spawning sites and five rearing sites to provide data for biological validation of juvenile fall-run Chinook salmon rearing habitat simulation. Biovalidation data were collected on March 31-April 3, 2008, June 23-25, 2008, and September 15-17, 2008. We sampled a total of 8,645 feet and collected data for 103 occupied and 214 unoccupied locations. We made 14 observations of fall-run Chinook salmon less than 40 mm, 60 observations of 40-60 mm Chinook, 28 observations of 60-80 mm Chinook and 7 observations of greater than 80 mm Chinook.

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

Table 12. Distances sampled for YOY fall-run Chinook salmon HSC data - mesohabitat types

Mesohabitat Type	Habitat distance sampled (ft)
Main Channel Glide	3,264 (995 m)
Main Channel Pool	2,823 (860 m)
Main Channel Riffle	1,658 (505 m)
Main Channel Run	4,207 (1,282 m)
Side Channel Glide	206 (63 m)
Side Channel Pool	162 (49 m)
Side Channel Riffle	50 (15 m)
Side Channel Run	429 (131 m)
Cascade	0 (0 m)

Table 13. Distances sampled for YOY fall-run Chinook salmon HSC data - cover types.

Cover Type	Habitat distance sampled (ft)
None	8,311 (2,533 m)
Cobble	962 (293 m)
Boulder	207 (63 m)
Fine Woody	1,643 (501 m)
Branches	656 (200 m)
Log	309 (94 m)
Overhead	341 (104 m)
Undercut	13 (4 m)
Aquatic Vegetation	354 (108 m)
Rip Rap	4 (1 m)
Overhead + instream	1,741 (531 m)

Habitat Suitability Criteria (HSC) 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 depth and velocity for all three criteria to separate fry from juveniles, but no significant difference for adjacent velocity and cover for the, respectively, < 40 mm versus > 40 mm and <80 mm versus > 80 mm, criteria to separate fry from juveniles. In addition, there was the greatest difference between fry and juvenile habitat use for three of the four parameters for the < 60 mm versus > 60 mm criteria to separate fry from juveniles (see Z and C values in Table 14). Therefore, we selected 60 mm as the criteria to separate fry from juveniles. Hereafter, fry refers to YOY less than 60 mm, while juvenile refers to YOY greater than 60 mm.

Based on observations, fall-run Chinook salmon fry were present between January 22 and May 17, and fall-run Chinook salmon juveniles were present between May 14 and September 6, with the exception of one juvenile seen prior to that time period. As a result, we only used unoccupied data collected between January 22 and May 17 (358 observations) to develop fall-run Chinook salmon fry criteria, and only used unoccupied data collected between May 14 and September 6 (355 observations) to develop fall-run Chinook salmon juvenile criteria. The number of occupied and unoccupied locations for each parameter and life-stage are shown in Table 15.

The coefficients for the final logistic regressions for depth and velocity for fall-run Chinook salmon are shown in Table 16. The p values for all of the non-zero coefficients in Table 16 were less than 0.05, as were the p values for the overall regressions. The final depth and velocity criteria, along with the frequency distributions of occupied and unoccupied locations, are shown in Figures 4 through 7 and Appendix J.

Adjacent velocities were highly correlated with velocities (Table 17). For fall-run fry, the J term was dropped from the regressions because the p-value for velocity was greater than 0.05. For fall-run juvenile adjacent velocity, the K, L and M terms were dropped from the regressions because the p-values for $velocity^2$,$velocity^3$ and $velocity^4$ were greater than 0.05. The logistic regression and remaining coefficients were statistically significant, with the exception of the N term for fall-run juveniles, where the p-value was 0.076. We decided to use this regression because this expression had the lowest p-value for adjacent velocity where all of the other p-values were less than 0.05. The I and N coefficients from equation 3 are given in Table 17. The results of equation 3 and the derivation of the final adjacent velocity criteria (Appendix K) are shown in Figures 8 and 9.

Table 14. Differences in YOY fall-run Chinook salmon 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 = 17.2, p = 0.00003, n = 18, 481	χ^2 = 50.7, p < 0.000001, n = 326, 174	χ^2 = 12.9, p = 0.0003, n = 479, 47
Velocity	χ^2 = 5.8, p = 0.016, n = 18, 481	χ^2 = 30.4, p < 0.000001, n = 326, 174	χ^2 = 13, p = 0.0003, n = 479, 47
Adjacent Velocity	χ^2 =0.6, p = 0.43, n = 18, 481	χ^2 = 5.8, p = 0.02, n = 326, 174	χ^2 = 6.6, p = 0.01, n = 479, 47
Cover	C = 28, p = 0.0058, n = 18, 468	C = 79, p < 0.000001, n = 316, 170	C = 17, p = 0.14, n = 466, 47

Table 15. Number of occupied and unoccupied locations used to develop criteria.

		Depth	Velocity	Adjacent Velocity	Cover
Fall-run Chinook salmon fry	**Occupied**	326	326	326	316
	Unoccupied	358	358	356	358
Fall-run Chinook salmon juvenile	**Occupied**	174	174	174	170
	Unoccupied	355	355	354	355

The initial analysis of cover used the occupied and unoccupied observations in Table 15. For fall-run Chinook salmon fry, there was a total of two or less observations for cover codes 5 (log), 8 (undercut bank) and 9.7 (aquatic vegetation plus overhead). For fall-run Chinook salmon juveniles, there was a total of two or less observations for cover codes 5 and 8. The statistical tests for cover are presented in Tables 18 and 19. For Table 18, an asterisk indicates that presence/absence of fish for those cover codes were significantly different at p = 0.05. For Table 19, 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 both fall-run Chinook salmon fry and juveniles. 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 both 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. For fall-run Chinook salmon fry, we assigned cover codes 5, 8 and 9.7 the same suitability as cover codes 4.7 (branches plus overhead), 3.7 (fine woody plus overhead), 5.7 (log plus overhead) and 4 (branches), since there were no unoccupied observations for cover codes 5, 8 and 9.7, indicating that these cover codes should have a high suitability. For fall-run Chinook juvenile, we assigned cover codes 5 and 8 the same suitability as cover codes 3.7 and 4.7, since the Sacramento River cover criteria had the same suitability for cover codes

Table 16. 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.

Life stage	Parameter	I	J	K	L	M	R^2
fry	depth		0.82889	-1.003297	0.316416	-0.029852	N/A[23]
fry	velocity	0.86261		-3.087963	1.958996	-0.341155	0.13
juvenile	depth	-2.5498	1.60091	-0.261688			0.05
juvenile	velocity		-1.2715		0.564453	-0.166814	N/A[21]

Table 17. 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 3.

Life Stage	Velocity/Adjacent Velocity Correlation	I	N	R^2
fry	0.87	0.379762	0.964650	0.16
juvenile	0.92	-0.384384	0.397939	0.03

3.7, 4.7, 5, 5.7 and 8. The final cover HSC values for both life stages are shown in Figures 10 to 11 and in Appendix J. The spring-run Chinook salmon and steelhead/rainbow trout rearing criteria from U.S. Fish and Wildlife Service (2011b) are given in Appendix J.

Biological Validation

For fall-run Chinook salmon fry, the combined habitat suitability predicted by the 2-D model (Figure 12) was significantly higher for locations with fry (median = 0.33, n = 73) than for locations without fry (median = 0.16, n = 127), based on the Mann-Whitney U test (U =2653.5, $p < 0.000001$). For fall-run Chinook salmon juveniles, the combined habitat suitability predicted by the 2-D model (Figure 13) was significantly higher for locations with juveniles (median = 0.13, n = 29) than for locations without juveniles (median = 0.10, n = 165), based on the Mann-Whitney U test (U =1769.5, p = 0.025). A greater number in the suitability index indicates greater

[23] 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 4. Fall-run Chinook salmon fry rearing depth HSC. The HSC show that fall-run Chinook salmon fry rearing has a non-zero suitability for depths of 0.1 to 6.0 feet (0.03 to 1.83 m) and an optimum suitability at a depth of 0.4 to 0.6 feet (0.12 to 0.18 m).

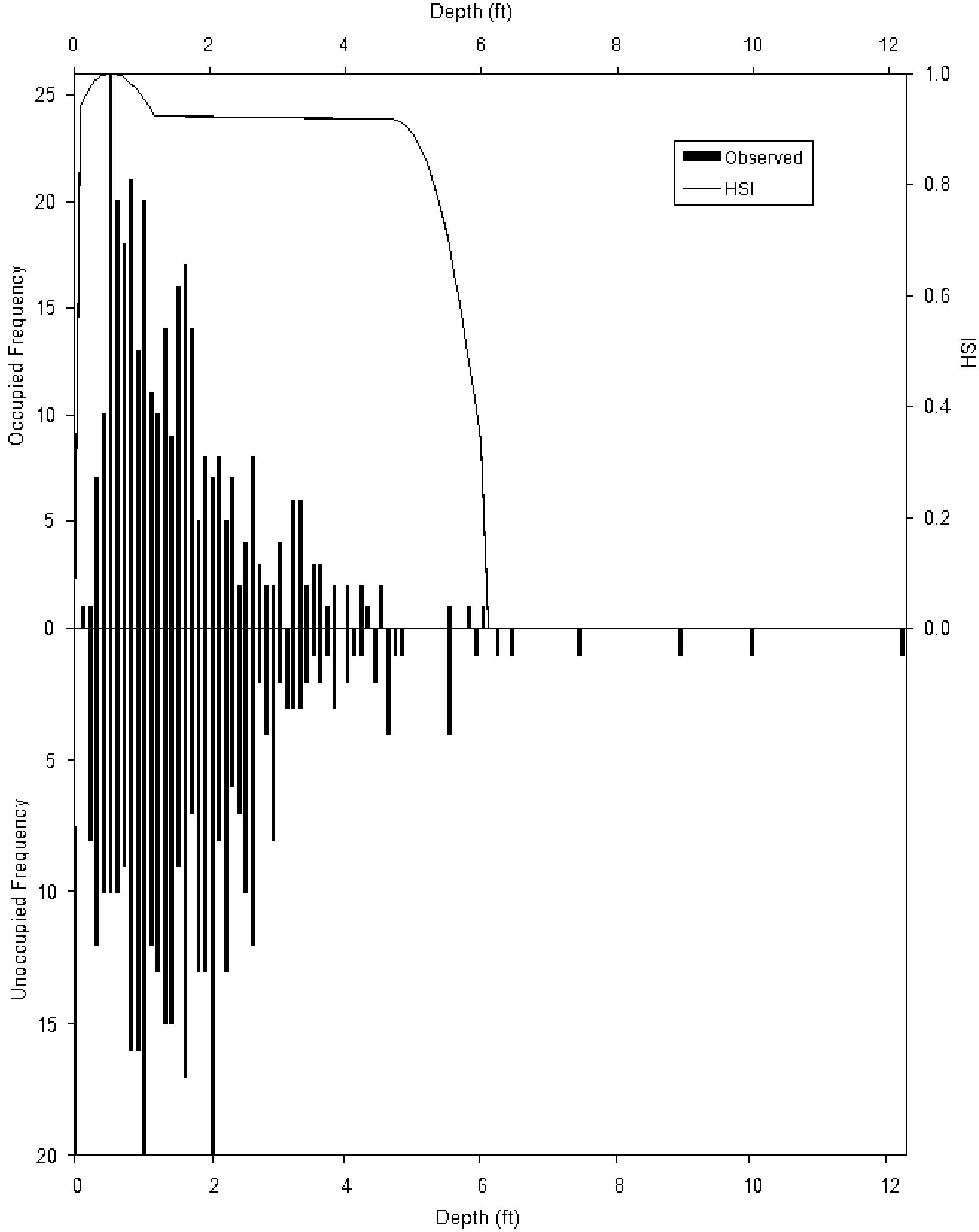


Figure 5. Fall-run Chinook salmon fry rearing velocity HSC. The HSC show that fall-run Chinook salmon fry rearing has a non-zero suitability for velocities of 0 to 3.11 feet/sec (0 to 0.948 m/s) and an optimum suitability at a velocity of zero.

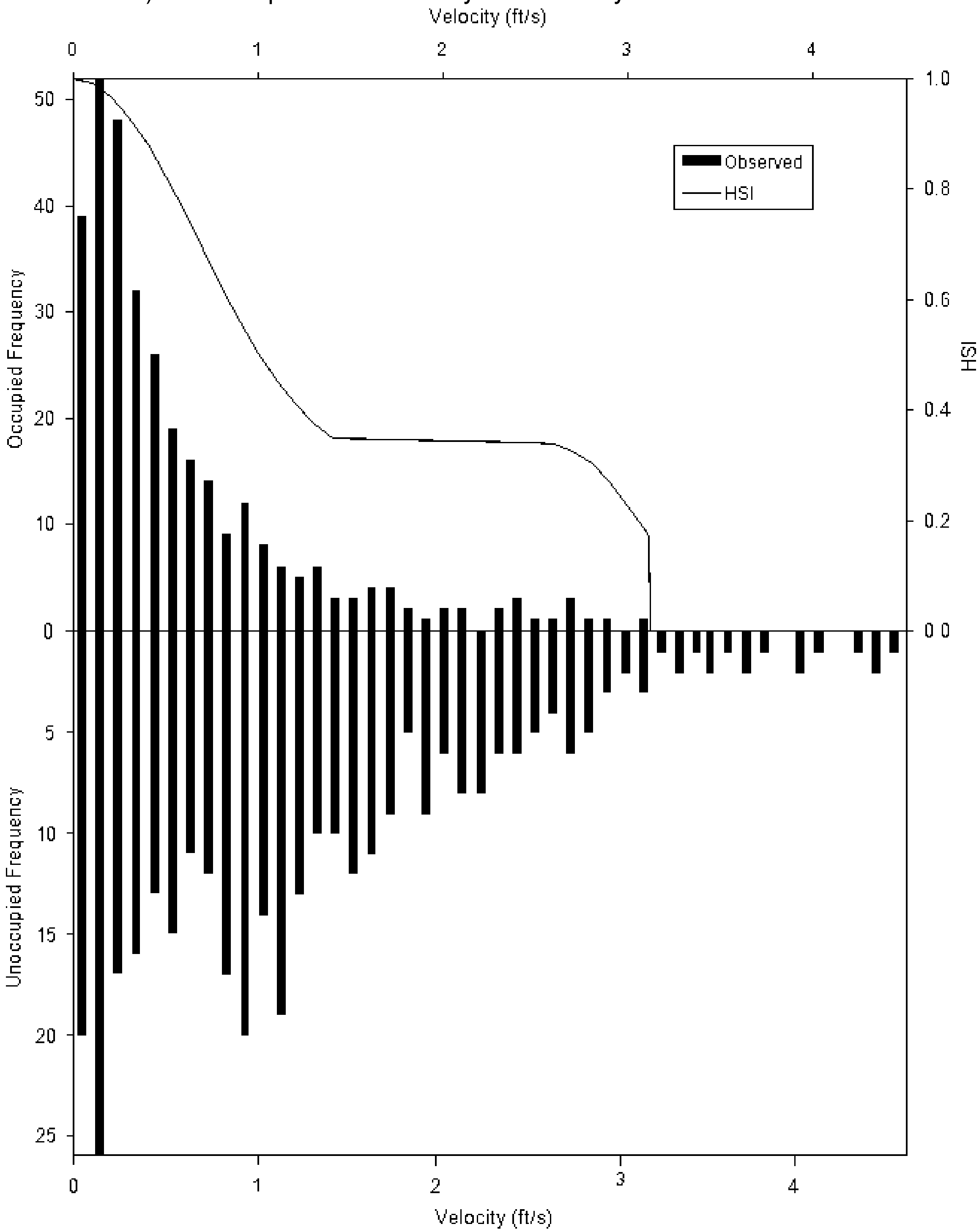


Figure 6. Fall-run Chinook salmon juvenile rearing depth HSC. The HSC show that fall-run Chinook salmon juvenile rearing has a non-zero suitability for depths of 0.5 to 5.3 feet (0.15 to 1.62 m) and an optimum suitability at a depth of 2.9 to 3.2 feet (0.88 to 0.98 m).

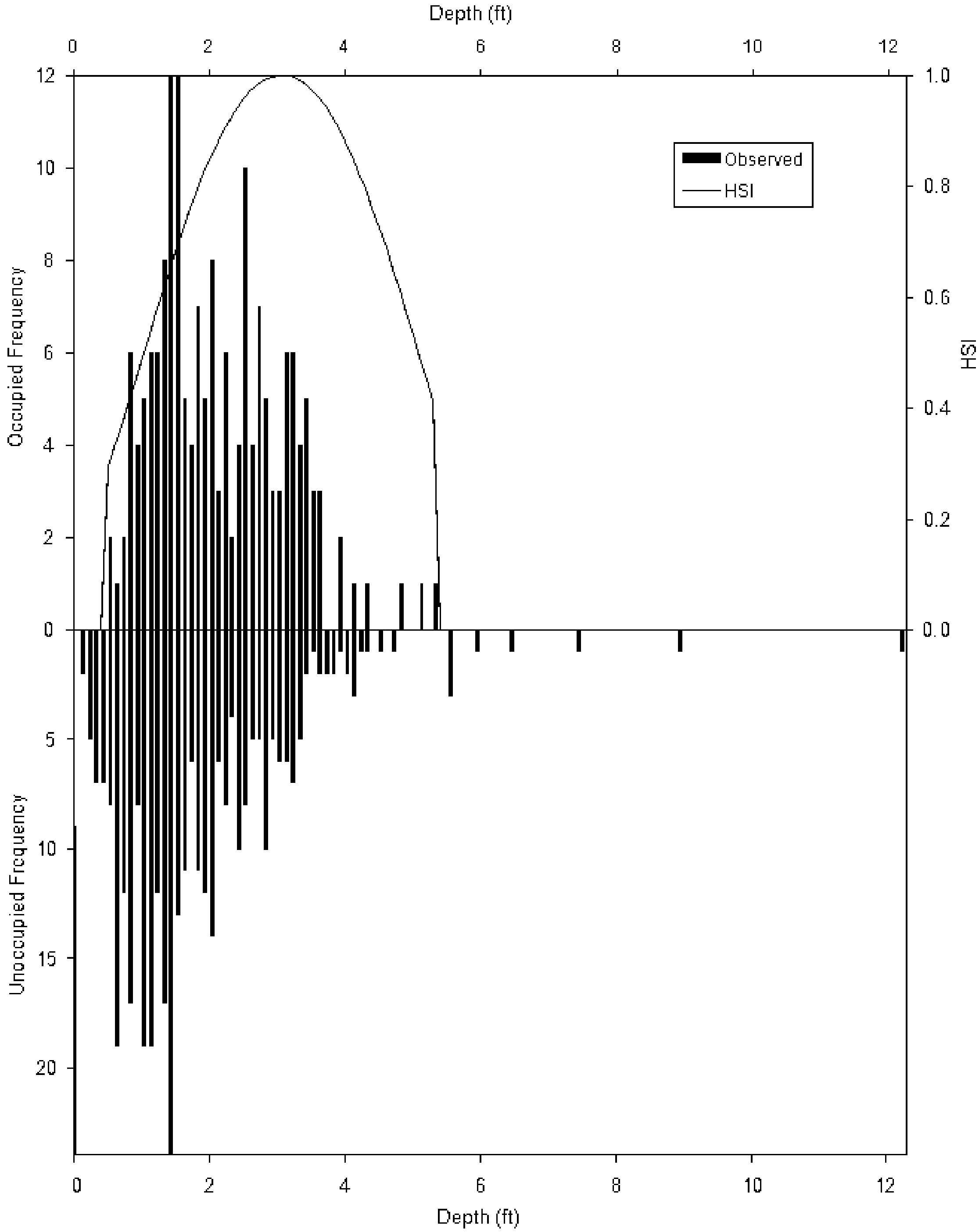


Figure 7. Fall-run Chinook salmon juvenile rearing velocity HSC. The HSC show that fall-run Chinook salmon juvenile rearing has a non-zero suitability for velocities of 0 to 3.06 feet/sec (0 to 0.933 m/s) and an optimum suitability at a velocity of zero.

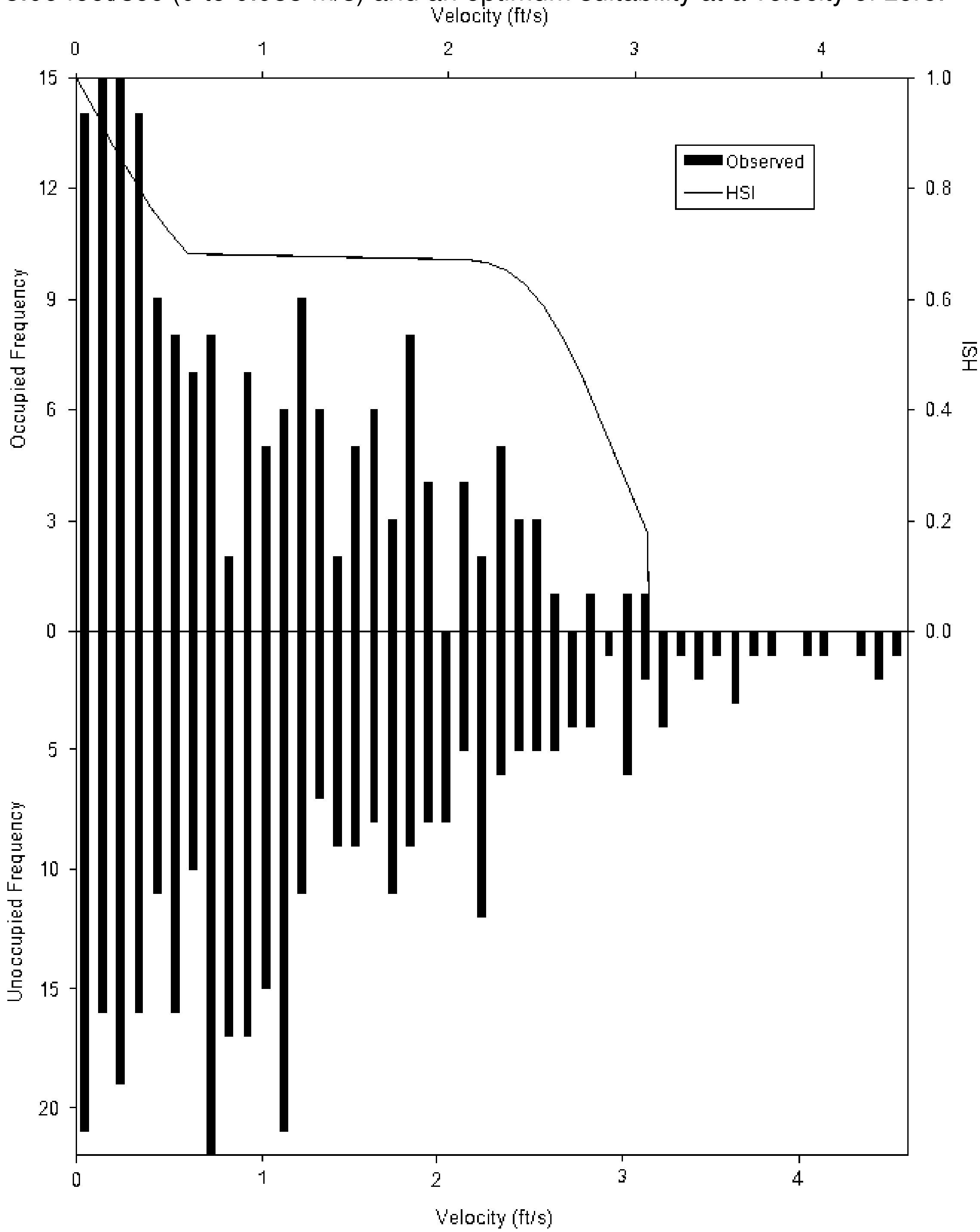


Figure 8. Fall-run Chinook salmon fry rearing adjacent velocity HSC.

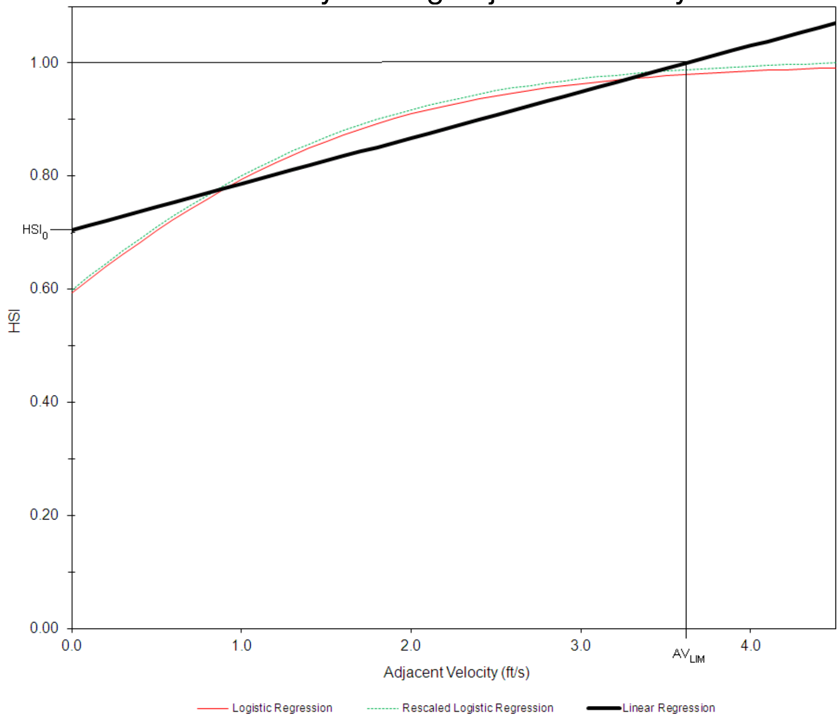


Figure 9. Fall-run Chinook salmon juvenile rearing adjacent velocity HSC.

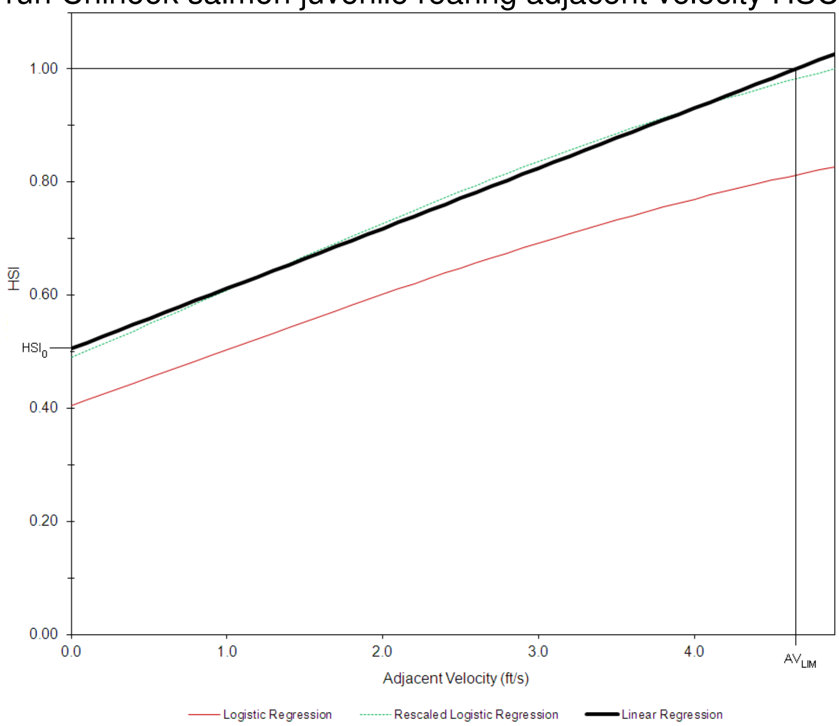


Table 18. Statistical tests of difference between cover codes, using the number of observations where fish were present and absent. An asterisk indicates that presence/absence of fish for those cover codes were significantly different at p = 0.05.

Life stage	Cover Codes	c-value
fry	0, 1, 2, 3, 3.7, 4, 4.7, 5, 5.7, 7, 8, 9, 9.7	191*
fry	0, 1, 2, 7	4.86
fry	3, 3.7, 4, 4.7, 5, 5.7, 8, 9, 9.7	9.81
Juvenile	0, 1, 2, 3, 3.7, 4, 4.7, 5, 5.7, 7, 9, 9.7	90*
Juvenile	0, 2, 3, 7	3.08
Juvenile	1, 3.7, 4, 4.7, 5, 5.7, 9, 9.7	7.25

Table 19. 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		
Life stage	Group A	Group B	c-value
fry	0, 1, 2, 7	3, 3.7, 4, 4.7, 5, 5.7, 8, 9, 9.7	182*
Juvenile	0, 2, 3, 7	1, 3.7, 4, 4.7, 5, 5.7, 9, 9.7	87*

suitability. The location of fall-run Chinook salmon fry and juveniles relative to the distribution of combined suitability is shown in Appendix J. The 2-D model did not predict that any of the fry locations had a combined suitability of zero, but predicted that three of the 29 (3%) juvenile locations had a combined suitability of zero; one had a combined suitability of zero due to the location having been predicted as being dry, while two had a combined suitability of zero due to the predicted depth being too high (greater than 5.3 feet [1.62 m]).

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.

Figure 10. Fall-run Chinook salmon fry rearing cover HSC.

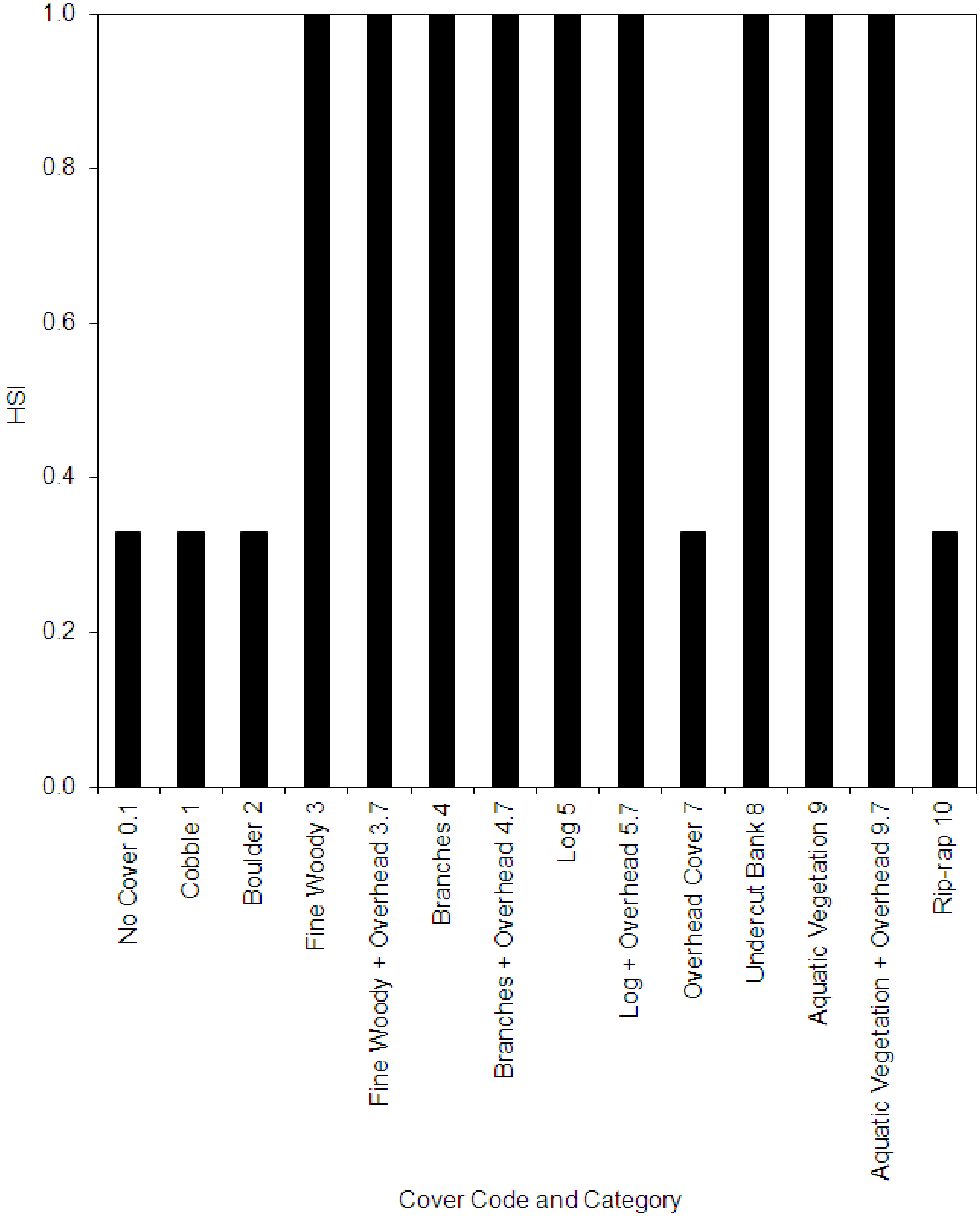


Figure 11. Fall-run Chinook salmon juvenile rearing cover HSC.

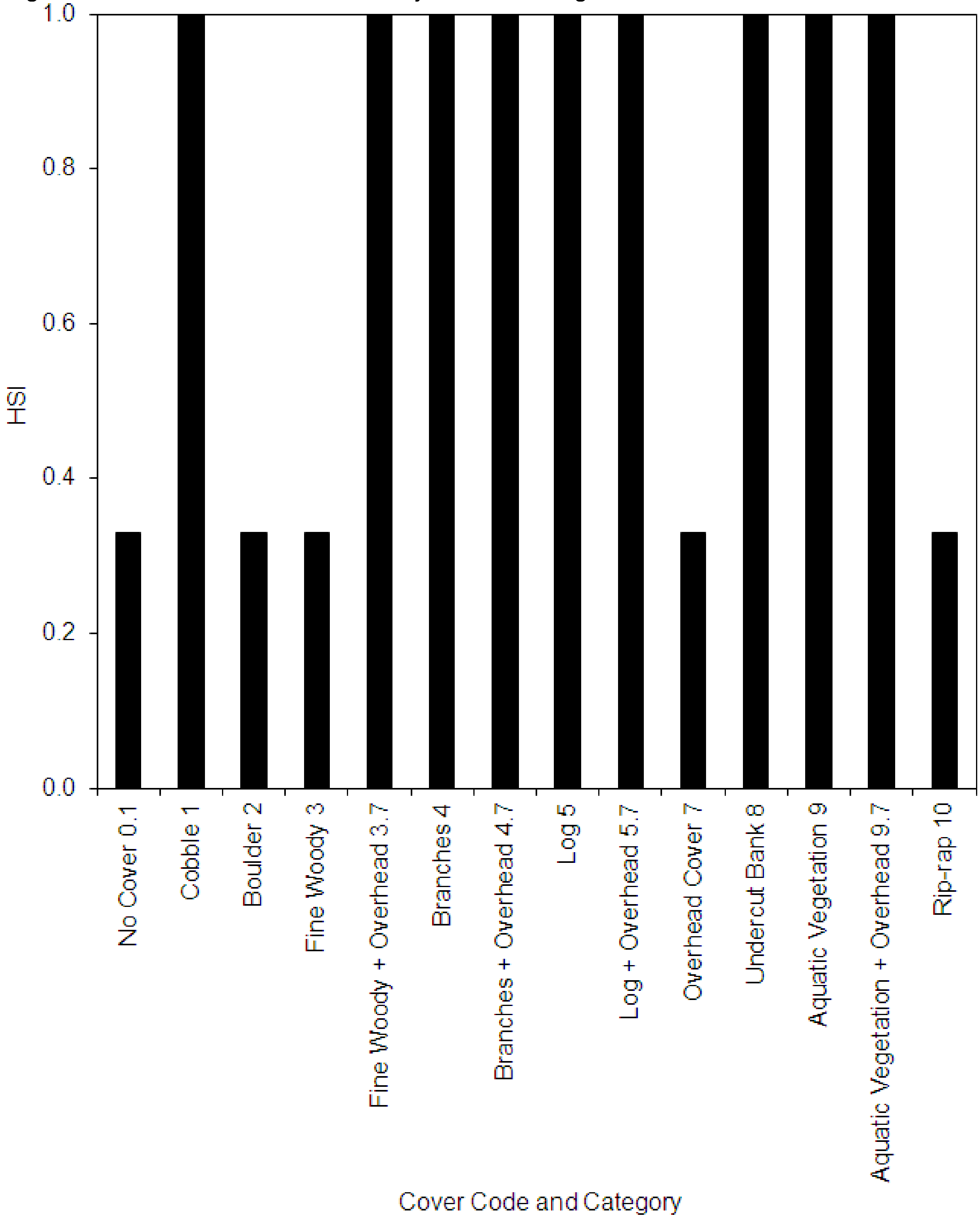


Figure 12. Combined suitability for 2-D model locations with (occupied) and without (unoccupied) fall-run Chinook salmon fry. The median combined suitability for occupied and unoccupied locations was, respectively, 0.33 and 0.16.

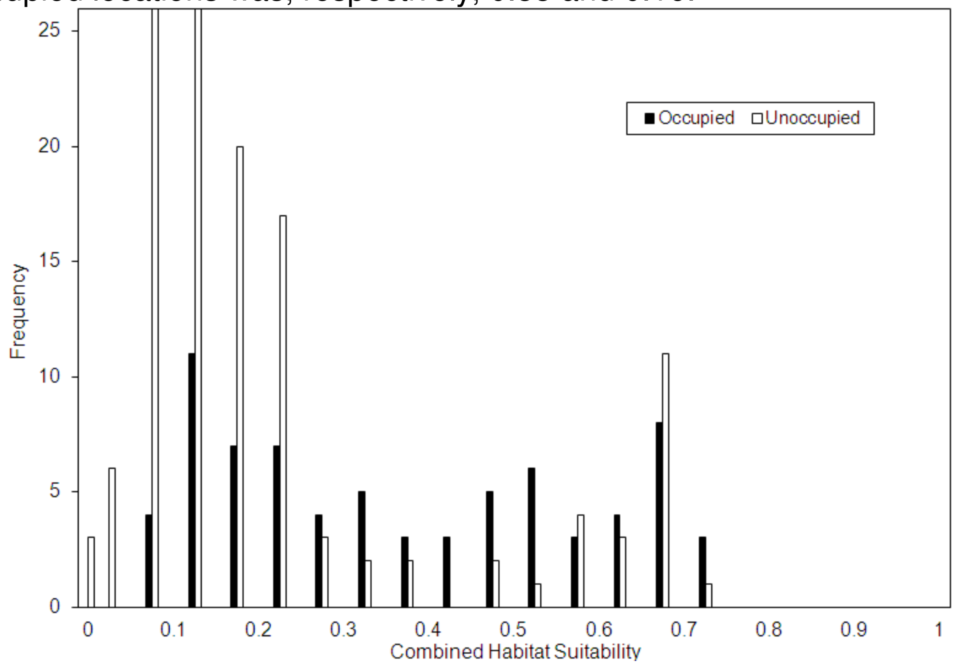


Figure 13. Combined suitability for 2-D model locations with (occupied) and without (unoccupied) fall-run Chinook salmon juveniles. The median combined suitability for occupied and unoccupied locations was, respectively, 0.13 and 0.10.

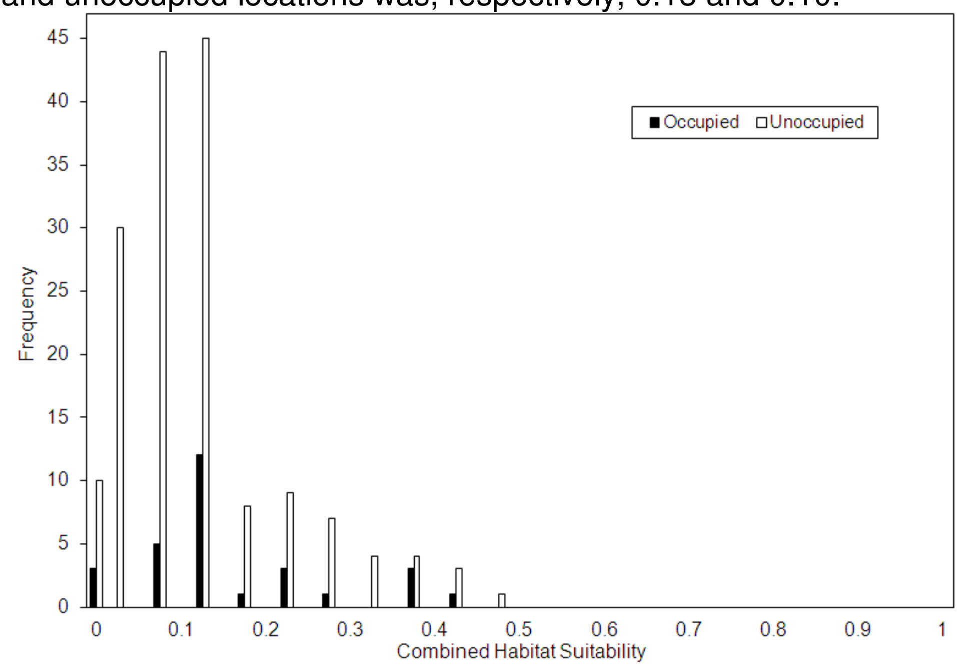


Table 21. Ratio of habitat areas in segment to habitat areas in modeled sites. Entries with an asterisk indicate that the habitat type was not modeled in that segment. Entries with two asterisks indicate that the habitat type was not present in that segment. The ratios were adjusted to account for study 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	Lower Alluvial Segment
Main Channel Glide	3.42
Main Channel Pool	11.42
Main Channel Riffle	3.28
Main Channel Run	4.93
Side Channel Glide	*
Side Channel Pool	42.25
Side Channel Riffle	*
Side Channel Run	43.80
Restored Channel	1.41

The flow habitat relationships for spring-run and fall-run Chinook salmon and steelhead/rainbow trout fry and juvenile rearing are shown in Figures 14-18 and Appendix K. The 2-D model predicts the highest total weighted usable area values (WUA) for: 1) spring-run Chinook salmon fry rearing at 900 cfs; 2) spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing at 850 cfs; 3) fall-run Chinook salmon fry rearing at 50 cfs; 4) fall-run Chinook salmon juvenile rearing at 350 cfs; and 5) steelhead/rainbow trout fry rearing at 50 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 19, two-dimensional habitat mapping better captures the complexity of mesohabitat units in Clear Creek.

Figure 14. Spring-run Chinook salmon fry rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum spring-run Chinook salmon fry rearing habitat was 900 cfs.

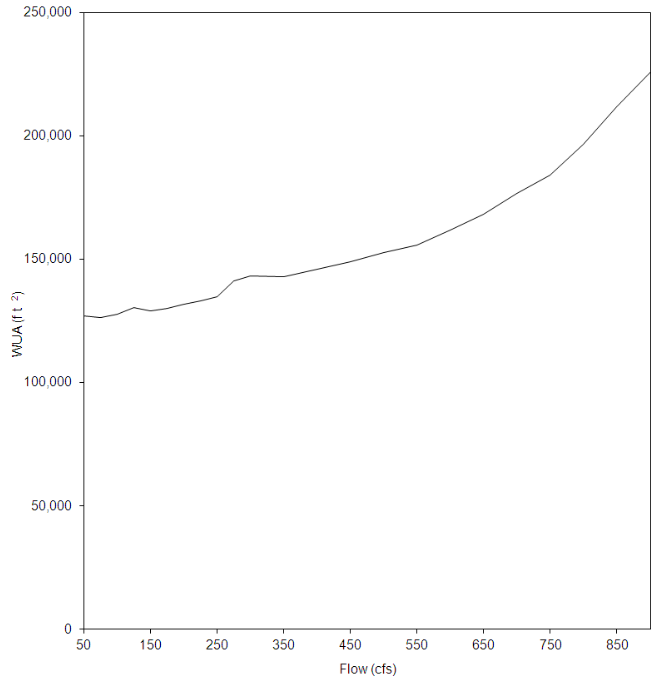


Figure 15. Fall-run Chinook salmon fry rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum fall-run Chinook salmon fry rearing habitat was 50 cfs.

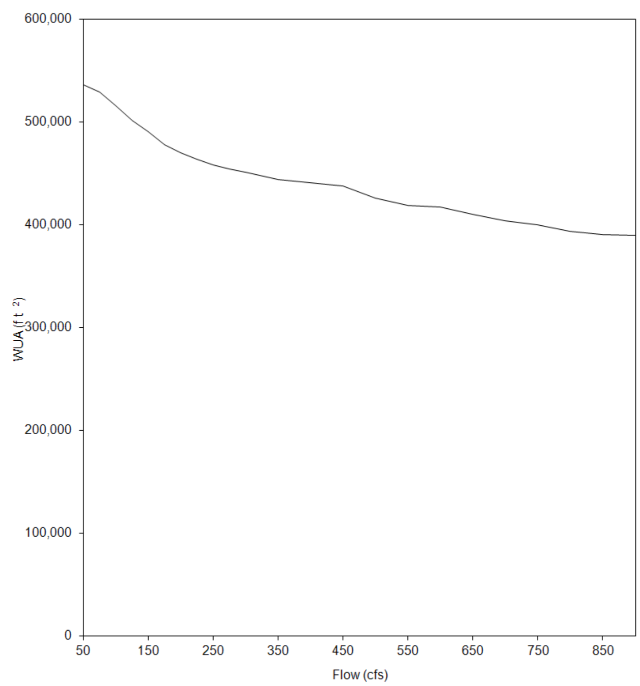


Figure 16. Steelhead/rainbow trout fry rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum steelhead/rainbow trout fry rearing habitat was 50 cfs.

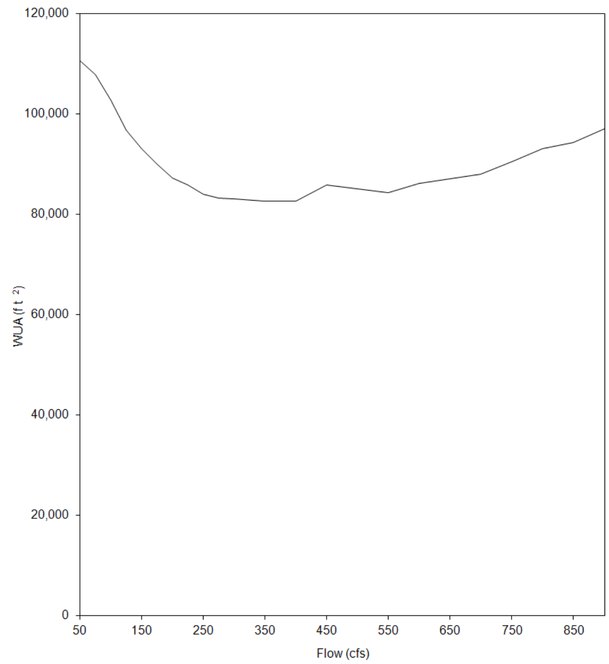


Figure 17. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing habitat was 850 cfs.

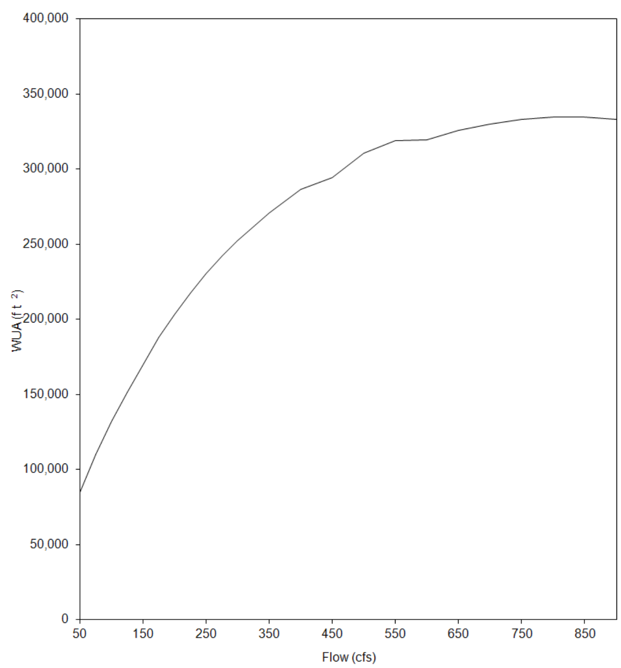


Figure 18. Fall-run Chinook salmon juvenile rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum fall-run Chinook salmon juvenile rearing habitat was 350 cfs.

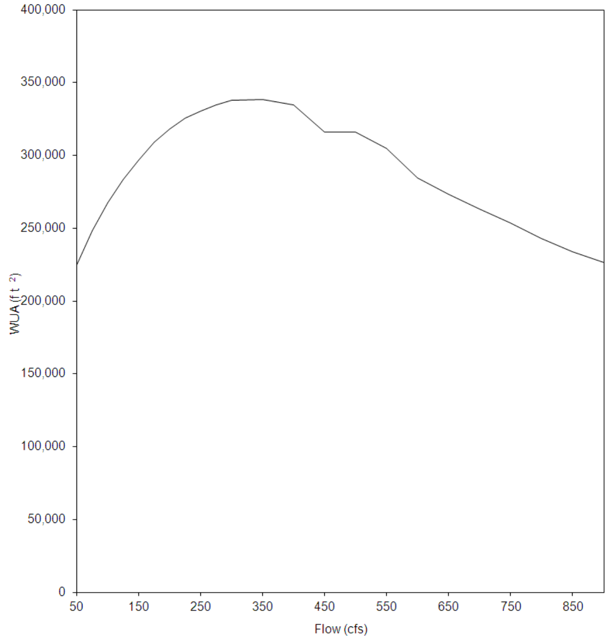
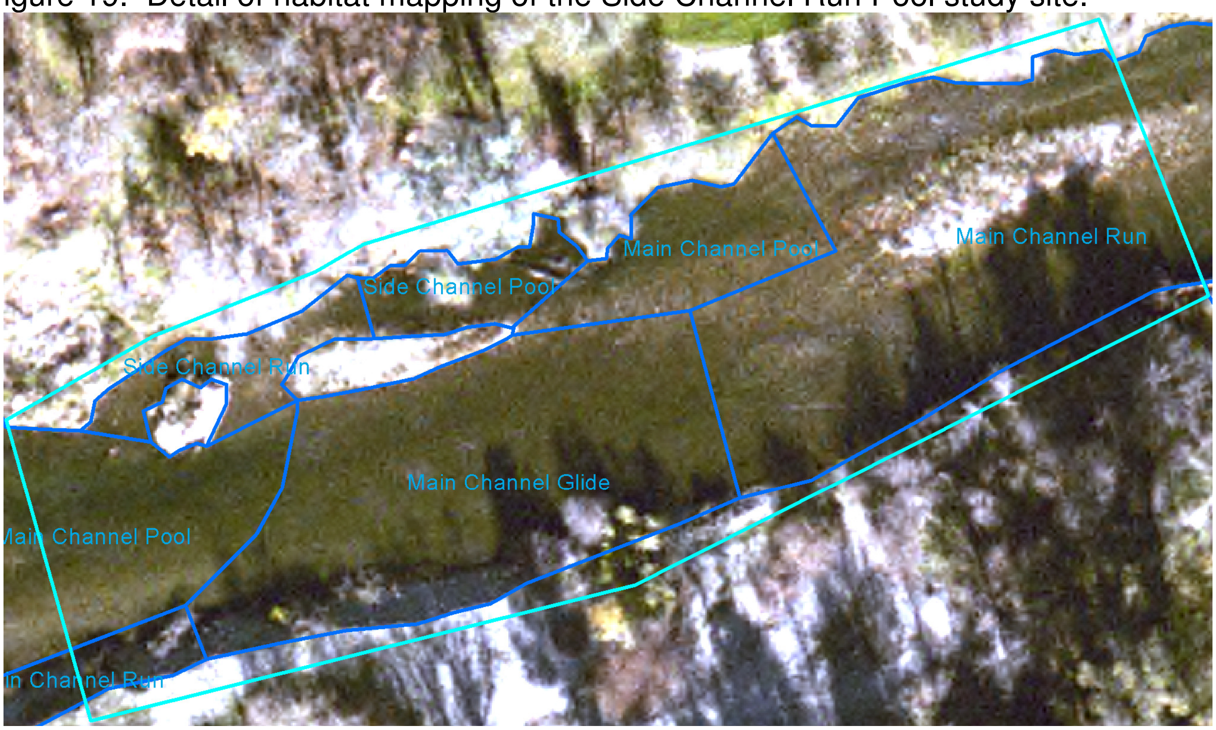


Figure 19. Detail of habitat mapping of the Side Channel Run Pool study site.



PHABSIM WSEL Calibration

The use of two calibration flows, as was done for ACID Glide at low flows, is not usually considered acceptable for developing stage-discharge relationships. However, we believe that it is sufficiently accurate for developing a stage-discharge relationship over a small range of flows (50 to 225 cfs), where the two calibration flows (95 and 230 cfs) encompassed most of the range of simulation flows, because errors in stage-discharge relationships are typically large only for extrapolation outside of the range of calibration flows. The high beta coefficients for the low flow range for both ACID Glide transects were likely due to a very strong downstream control that was only active at low flows. Specifically, there is sheet piling, with only a small slot for fish passage, located 850 feet (259 m) downstream of the downstream end of the ACID Glide site; the configuration of this control does not allow for the stage of zero flow to be assessed with the methods in PHABSIM.

For the 3B upstream transect, the model, in mass balancing, was decreasing water velocities at high flows so that the known discharge would pass through the increased cross-sectional area. We concluded that this phenomena was caused by channel characteristics which form hydraulic controls at some flows but not others (compound controls), thus affecting upstream water elevations. Accordingly, the performance of IFG4 for this transect was considered adequate despite unusual VAF pattern. We did not regard the deviation in the VAF values for this 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 (0.03 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.03 m) vertically of the bed file within 1.0 foot (0.3 m) horizontally of the bed file location. Given that we had a 1-foot (0.3 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 Side Channel Run Pool, 3B and ACID Glide sites at the highest simulated flow had WSELs on the two banks that differed by more than 0.1 foot. In all three cases, we were uncertain which model was responsible for the discrepancies between the WSELs predicted by RIVER2D and PHABSIM. As a result, we felt that it would be more accurate to calibrate these sites using the measured WSELs for the highest flow within the range of simulated flows. 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 height multiplier at higher flows, versus lower flows. However, when we have concluded, as for these sites, that the simulation of the WSEL at the upstream transect at the highest simulation flow by PHABSIM is potentially inaccurate, it no longer makes sense to calibrate RIVER2D using the WSELs simulated by PHABSIM at the highest simulation flow. In these cases, we use the fall-back option of calibrating RIVER2D using the WSELs measured at the highest flow within the range of simulation flows.

We considered the solution to be acceptable for the study site cdg files which had a maximum Froude Number greater than 1, since the Froude Number only exceeded one at a few nodes, with the vast majority of the site having Froude Numbers less than one. 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. The average and maximum difference between measured and simulated WSELs for 3B exceeded the 0.1 foot (0.031 m) criterion. However, at the 651 cfs flow at which the WSELs were measured, we were only able to take a measurement next to the right and left banks due to safety concerns. The WSELs simulated in these portions of the upstream transect were within 0.09 foot (0.027 m) of the measured value. Because of this result, the calibration was considered acceptable. For North State Riffle, the WSELs simulated by River2D ranged from 0.12 feet (0.037 m) higher to 0.05 feet (0.015 m) lower than the WSEL simulated by PHABSIM at 900 cfs, with an average difference of 0.02 feet (0.006 m). In addition, the WSELs simulated by River2D only differed by more than 0.1 foot (0.031 m) from the PHABSIM simulated WSEL at three out of 40 wetted verticals on the transect. Accordingly, we concluded that the final bed roughness height multiplier of 0.8 for this site resulted in a close to optimum match between the River2D and PHABSIM simulated WSELs. While a slightly lower bed roughness height multiplier might have brought the maximum difference between River2D and PHABSIM simulated WSELs down to 0.1 foot (0.031 m), such a change would likely have had almost no effect on the hydraulic simulations for this site. Thus we conclude that the 2D calibration for this site was acceptable.

RIVER2D Model Velocity Validation

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; (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 on the transects 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[24]. We attribute most of the differences between measured and predicted velocities to noise in the measured velocity measurements. 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. For the Side Channel Run Pool and Tarzan Pool downstream transects and ACID Glide upstream transect, where RIVER2D over or under-predicted the velocities on both sides of the channel, we attribute this to errors in the bed topography that did not properly characterize features that resulted in faster/slower velocities. For the ACID Glide downstream transect, the over-predicted velocities on the north and south sides of the channel can be attributed to errors in the velocity measurement on the transect (being too low), since the discharge calculated from the measured velocities was 22 percent lower than the gage flow.

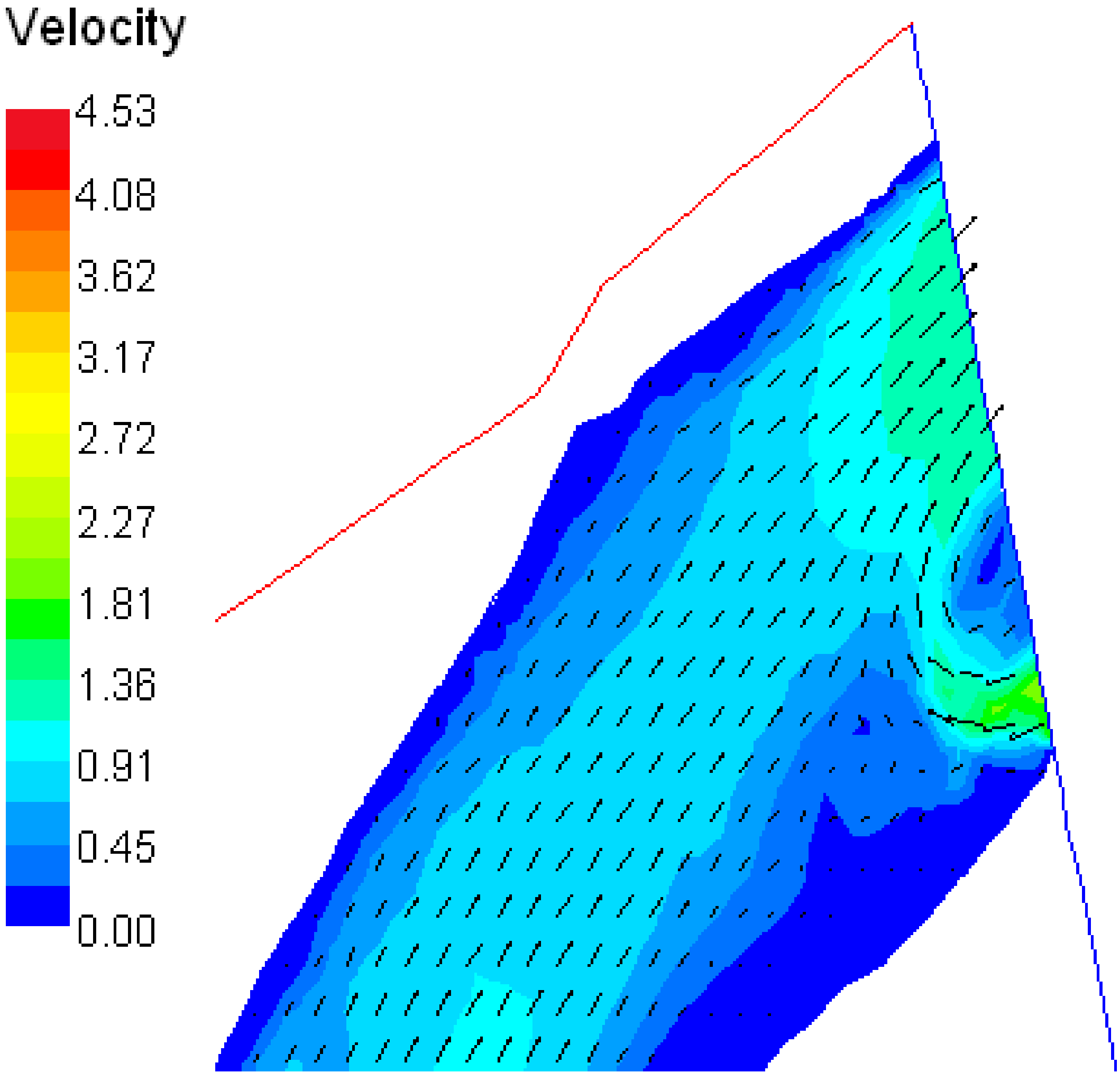
The velocity simulation errors for the 3B downstream transect were caused by eddies that the model generated at the downstream boundary (Figure 20). In contrast, the measured data did not show an eddy at this location. For this transect, the highest simulated velocities were in the eddy generated on the south bank. The eddy resulted in flows going upstream of 22 cfs. To achieve a mass balance, River2D simulated higher than measured velocities in the north half of the channel, so that the downstream flow in this part of the channel was 22 cfs higher than the gage flow for 3B. It is likely that we could have improved the velocity validation of 3B by adding a downstream extension onto the hydraulic model. For the 3B site, excluding the four velocity measurements located in the eddy increased the correlation between measured and simulated velocities to 0.67. Thus, the River2D model was validated for most of the area of the site. As a result, we conclude that the velocity validation was acceptable for all five sites.

RIVER2D Model Simulation Flow Runs

The three lowest simulation flow run cdg files for North State Riffle, as well as one flow for Side Channel Run Pool and 11 flows for 3B, 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. In the case of the Side Channel Run Pool lowest flow simulation run and 6 of the 3B simulation flows, where the net Q significantly exceeded the 5% level, we consider that a level of uncertainty applies to results for those production files. We attribute the high net Q in the 3B simulation

[24] 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.

Figure 20. Velocity (m/s) vectors (black arrows) near the downstream boundary (right side of figure) of 3B site at 226 cfs. An eddy (velocity vectors going upstream) is shown in the lower edge of the boundary. Blue lines denote water's edge.



flows to the eddy that the model generated at the downstream boundary. It is likely that we could have reduced the net Q for these files by adding a downstream extension onto the hydraulic model. In contrast, the Side Channel Run Pool lowest flow production cdg file did not have an eddy at the downstream transect (Figure 21); instead in this case the high net Q was due to the amount of water being passed through a very small cross-sectional profile, with a longitudinal mid-channel bar upstream of the downstream transect limiting the amount of flow though the deepest portion of the transect.

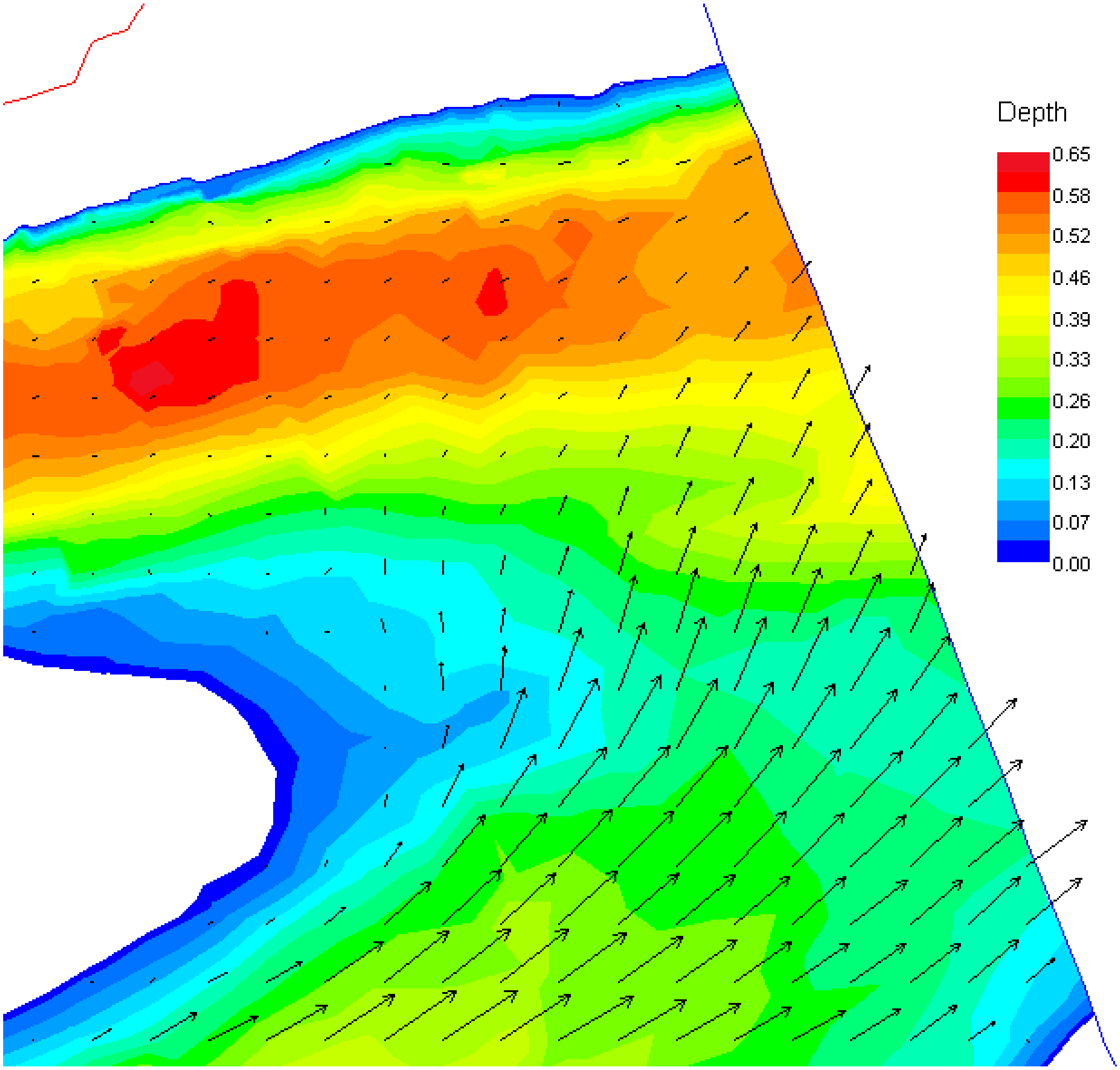
Although a majority of the simulation flow files had Max Froude values that exceeded 1, we considered these production runs to be acceptable since the Froude Number was only greater than 1 at a few nodes, with the vast majority of the area within the site having Froude Numbers less than 1. Again, as 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.

Habitat Suitability Criteria (HSC) Development

The R^2 values in Tables 16 and 17 in general reflect the large degree of overlap in occupied and unoccupied depths and velocities, as shown in Figures 4 to 7. 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. 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 4 through 7. 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.

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

Figure 21. Velocity vectors (black arrows proportional to magnitude) and depths (m) near the downstream boundary (right side of figure) of Side Channel Run Pool site at 50 cfs.



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, 31-315 fish would represent a value of three, and 316-3161 fish would represent a value of four[25]. 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.

Figures 22 to 25 compare the four to five 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 selection 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.

Figures 26 to 33 compare the fall-run Chinook salmon criteria from this study with the criteria from other studies. See U.S. Fish and Wildlife Service (2011b) for a comparison of the spring-run Chinook salmon and steelhead/rainbow trout criteria from this study with criteria from other studies. We compared the fall-run Chinook salmon juvenile depth and velocity criteria with those from 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. Since Bovee (1978) does not have criteria for Chinook salmon fry, we used another commonly cited reference criteria (Raleigh et al. 1986). We also used criteria from Battle Creek (TRPA 1988) and the Feather River (California Department of Water Resources 2005), since these streams are also located in the Sacramento River basin. For cover, we were limited to comparing the criteria from this study to criteria we had developed on other studies which used the same, unique cover coding system. We compared the fall-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) and the Yuba River (U.S. Fish and Wildlife Service 2010). 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) and the Yuba River (U.S. Fish and Wildlife Service 2010).

The fall-run Chinook salmon fry depth criteria show higher suitability for a wider range of conditions, while the fall-run Chinook salmon juvenile depth criteria fell within the range of the other criteria. We attribute the difference in the fry criteria to the use of a logistic regression to address availability, and that the other fall-run Chinook salmon fry criteria, developed using use data, underestimate the suitability of deeper conditions (in the range of 2.5 to 6.1 feet [0.76 to 1.86 m]) because they do not take availability into account.

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[25] The largest number of fish that were in one observation was 1000 fish.

Figure 22. Comparison of depth HSC from this study. These criteria indicate that the optimum depths for juvenile fish are greater than those for fry.

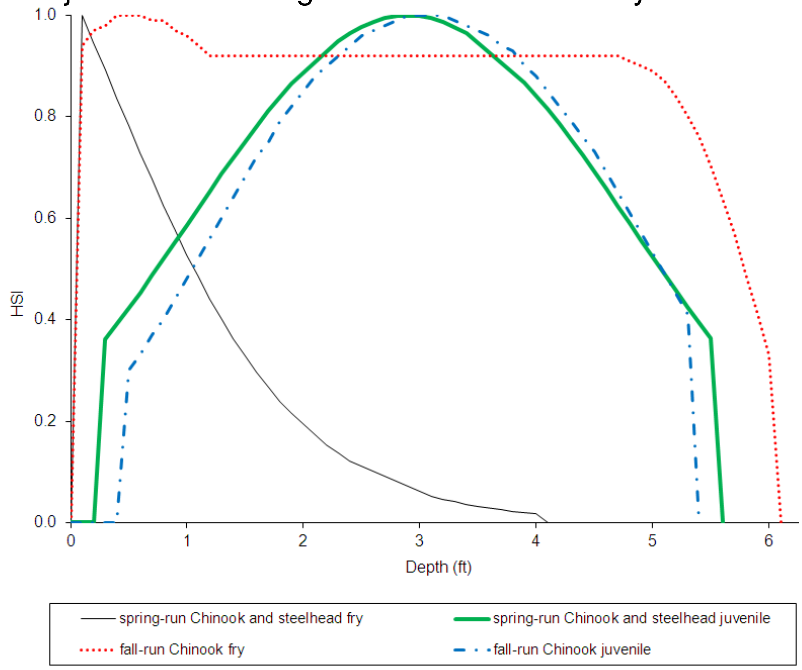


Figure 23. Comparison of velocity HSC from this study. These criteria indicate that there was a slower rate of decline of suitability with increasing velocity for Chinook and steelhead/rainbow trout juveniles than for Chinook salmon and steelhead/ rainbow trout fry.

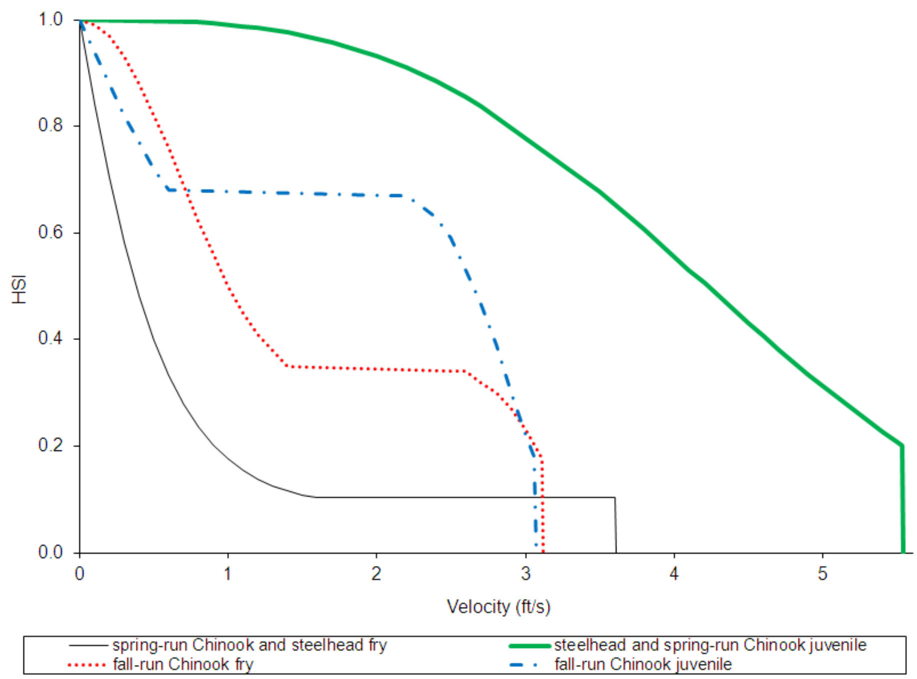


Figure 24. Comparison of cover HSC from this study. These criteria indicate that cobble had a lower suitability for fry than juveniles, but that there was a consistent selection of composite cover (instream woody plus overhead).

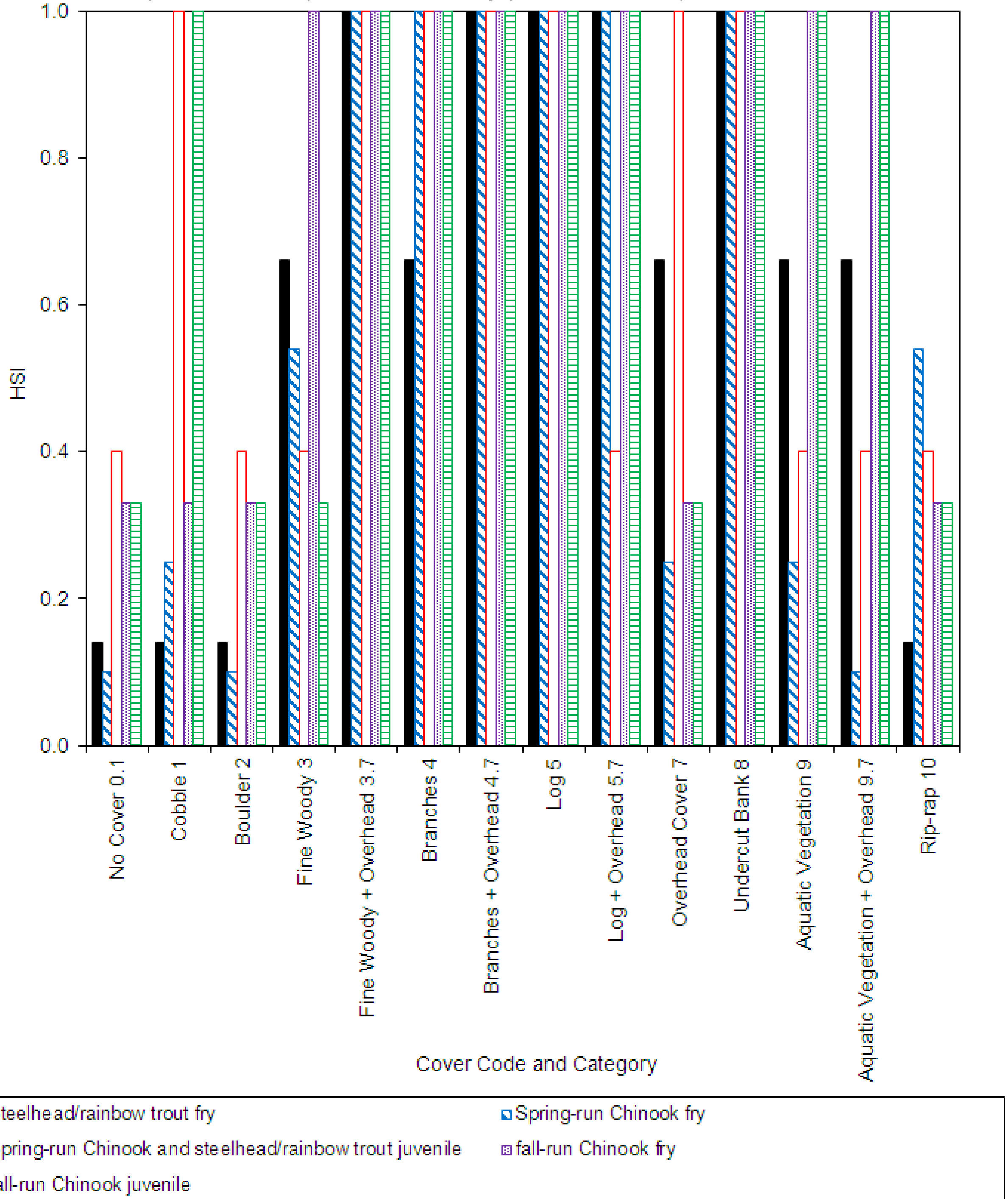


Figure 25. Comparison of adjacent velocity HSC from this study. These criteria indicate that adjacent velocity was most important for spring-run Chinook salmon and steelhead juveniles. There were no adjacent velocity criteria for spring-run Chinook salmon fry.

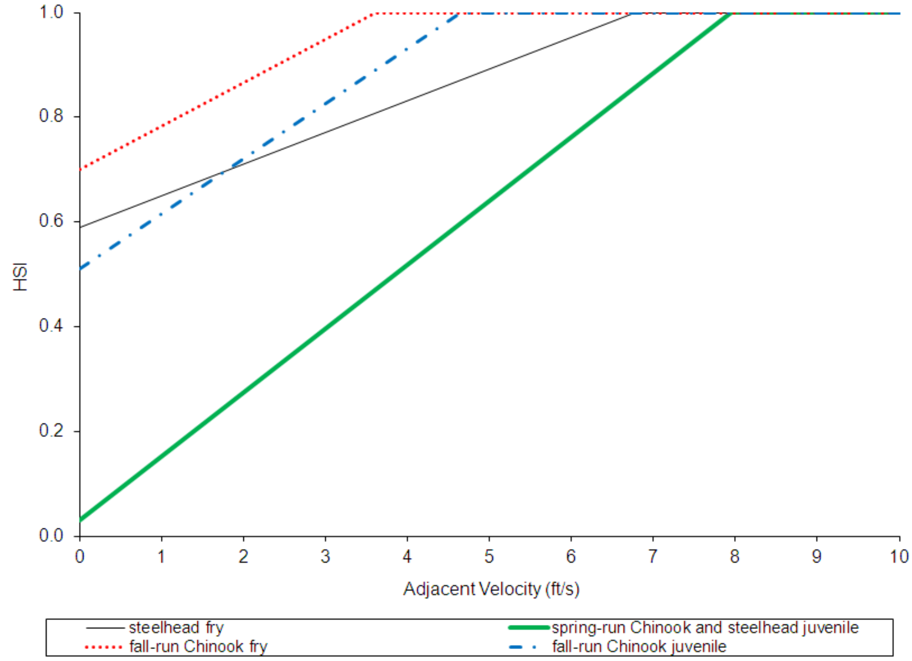


Figure 26. Comparison of fall-run Chinook salmon fry depth HSC from this study with other fall-run Chinook salmon fry depth HSC. The criteria from this study show high suitability for a wider range of depths than the other criteria.

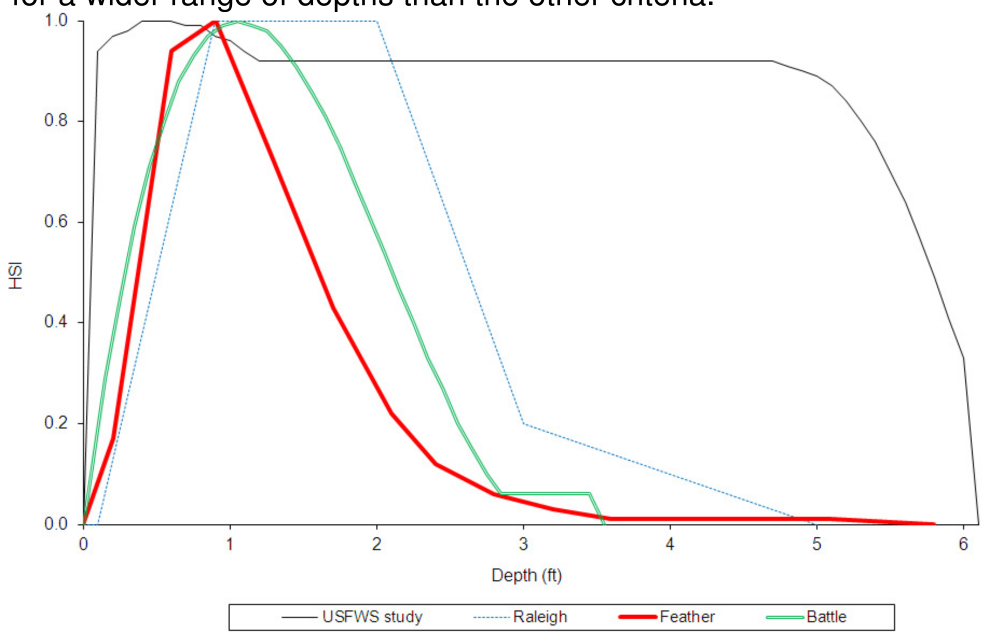


Figure 27. Comparison of fall-run Chinook salmon fry velocity HSC from this study with other fall-run Chinook salmon fry velocity HSC. The criteria from this study show non-zero suitability, albeit at low values, for faster conditions than other criteria.

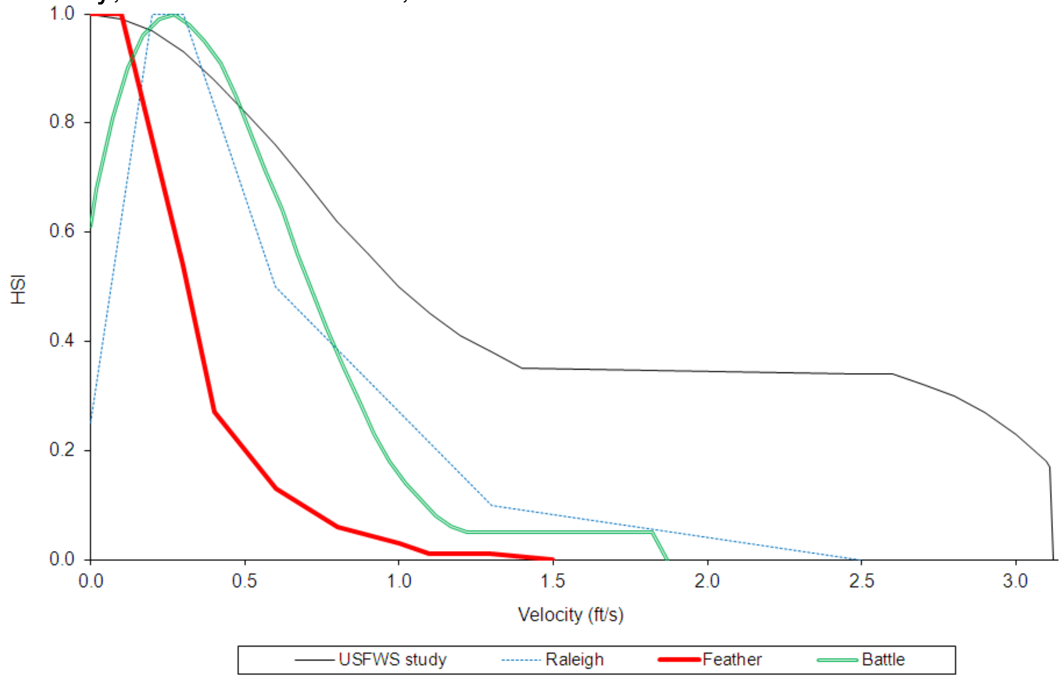


Figure 28. Comparison of fall-run Chinook salmon juvenile depth HSC from this study with other fall-run Chinook salmon juvenile depth HSC. The criteria from this study fall within the range of the other criteria.

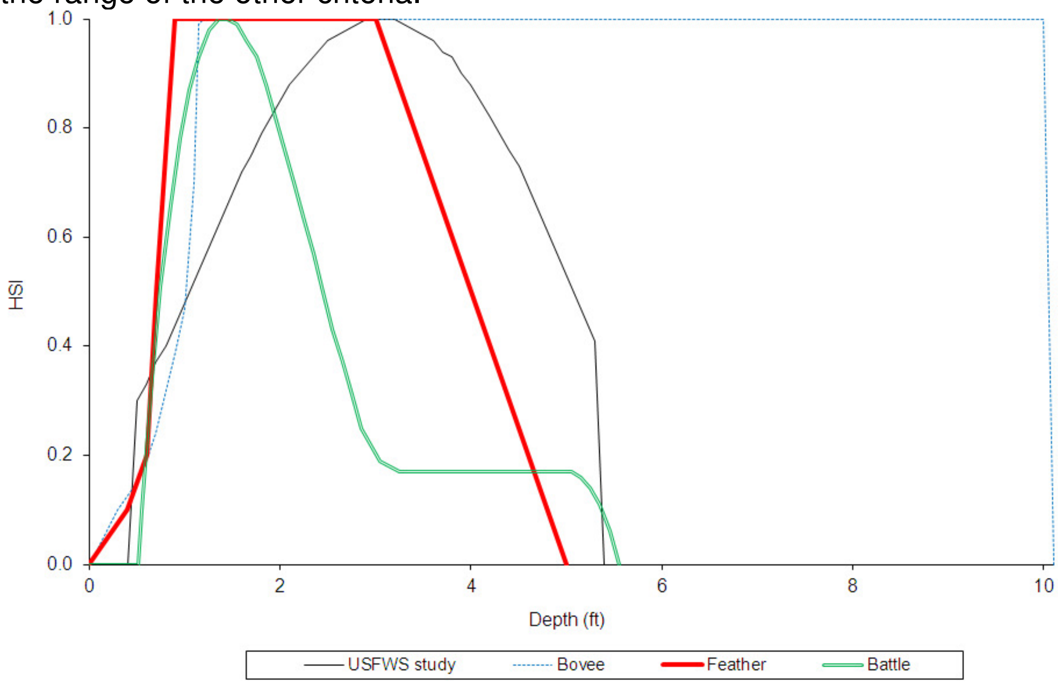


Figure 29. Comparison of fall-run Chinook salmon juvenile velocity HSC from this study with other fall-run Chinook salmon juvenile velocity HSC. The criteria from this study show relatively high suitability for faster conditions than other criteria.

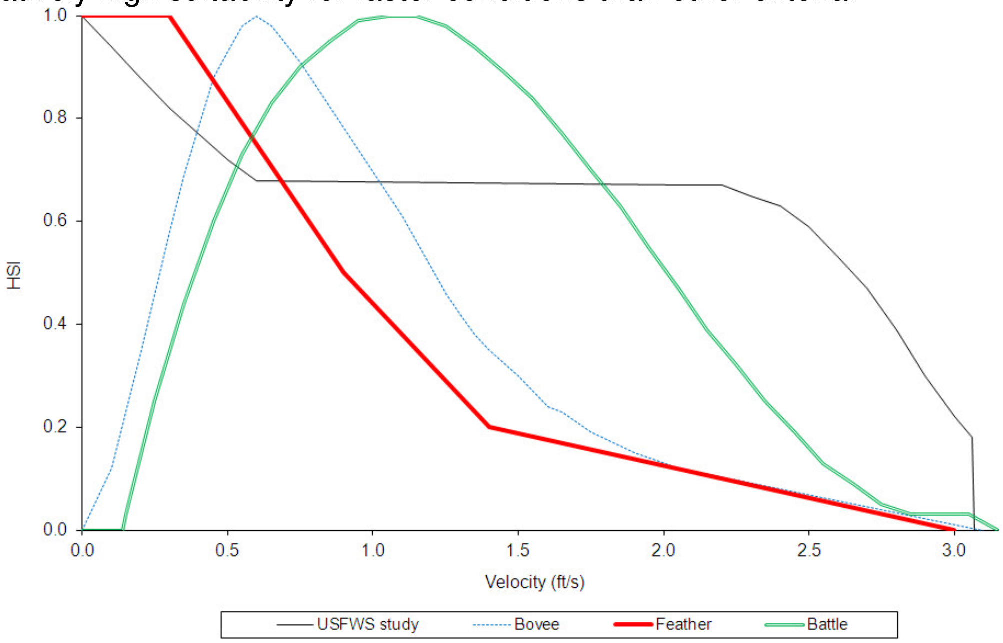


Figure 30. Comparison of fall-run Chinook salmon fry adjacent velocity HSC from this study with other Chinook salmon fry adjacent velocity HSC. The criteria indicate that adjacent velocity was less important for Clear Creek fall-run Chinook salmon juvenile than for Yuba River Chinook salmon juvenile.

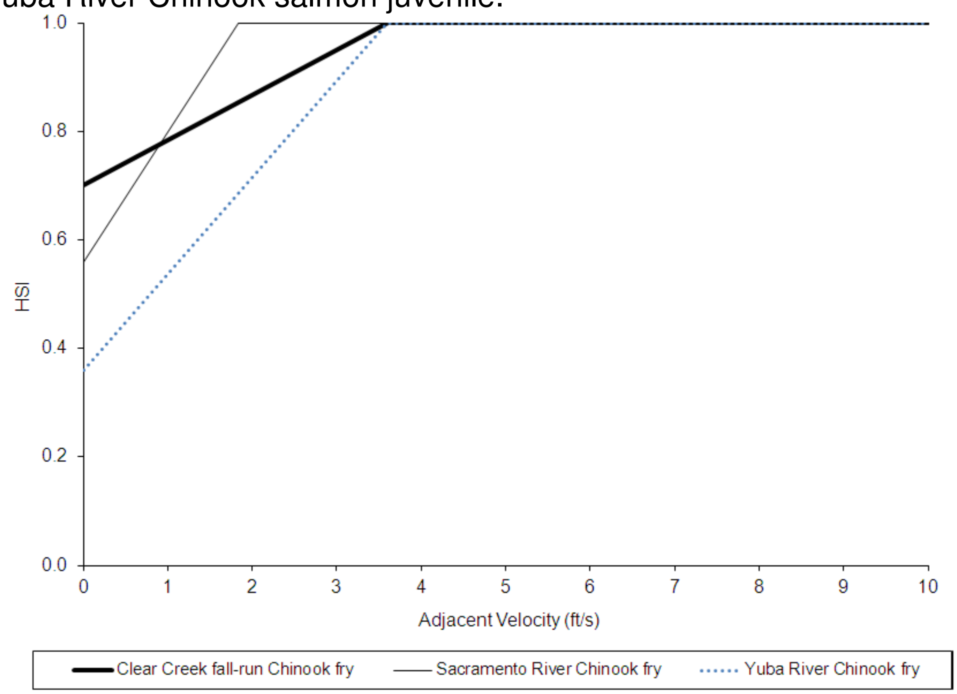
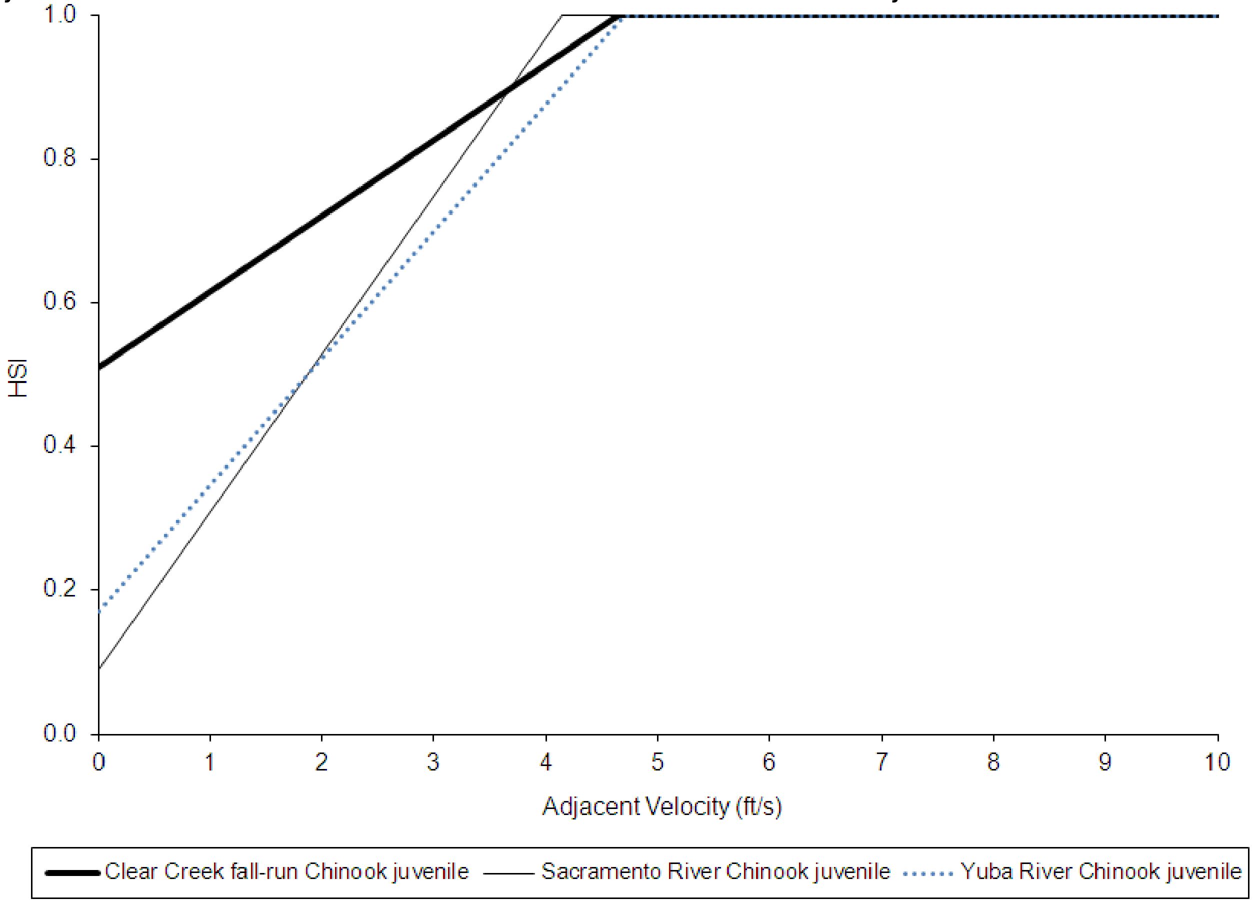


Figure 31. Comparison of fall-run Chinook salmon juvenile adjacent velocity HSC from this study with other Chinook salmon juvenile adjacent velocity HSC. The criteria indicate that adjacent velocity was less important for Clear Creek Chinook salmon juvenile than for Sacramento and Yuba River Chinook salmon juvenile.



The fall-run Chinook salmon 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 fall-run Chinook salmon fry at higher velocities than for other criteria; there were observations of fall-run Chinook salmon fry in Clear Creek at velocities as high as 3.11 feet/sec (0.948 m/s), while both the Feather River and Battle Creek HSC had zero suitability for velocities greater than 1.86 feet/sec (0.567 m/s). Similarly, our fall-run Chinook salmon juvenile velocity criteria show non-zero suitability for faster conditions than other criteria. We attribute this to the to the use of a logistic regression to address availability, and that the other fall-run Chinook salmon juvenile criteria, developed using use data, underestimate the suitability of faster conditions (in the range of 1.8 to 3.06 feet/sec [0.55 to 0.933 m/s]) because they do not take availability into account.

Figure 32. Comparison of fall-run Chinook salmon fry cover HSC from this study with other Chinook salmon fry cover HSC. These criteria indicate a consistent selection of composite cover (instream woody plus overhead).

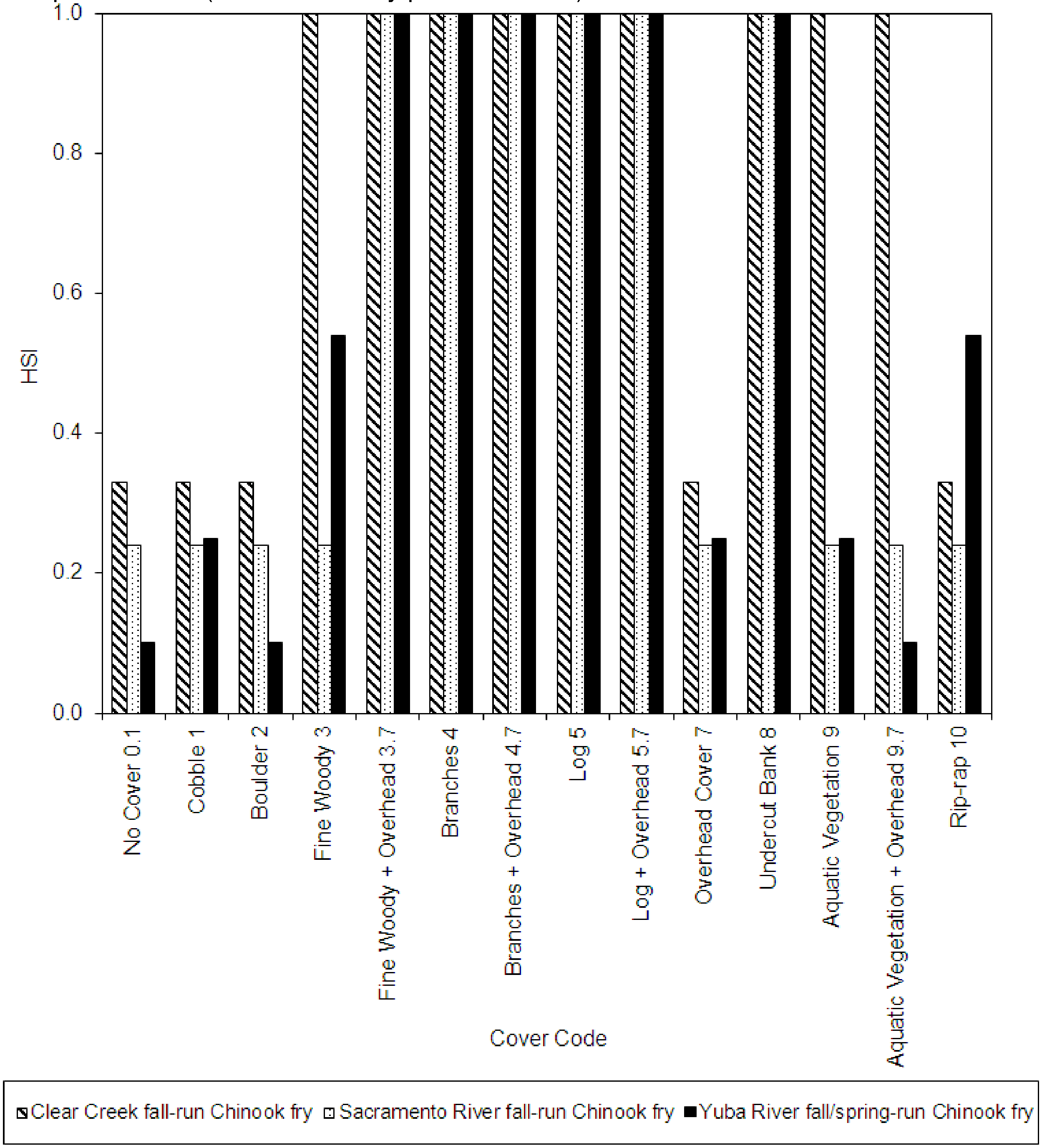
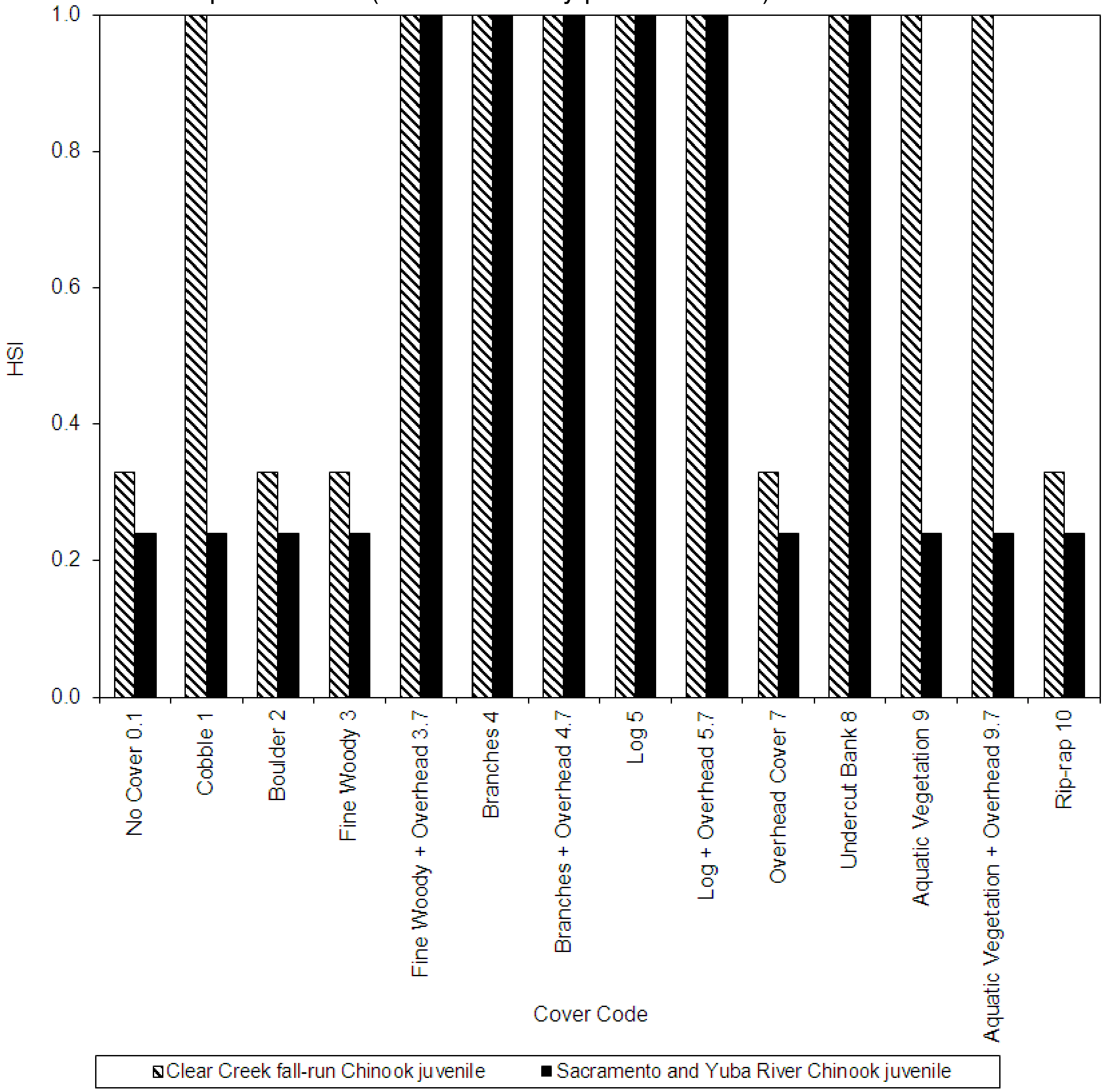


Figure 33. Comparison of fall-run Chinook salmon juvenile cover HSC from this study with other Chinook salmon juvenile cover HSC. These criteria indicate a consistent selection of composite cover (instream woody plus overhead).



The consistency between the Clear Creek, Sacramento River and Yuba River fry and juvenile Chinook salmon cover criteria, relative to selection of 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 2005b) 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. It would be valuable to explore the scale, geometry, and processes of adjacent velocity in more detail in future studies.

Biological Validation

The statistical tests used in this report for biological validation differ from those used in Guay et al. (2000). In Guay et al. (2000), biological validation was accomplished by testing for a statistically significant positive relationship between fish densities, calculated as the number of fish per area of habitat with a given range of habitat suitability (i.e. 0 to 0.1), and habitat quality indexes. We were unable to apply this approach in this study because of the low number of fry and juveniles and low area of habitat with high values of habitat quality. As a result, the ratio of fry and juvenile numbers to area of habitat for high habitat quality values exhibits significant variation simply due to chance. Both the number of fry and juveniles and amount of habitat at high values of habitat quality is quite sensitive to the method used to calculate combined suitability. When combined suitability is calculated as the product of the individual suitabilities, as we did in this study and is routinely done in instream flow studies, very low amounts of high quality habitat will be predicted. For example, if depth, velocity, adjacent velocity and cover all have a high suitability of 0.9, the combined suitability would be only 0.66. In contrast, Guay et al. (2000) calculated combined suitability using an equation that results in combined suitabilities that are similar to those produced by the geometric mean of the individual suitabilities; for the above example, the combined suitability calculated as a geometric mean would be 0.9.

Errors in River2D predicting the CSI of occupied locations likely is related to errors due to: 1) the predictive accuracy of the HSC; and 2) the predictive accuracy of the hydraulic modeling. Errors in the habitat predictions for occupied locations for River2D can be due to inadequate detail in mapping cover distribution, insufficient data collected to correctly map the bed topography of the site, or effects of the bed topography upstream of the study site not being included in the model. For the three juvenile occupied locations where River2D predicted a CSI of zero, the performance of River2D predicting the CSI can be attributed to errors in the hydraulic modeling resulting from insufficient data collected to correctly map the bed topography of the site. Specifically, the measured depths of these two locations were 1.0 and 3.0 feet (0.30 and 0.91 m), while the predicted depths of these locations were, respectively, 0.0 and 7.8 feet (0.00 and 2.38 m). The performance of River2D predicting the CSI of the third location can be attributed to an error in the fall-run juvenile depth HSC, since the measured depth was 6.9 feet (2.10 m), while the fall-run juvenile depth HSC have a suitability of zero for depths greater than 5.3 feet (1.62 m). This characteristic of the fall-run juvenile depth HSC is due to a combination of the deepest observation of juvenile fall-run used to develop the HSC (5.3 feet [1.62 m]) and the HSC method to set the suitability to zero for depths greater than the deepest use observation. This reflects a common problem in developing HSC: how to address rare observations at the limits of fish use. We felt that extrapolating the logistic regression HSC beyond the deepest observation was not supportable because there was no data to support the extrapolation. Since the biological validation data were not included in the data used to develop the criteria (an essential part of any validation), we did not have the observation of a fish at 6.9 feet (2.10 m) to use in developing the criteria. If we had extrapolated the logistic regression out further, the predicted suitability at 6.9 feet (2.10 m) would have been 0.04. Such a modification to the HSC would likely have had a small effect on the overall flow-habitat relationship for juvenile fall-run Chinook salmon, given the low suitability of deeper conditions and the limited amount of area in Clear Creek with depths greater than 5.3 feet (1.62 m).

The plots of combined suitability of fry and juvenile locations in Appendix M are similar to the methods used for biological validation in Hardy and Addley (2001). In general, Hardy and Addley (2001) report a much better agreement between fry and juvenile locations and areas with high suitability than what we found in this study. We attribute the differences between our study and Hardy and Addley (2001) to the following two factors: 1) Hardy and Addley (2001) present results for an entire study site, while our results are just for the portion of the site that we sampled; and 2) Hardy and Addley (2001) calculated combined suitability as the geometric mean of the individual suitabilities, while we calculated combined suitability as the product of the individual suitabilities. The combination of the above two factors results in the plots in Hardy and Addley (2001) having large areas with zero suitability (away from the channel margins) and smaller areas of high suitabilities near the channel margins where fish were located. However, Hardy and Addley (2001) did report lower quality simulation results for juvenile steelhead, as a result of insufficient bed topography detail, particularly around boulder clusters. The successful biological validation in this study increases the confidence in the use of the flow-habitat relationships from this study for fisheries management in Clear Creek.

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 six glides in the Lower Alluvial Segment varied from 50 to 900 cfs (Figures 34 to 38). We attribute the 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 species/race/life stage, as shown in Figures 14 to 18, 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 the Lower Alluvial Segment.

An earlier study (California Department of Water Resources 1985) also modeled fall-run Chinook salmon and steelhead 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 or fall-run Chinook salmon fry rearing habitat. 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. As shown in Figures 39 to 42, the results from this study predict a peak amount of habitat at slightly lower or much higher flows than the California Department of Water Resources (1985) study. The difference between studies in the flow with the peak amount of habitat varied by species. 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.

Factors Causing Uncertainty

Factors causing uncertainty in the flow-habitat relationships include: 1) extrapolation from the study sites to the entire lower alluvial segment; 2) errors in velocity simulation; 3) errors in bathymetry data; 4) computational mesh element size and density of bed topography data; 5) errors in velocity measurements used to develop habitat suitability criteria; 6) differences

Figure 34. Comparison of spring-run Chinook salmon fry flow-habitat relationship for the six glides in the Lower Alluvial Segment.

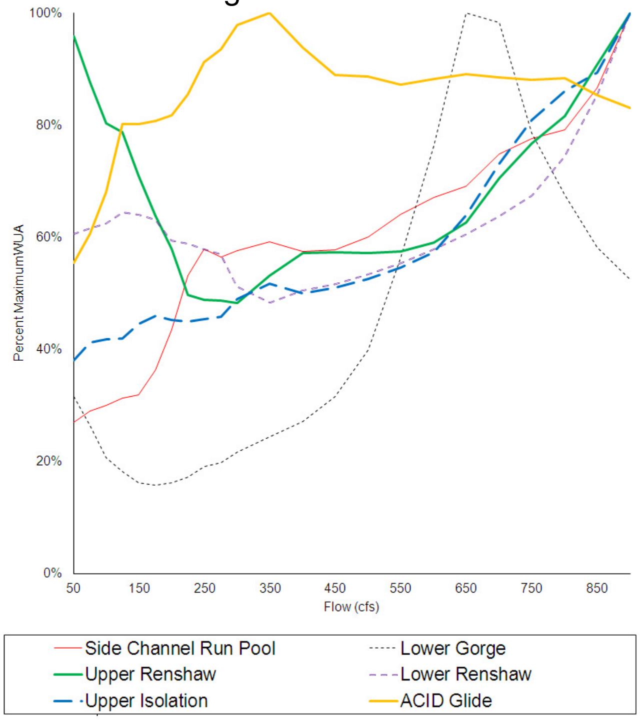


Figure 35. Comparison of spring-run Chinook salmon and steelhead/rainbow trout juvenile flow-habitat relationship for the six glides in the Lower Alluvial Segment.

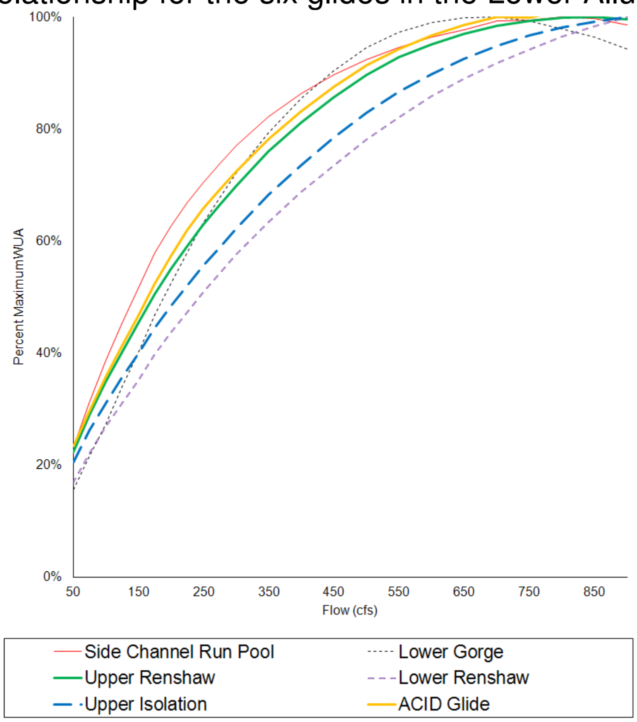


Figure 36. Comparison of steelhead/rainbow trout fry flow-habitat relationship for the six glides in the Lower Alluvial Segment.

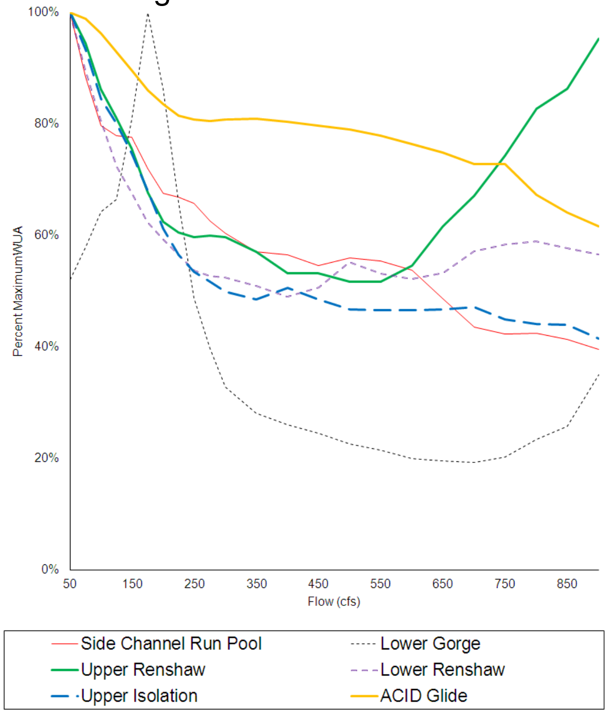


Figure 37. Comparison of fall-run Chinook salmon fry flow-habitat relationship for the six glides in the Lower Alluvial Segment.

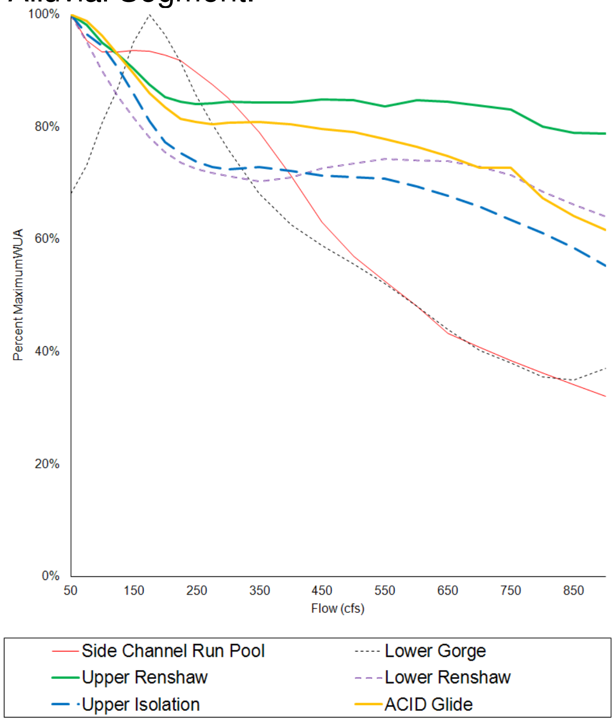


Figure 38. Comparison of fall-run Chinook salmon juvenile flow-habitat relationship for the six glides in the Lower Alluvial Segment .

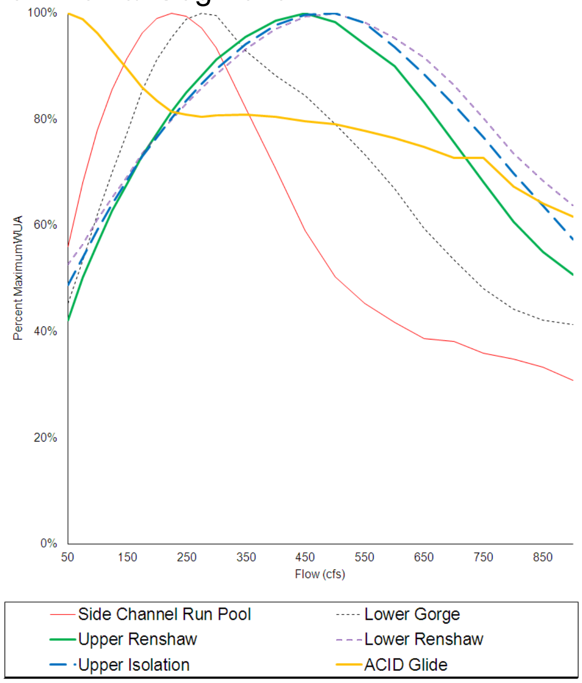


Figure 39. Comparison of steelhead/rainbow trout fry flow-habitat relationships from this study and the CDWR (1985) study. This study predicted the peak habitat at a slightly lower flow than the CDWR (1985) study.

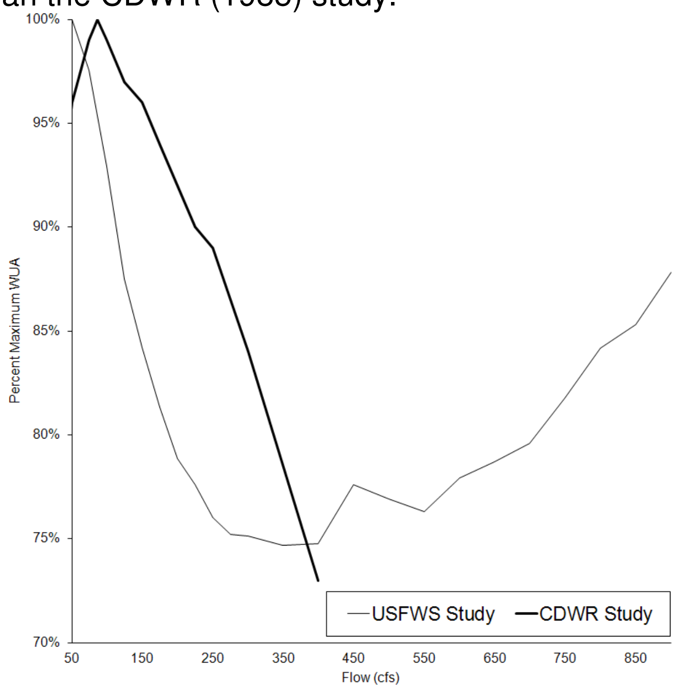


Figure 40. Comparison of spring-run Chinook salmon juvenile flow-habitat relationship from this study and fall-run Chinook salmon juvenile flow-habitat relationship from the CDWR (1985) study. This study predicted the peak habitat at a much higher flow than the CDWR (1985) study.

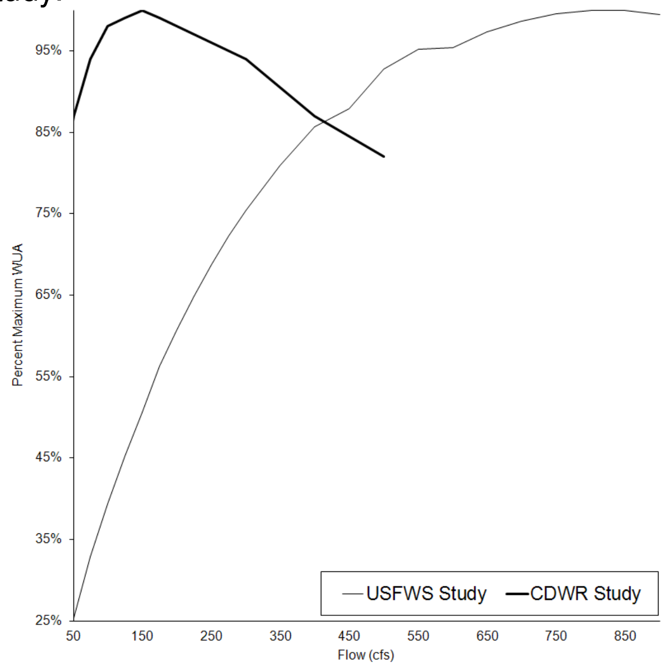


Figure 41. Comparison of fall-run Chinook salmon juvenile flow-habitat relationships from this study and the CDWR (1985) study. This study predicted the peak habitat at a much higher flow than the CDWR (1985) study.

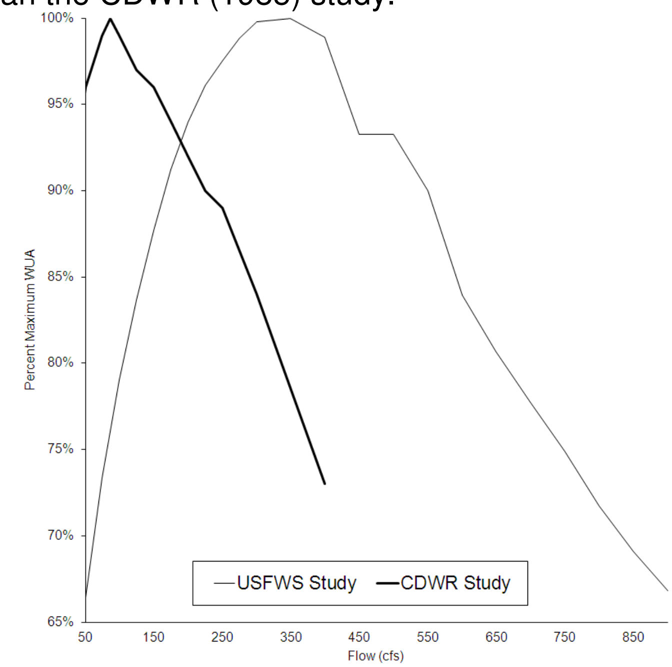
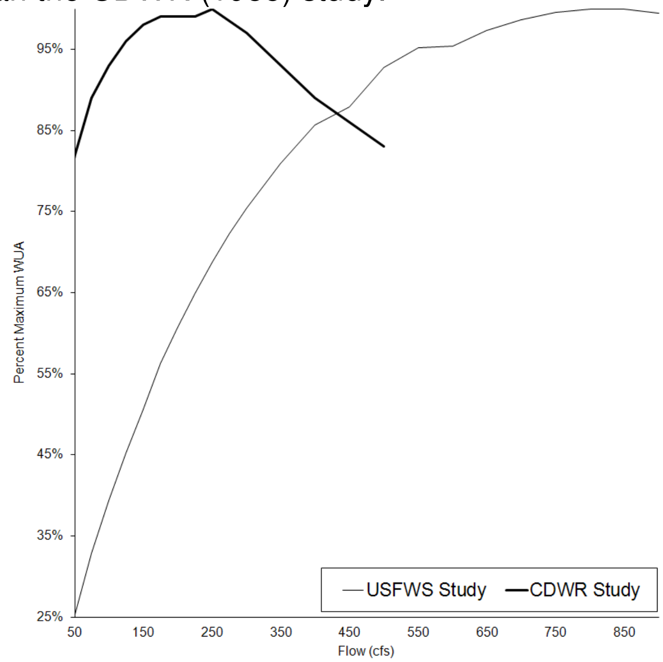


Figure 42. Comparison of steelhead/rainbow trout juvenile flow-habitat relationships from this study and the CDWR (1985) study. This study predicted the peak habitat at a much higher flow than the CDWR (1985) study.



between sampled versus population habitat suitability criteria data; and 7) potential biases in juvenile criteria due to survey techniques. Based on the number of study sites and the percentage of mesohabitat area found in the study sites, we believe that there is a low level of uncertainty associated with the extrapolation from the study sites to the entire lower alluvial segment.

We believe that over or under-predicted velocities at all sites would have a minimal effect on the overall flow-habitat relationships, given the high correlation between measured and predicted velocities. Specifically, the effects of over-predicted velocities would be cancelled out by the effect of under-predicted velocities, given the lack of bias in velocity predictions. The overall flow-habitat relationship is driven by the change in the distribution of depths and velocities with flow. The distribution of velocities would not be affected by over or under-predicted velocities because over-predicted velocities would have the opposite effect on the distribution of velocities as under-predicted velocities. Similarly, we believe that errors in bed bathymetry data, which would cause over-prediction or under-prediction of depths, would have a minimal effect on the overall flow-habitat relationships. Specifically, the effects of over-predicted depths would be cancelled out by the effect of under-predicted depths. The overall flow-habitat relationship is driven by the change in the distribution of depths and velocities with flow. The distribution of depths would not be affected by over or under-predicted depths because over-predicted depths would have the opposite effect on the distribution of depths as under-predicted depths.

The effects of discretization size and density of bed topography data on the flow-habitat relationships given in Appendix L are unknown but likely minor. Errors in velocity measurements used to develop habitat suitability criteria would likely be a minor source of uncertainty on the flow-habitat relationships given in Appendix L. Since errors in velocity measurement are random and not biased, effects of positive errors in velocity measurements would be cancelled out by the effect of negative errors in velocity measurements. The overall velocity habitat suitability curve is driven by the distribution of velocities. The distribution of velocities would not be affected by positive or negative errors in velocity measurements because positive errors in velocity measurements would have the opposite effect on the distribution of velocities as negative errors in velocity measurements.

The most likely source of uncertainty in the flow-habitat relationships given in Appendix L is the potential for difference between sampled versus population habitat suitability criteria data. The uncertainty from this factor could be quantified by a bootstrap analysis of the sampled HSC data to develop 95 percent confidence limit HSC, which could be applied to the hydraulic models of the ten study sites to determine 95 percent confidence limits for the flow-habitat relationships given in Appendix L. If juveniles were detecting the snorkelers and fleeing before we could observe them to collect HSC data, the HSC data could be biased towards fish that are more in the open, versus fish that are closer to cover. The likely effect of such a bias would be to overestimate the habitat value of no cover. We are unable to quantify what effect such a bias would have on the resulting flow-habitat relationships, other than it would tend to shift the peak of the curve to higher flows.

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 September would result in an increase of 6 % of habitat during this month for fall-run Chinook salmon juvenile rearing in the Lower 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. 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 Lower Alluvial segment of Clear Creek for spring-run and fall-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 introduction. The results of this study suggest that the flow recommendations in the CVPIA AFRP during the spring-run and fall-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 (51 to 84 % of maximum WUA), but may be close to achieving maximum habitat availability and productivity for rearing fall-run Chinook salmon in Clear Creek (88 to 94 % of maximum WUA) . Given the much larger population size of fall-run Chinook salmon, versus spring-run Chinook salmon (CDFG 2012) and steelhead, habitat is much more likely to be limiting for fall-run Chinook salmon.

REFERENCES

Annear, T., I. Chirholm, H. Beecher, A. Locke, P. Aarestad, N. Burkhart, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, C. Stalnaker and R. Wentworth. 2002. Instream Flows for Riverine Resource Stewardship. Instream Flow Council, Cheyenne, Wyoming.

Baltz, D.M. and P.B. Moyle. 1984. Segregation by species and size classes of rainbow trout, *Salmo gairdneri*, and Sacramento Sucker, *Catostomus occidentalis*, in three California streams. Environmental Biology of Fishes 10: 101-110.

Bartholow, J.M. 1996. Sensitivity of a salmon population model to alternative formulations and initial conditions. Ecological Modeling 88:215-226.

Bartholow, J.M., J.L. Laake, C.B. Stalnaker and S.C. Williamson. A salmonid population model with emphasis on habitat limitations. Rivers 4(4):265-279.

Bovee, K.D. 1978. Probability of use criteria for the family salmonidae. Instream Flow Information Paper 4. U.S. Fish and Wildlife Service FWS/OBS-78/07. 80 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U. S. Fish and Wildlife Service Biological Report 86(7). 235 pp.

Bovee, K.D., editor. 1996. The Complete IFIM: A Coursebook for IF 250. U.S. Geological Survey, Fort Collins, CO.

CDFG 2012. Grandtab. California Central Valley Sacramento and San Joaquin River Systems Chinook Salmon Escapement Hatcheries and Natural Areas. http://www.calfish.org/LinkClick.aspx?fileticket=k5ZkkcnoxZg%3d&tabid=104&mid=524

California Department of Water Resources. 1985. Clear Creek fishery study appendix, instream flow needs data, June 1985. California Department of Water Resources, Northern District, Red Bluff, CA.

California Department of Water Resources. 2005. Phase 2 report addendum evaluation of project effects on instream flows and fish habitat, SP F-16, Oroville Facilities Relicensing FERC Project No. 2100. California Department of Water Resources, Sacramento, CA.

Clackamas Instream Flow/Geomorphology Subgroup (CIFGS). 2003. Estimating salmonid habitat availability in the lower oak grove fork using expert habitat mapping, summary of methods and preliminary results. Report prepared by McBain and Trush Inc., Arcata, California, for Clackamas Instream Flow/Geomorphology Subgroup, March 5, 2003.

Cohen, J. 1992. Quantitative methods in psychology: A power primer. Psychological Bulletin 112(1): 155-159.

Crowder, D.W. and Diplas P. 2000. Using two-dimensional hydrodynamic models at scales of ecological importance. Journal of Hydrology. 230: 172-191.

Fausch, K.D. and R.J. White. 1981. Competition between brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38: 1220-1227.

Filipe, A., I. Cowx and M. Collares-pereira. 2002. Spatial modeling of freshwater fish in semi-arid river systems: a tool for conservation. River Research and Applications 18: 123-136.

Gard, M. 2006. Changes in salmon rearing and rearing habitat associated with river channel restoration. International Journal of River Basin Management 4: 201-211.

Gard, M. 2009a. Demonstration flow assessment and 2-D modeling: perspectives based on instream flow studies and evaluation of restoration projects. Fisheries 34(7):320-329.

Gard, M. 2009b. Comparison of spawning habitat predictions of PHABSIM and River2D models. International Journal of River Basin Management 7:55-71.

Geist, D.R., J. Jones, C.J. Murray and D.D. Dauble. 2000. Suitability criteria analyzed at the spatial scale of redd clusters improved estimates of spring Chinook salmon (*Oncorhynchus tshawytscha*) rearing habitat use in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57: 1636-1646.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1995. Two-dimensional modeling of flow in aquatic habitats. Water Resources Engineering Report 95-S1, Department of Civil Engineering, University of Alberta, Edmonton, Alberta. March 1995.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1996. Two-dimensional hydraulic simulation of physical habitat conditions in flowing streams. Regulated Rivers: Research and Management. 12: 185-200.

Gido, K.B. and D.L. Propst. 1999. Habitat use and association of native and nonnative fishes in the San Juan River, New Mexico and Utah. Copeia 1999: 321-332.

Gore, J.A. and J.M. Nestler. 1988. Instream flow studies in perspective. Regulated Rivers: Research & Management 2: 93–101.

Guay, J.C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57: 2065-2075.

Hardy, T.B. and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River, phase II, final report. Prepared for U.S. Department of the Interior. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah.

Hosmer, D.W. and S. Lemeshow. 2000. Applied Logistic Regression, Second Edition. John Wiley and Sons, Inc, New York.

Hudson, H.R., A.E. Byrom and W.L. Chadderton. 2003. A critique of IFIM – instream habitat simulation in the New Zealand context. Science for Conservation 231. New Zealand Department of Conservation, Wellington, New Zealand.

Hvidsten, H.B. 1993. High winter discharge after regulation increases production of Atlantic salmon, *Salmo salar*, smolts in the River Orkla, Norway. Pages 175-177 in: R.J. Gibson and R.E. Cutting, editors. Production of Juvenile Atlantic Salmon, *Salmo salar*, in Natural Waters. Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences 118.

Knapp, R.A. and H.K. Preisler. 1999. Is it possible to predict habitat use by rearing salmonids? A test using California golden trout (*Oncorhynchus mykiss aguabonita*). Canadian Journal of Fisheries and Aquatic Sciences 56: 1576-1584.

Leclerc, M., A. Boudreault, J.A. Bechara and G. Corfa. 1995. Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology. Transactions of the American Fisheries Society. 124(5): 645-662.

Maughan, O.E. and P.J. Barrett. 1992. An evaluation of the instream flow incremental methodology. Journal of the Arizona-Nevada Academy of Science 24-25:75-77.

McHugh, P. and P. Budy. 2004. Patterns of rearing habitat selection and suitability for two populations of spring chinook salmon, with an evaluation of generic verses site-specific suitability criteria. Transactions of the American Fisheries Society 133: 89-97.

Milhous, R.T., M.A. Updike and D.M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U. S. Fish and Wildlife Service Biological Report 89(16).

Moyle, P.B. and B. Vondracek. 1985. Persistence and structure of the fish assemblage in a small California stream. Ecology 66: 1-13.

Parasiewicz, P. 1999. A hybrid model – assessment of physical habitat conditions combining various modeling tools. In: Proceedings of the Third International Symposium on Ecohydraulics, Salt Lake City, Utah.

Pasternack G.B., C.L. Wang and J.E. Merz. 2004. Application of a 2D hydrodynamic model to design of reach-scale rearing gravel replenishment on the Mokelumne River, California. River Research and Applications. 20(2): 202-225.

Pampel, F.C. 2000. Logistic regression: a primer. Quantitative Applications in the Social Sciences 132.

Payne and Associates. 1998. RHABSIM 2.0 for DOS and Window's User's Manual. Arcata, CA: Thomas R. Payne and Associates.

Pearce, J. and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133(3): 225-245.

Raleigh, R.F., W.J. Miller and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook salmon. United States Fish and Wildlife Service, Biological Report 82(10.122). 64pp.

Rubin, S.P., T.C. Bjornn and B. Dennis. 1991. Habitat suitability curves for juvenile chinook salmon and steelhead development using a habitat-oriented sampling approach. Rivers 2(1):12-29.

Sechnick, C.W., R.F. Carline, R.A. Stein and E.T. Rankin. 1986. Habitat selection by smallmouth bass in response to physical characteristics of a simulated stream. Transactions of the American Fisheries Society 115: 314-321.

Snider, W.M., D.B. Christophel, B.L. Jackson and P.M. Bratovich. 1992. Habitat characterization of the Lower American River. California Department of Fish and Game, Sacramento, CA.

Steffler, P. 2002. River2D_Bed. Bed Topography File Editor. User's manual. University of Alberta, Edmonton, Alberta. 32 pp. http://www.River2D.ualberta.ca/download.htm

Steffler, P. and J. Blackburn. 2002. River2D: Two-dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat. Introduction to Depth Averaged Modeling and User's Manual. University of Alberta, Edmonton, Alberta. 120 pp. http://www.River2D.ualberta.ca/download.htm

SYSTAT. 2002. SYSTAT 10.2 Statistical Software. SYSTAT Software Inc., Richmond, CA.

Thielke, J. 1985. A logistic regression approach for developing suitability-of-use functions for fish habitat. Pages 32-38 in F.W. Olson, R.G. White, and R.H. Hamre, editors. Proceedings of the symposium on small hydropower and fisheries. American Fisheries Society, Western Division and Bioengineering Section, Bethesda, Maryland.

Tiffan, K.E., R.D. Garland and D.W. Rondorf. 2002. Quantifying flow-dependent changes in subyearling spring Chinook salmon rearing habitat using two-dimensional spatially explicit modeling. North American Journal of Fisheries Management 22: 713-726.

Tirelli, T., L. Pozzi and D. Pessani. 2009. Use of different approaches to model presence/absence of salmon marmoratus in Piedmont (NorthWestern Italy). Ecological Informatics 4: 234-243.

Thomas R. Payne and Associates (TRPA). 1998. Battle Creek fisheries studies. Task 2: habitat suitability criteria. Draft report to CDFG, Redding, CA.

U.S. Fish and Wildlife Service. 1994. Using the computer based physical habitat simulation system (PHABSIM). Fort Collins, CO: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 2000. Effects of the January 1997 flood on flow-habitat relationships for steelhead and fall-run Chinook salmon in the Lower American River. U.S. Fish and Wildlife Service, Sacramento, CA.

U.S. Fish and Wildlife Service. 2001. Final restoration plan for the anadromous fish restoration program. A plan to increase natural production of anadromous fish in the Central Valley of California. January 9, 2001. Prepared for the U. S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. U.S. Fish and Wildlife Service, Stockton, CA.

U.S. Fish and Wildlife Service. 2005a. Monitoring of restoration projects in Clear Creek using 2-dimensional modeling methodology. U.S. Fish and Wildlife Service: Sacramento, CA.

U. S. Fish and Wildlife Service. 2005b. Flow-habitat relationships for Chinook salmon rearing in the Sacramento River between Keswick Dam and Battle Creek. U.S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2007. Flow-habitat relationships for spring Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Whiskeytown Dam and Clear Creek Road. U.S. Fish and Wildlife Service, Sacramento, CA.

U. S. Fish and Wildlife Service. 2010. Flow-habitat relationships for fall/spring-run Chinook salmon and steelhead/rainbow trout rearing in the Yuba River. U.S. Fish and Wildlife Service, Sacramento, CA.

U.S. Fish and Wildlife Service. 2011a. Flow-habitat relationships for fall-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Clear Creek Road and the Sacramento River. U.S. Fish and Wildlife Service: Sacramento, CA.

U.S. Fish and Wildlife Service. 2011b. Flow-habitat relationships for spring-run Chinook salmon and steelhead/rainbow trout rearing in Clear Creek between Whiskeytown Dam and Clear Creek Road. U.S. Fish and Wildlife Service: Sacramento, CA.

Waddle, T. and P. Steffler. 2002. R2D_Mesh - Mesh Generation Program for River2D Two Dimensional Depth Averaged Finite Element. Introduction to Mesh Generation and User's manual. U.S. Geological Survey, Fort Collins, CO. 32 pp. http://www.river2d.ualberta.ca/download.htm

Williamson, S.C., J.M. Bartholow and C.B. Stalnaker. 1993. Conceptual model for quantifying pre-smolt production from flow-dependent physical habitat and water temperature. Regulated Rivers: Research and Management 8:15-28.

Yalin, M.S. 1977. Mechanics of Sediment Transport. Pergamon Press, New York.

Zar, J.H. 1984. Biostatistical Analysis, Second Edition. Prentice-Hall, Inc, Englewood Cliffs, NJ.

APPENDIX A
HABITAT MAPPING DATA

Habitat distribution identified in the Clear Creek Lower Alluvial Segment

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
1	Main Channel Glide	9,468
2	Main Channel Run	16,646
3	Main Channel Riffle	9,113
4	Side Channel Pool	2,994
5	Side Channel Run	654
6	Side Channel Riffle	689
7	Main Channel Run	20,365
8	Main Channel Pool	13,333
9	Main Channel Run	65,995
10	Main Channel Pool	50,269
11	Side Channel Pool	2,470
12	Main Channel Run	9,586
13	Main Channel Riffle	19,734
14	Main Channel Run	9,833
15	Main Channel Pool	9,772
16	Main Channel Run	26,270
17	Main Channel Pool	34,806
18	Side Channel Run	9,017
19	Side Channel Run	5,713
20	Main Channel Run	21,026
21	Main Channel Pool	58,489
22	Main Channel Run	9,873
23	Main Channel Run	13,119
24	Main Channel Run	115,852
25	Side Channel Pool	5,106
26	Side Channel Glide	1,999
27	Side Channel Riffle	773
28	Side Channel Pool	3,469
29	Side Channel Riffle	694
30	Main Channel Pool	10,085
31	Main Channel Run	32,109
32	Side Channel Run	5,104
33	Main Channel Run	9,943
34	Main Channel Pool	8,133
35	Main Channel Run	8,972

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
36	Main Channel Pool	9,694
37	Side Channel Run	1,466
38	Side Channel Pool	1,320
39	Main Channel Glide	9,778
40	Main Channel Pool	2,447
41	Main Channel Run	47,456
42	Main Channel Pool	9,985
43	Side Channel Run	1,070
44	Side Channel Pool	820
45	Side Channel Run	995
46	Side Channel Pool	862
47	Main Channel Run	26,416
48	Cascade	2,510
49	Main Channel Run	30,480
50	Main Channel Pool	13,799
51	Main Channel Run	5,148
52	Side Channel Pool	1,861
53	Side Channel Pool	2,939
54	Side Channel Pool	1,432
55	Side Channel Run	1,310
56	Side Channel Pool	1,170
57	Side Channel Run	1,675
58	Side Channel Pool	570
59	Cascade	22,470
60	Main Channel Pool	11,801
61	Main Channel Run	2,040
62	Main Channel Pool	10,524
63	Main Channel Glide	1,785
64	Main Channel Glide	3,477
65	Main Channel Run	11,528
66	Main Channel Pool	7,993
67	Main Channel Run	9,243
68	Main Channel Pool	7,775
69	Main Channel Glide	7,644
70	Main Channel Pool	23,504
71	Main Channel Riffle	3,159
72	Main Channel Run	11,471

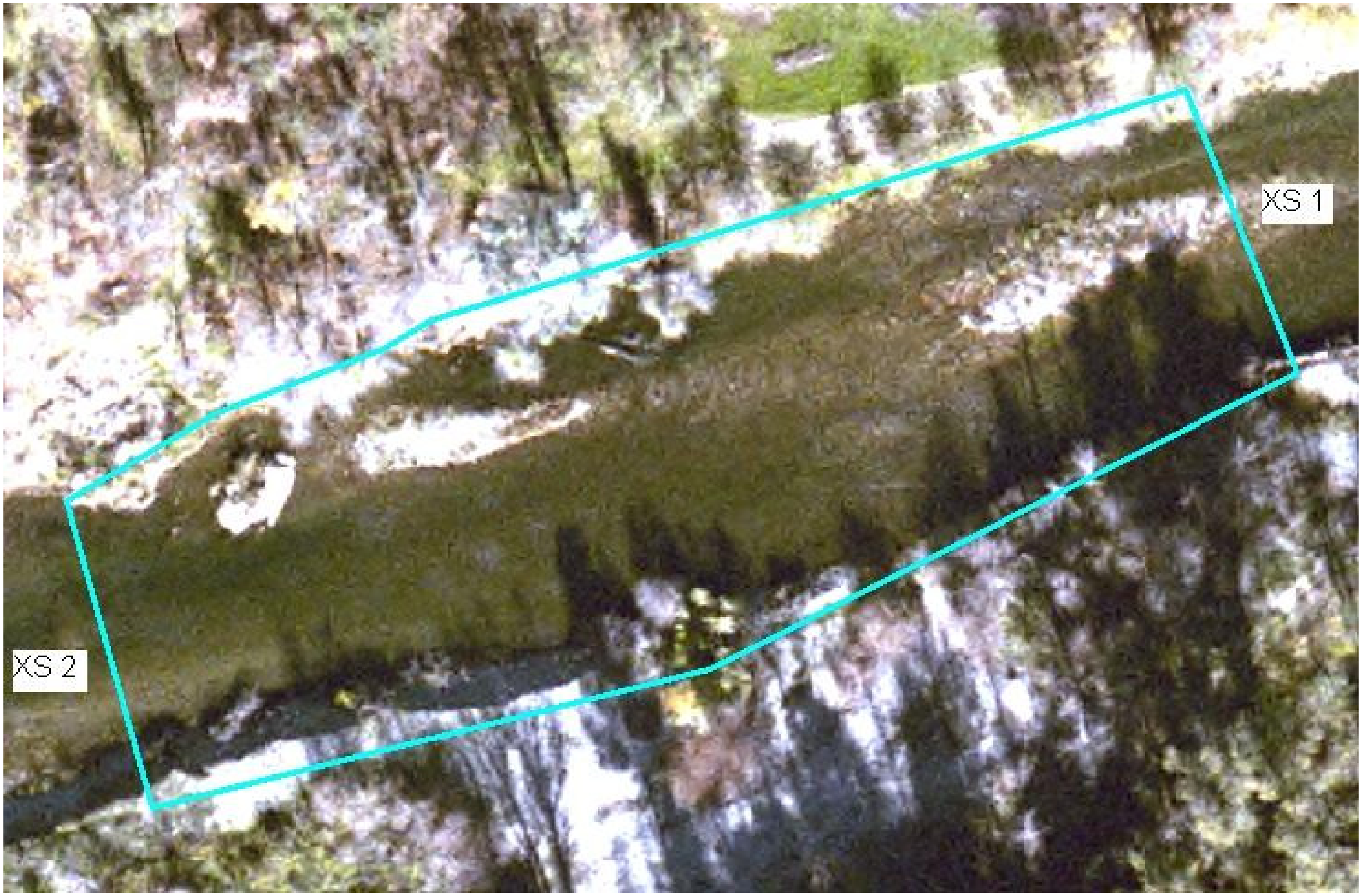
Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
73	Main Channel Pool	3,593
74	Main Channel Pool	8,575
75	Side Channel Run	847
76	Main Channel Run	26,112
77	Main Channel Glide	7,909
78	Main Channel Run	13,603
79	Side Channel Run	955
80	Side Channel Glide	692
81	Side Channel Run	1,211
82	Side Channel Pool	1,224
83	Main Channel Run	6,163
84	Main Channel Pool	13,536
85	Side Channel Pool	2,384
86	Side Channel Run	1,050
87	Main Channel Run	25,123
88	Main Channel Glide	111,370
89	Main Channel Run	143,517
90	Main Channel Glide	31,119
91	Main Channel Riffle	5,461
92	Main Channel Run	33,022
93	Main Channel Riffle	4,824
94	Main Channel Run	27,704
95	Main Channel Riffle	5,177
96	Main Channel Pool	26,466
97	Main Channel Glide	12,462
98	Main Channel Run	20,847
99	Main Channel Glide	19,602
100	Main Channel Run	38,390
101	Main Channel Pool	4,222
102	Main Channel Glide	6,036
103	Main Channel Riffle	16,532
104	Side Channel Riffle	1,968
105	Side Channel Run	685
106	Side Channel Pool	3,022
107	Side Channel Run	2,293
108	Side Channel Glide	911
109	Side Channel Pool	725

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
110	Main Channel Pool	15,923
111	Main Channel Glide	14,089
112	Main Channel Riffle	6,682
113	Main Channel Run	8,349
114	Main Channel Riffle	6,014
115	Main Channel Run	129,041
	Restoration Reach	
117	Main Channel Run	6,974
118	Main Channel Pool	10,749
119	Main Channel Glide	9,097
120	Main Channel Pool	24,725
121	Main Channel Glide	11,420
122	Main Channel Run	17,246
123	Main Channel Pool	15,181
124	Main Channel Glide	7,470
125	Main Channel Pool	32,214
126	Main Channel Glide	7,454
127	Main Channel Run	5,680
128	Main Channel Glide	14,845
129	Main Channel Run	9,984
130	Side Channel Run	269
131	Side Channel Pool	7,716
132	Side Channel Run	166
133	Main Channel Glide	127,340
134	Main Channel Pool	23,062
135	Main Channel Pool	14,922
136	Main Channel Run	13,125
137	Main Channel Pool	20,368
138	Side Channel Pool	7,050
139	Side Channel Run	7,001
140	Main Channel Run	34,880
141	Main Channel Pool	98,723
142	Main Channel Riffle	7,287
143	Main Channel Run	12,938
144	Main Channel Pool	35,932
145	Main Channel Run	7,519
146	Main Channel Pool	15,074

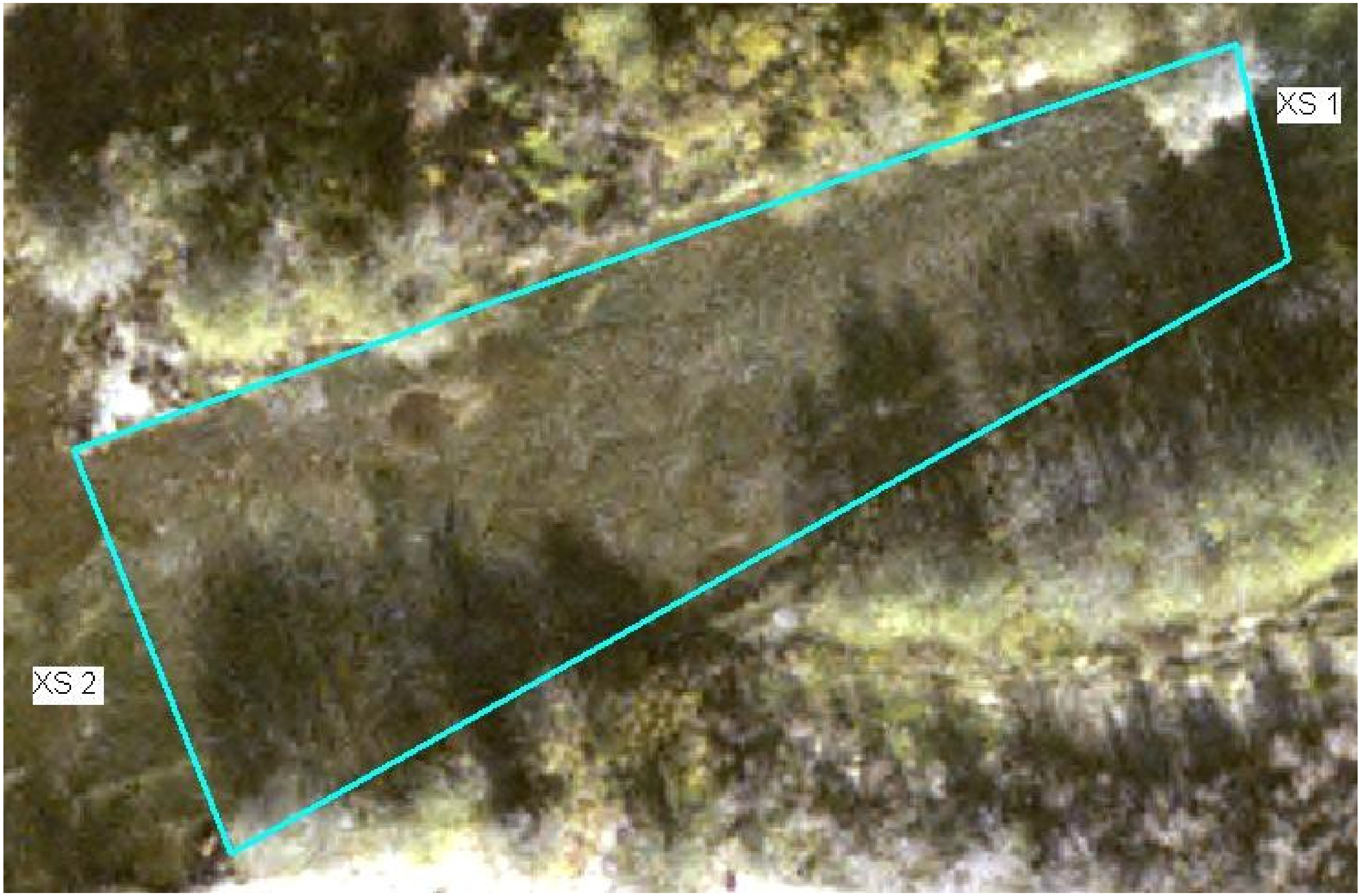
Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
147	Side Channel Run	4,335
148	Main Channel Run	16,051
149	Side Channel Pool	3,063
150	Main Channel Glide	9,692
151	Main Channel Run	17,646
152	Main Channel Glide	39,019
153	Main Channel Pool	24,030
154	Main Channel Run	24,066
155	Main Channel Pool	12,732
156	Side Channel Run	2,396
157	Side Channel Pool	933
158	Side Channel Run	1,426
159	Side Channel Pool	1,045
160	Side Channel Run	10,456
161	Main Channel Run	15,114
162	Main Channel Pool	41,796
163	Main Channel Pool	68,109
164	Main Channel Glide	51,740
165	Main Channel Riffle	14,269
166	Main Channel Run	2,719

APPENDIX B
STUDY SITE AND TRANSECT LOCATIONS

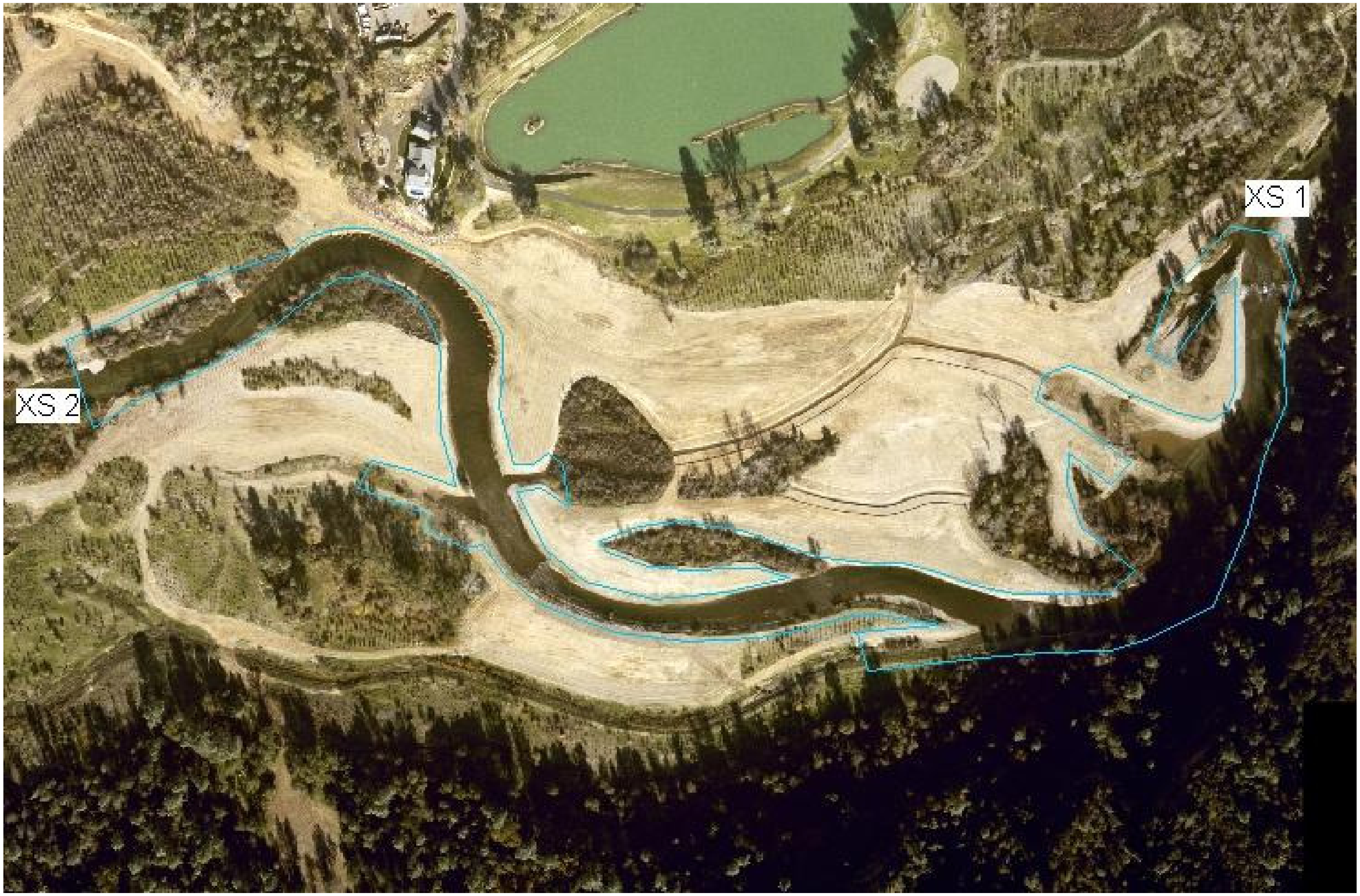
SIDE CHANNEL RUN POOL STUDY SITE



NORTH STATE RIFFLE STUDY SITE

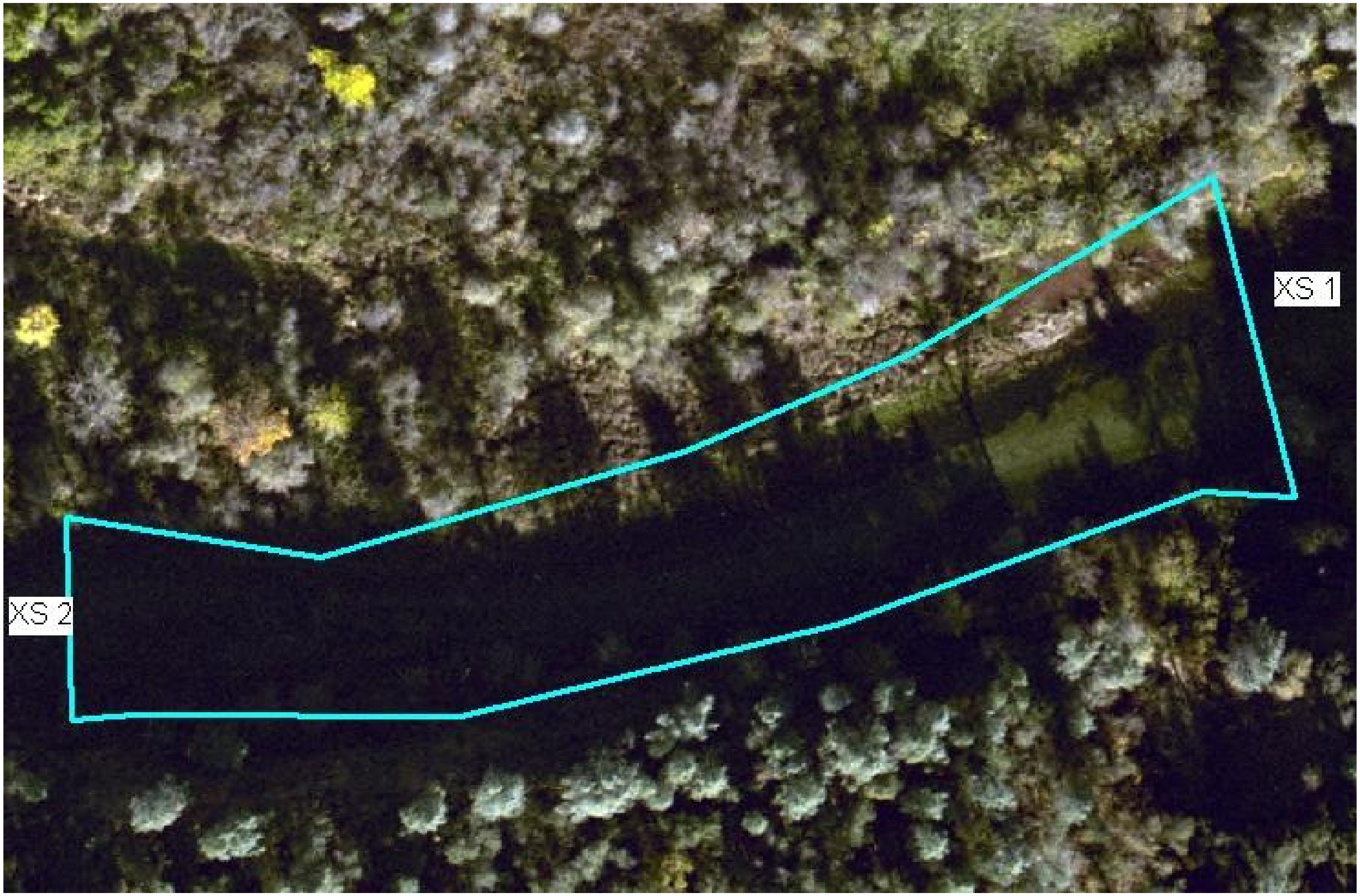


STUDY SITE 3B



TARZAN POOL STUDY SITE

ACID GLIDE STUDY SITE



APPENDIX C
RHABSIM WSEL CALBRATION

Stage of Zero Flow Values

Study Site	XS # 1 SZF	XS # 2 SZF
Side Channel Run Pool	87.7	89.1
North State Riffle	94.1	95.6
Restoration Site 3B	45.1	57.0
Tarzan Pool	93.2	93.4
ACID Glide	94.7	94.7

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range	Calibration Flows	Method	Parameters
Side Channel Run Pool	1	50-225	81, 201, 246	MANSQ	CalQ = 81, β = 0.5
Side Channel Run Pool	1	250-900	246, 404, 650	IFG4	- - -
Side Channel Run Pool	2	50-900	81, 201, 246, 398, 650	IFG4	- - -
North State Riffle	1	50-900	79, 208, 378, 570	IFG4	- - -
North State Riffle	2	50-900	79, 208, 378, 568	IFG4	- - -
Restoration Site 3B	1	50-900	86.9, 226, 434, 630	IFG4	- - -
Restoration Site 3B	2	50-900	86.9, 215, 433, 651	IFG4	- - -
Tarzan Pool	1	50-900	94, 228, 445, 643	IFG4	- - -
Tarzan Pool	2	50-900	94, 228, 439, 646	IFG4	- - -
ACID Glide	1, 2	50-225	95, 230	IFG4	- - -
ACID Glide	1	250-900	230, 445, 645	IFG4	- - -
ACID Glide	2	250-900	230, 445, 650	IFG4	- - -

Side Channel Run Pool Study Site[26]

XS		%MEAN ERROR	Calculated vs Given Discharge (%) 81	201	246	Difference (measured vs. pred. WSELs) 81	201	246
1		3.9	0.0	0.0	11.8	0.00	0.00	0.06

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 246	404	650	Difference (measured vs. pred. WSELs) 246	404	650
1	2.55	0.7	0.5	1.0	0.5	0.08	0.02	0.06

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 81	201	246	398	650	Difference (measured vs. pred. WSELs) 81	201	246	398	650
2	3.75	7.6	10.2	12.4	2.4	5.8	7.6	0.06	0.05	0.08	0.02	0.06

North State Riffle Study Site

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 79	208	378	570	Difference (measured vs. pred. WSELs) 79	208	378	570
1	2.66	2.4	2.6	4.9	0.1	2.1	0.01	0.04	0.00	0.02

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 79	208	378	568	Difference (measured vs. pred. WSELs) 79	208	378	568
2	3.17	2.5	2.4	5.3	1.8	9.2	0.01	0.03	0.01	0.01

[26] Both the percentage difference between calculated and given discharge and difference (measured versus predicted WSEL, feet) are absolute values.

Restoration Study Site 3B

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	86.9	226	434	630	86.9	226	434	630
1	2.23	4.7	3.5	4.3	5.3	5.6	0.03	0.05	0.08	0.10

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	86.9	215	433	651	86.9	215	433	651
2	2.88	9.5	10.8	16.5	4.0	7.5	0.06	0.10	0.03	0.08

Tarzan Pool Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	94	228	445	643	94	228	445	643
1	2.40	4.2	3.8	5.6	2.9	4.4	0.06	0.06	0.04	0.07

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	94	228	439	646	94	228	439	646
2	2.25	4.5	4.1	6.0	3.1	4.6	0.03	0.07	0.05	0.09

ACID Glide Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)		Difference (measured vs. pred. WSELs)	
XS	COEFF.	ERROR	95	230	95	230
1	7.2	0.0	0.0	0.0	0.00	0.00
2	7.0	0.0	0.0	0.0	0.00	0.00

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	230	445	645	230	445	645
1	2.59	1.2	0.7	1.8	1.1	0.01	0.02	0.01

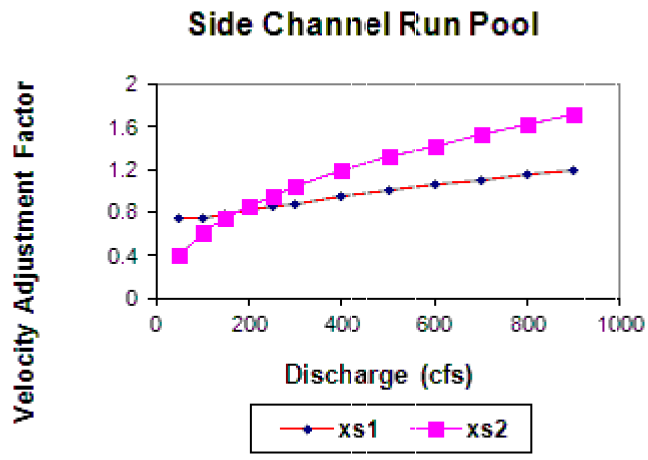
	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	230	445	650	230	445	650
2	2.50	1.5	0.9	2.2	1.3	0.01	0.02	0.02

APPENDIX D
VELOCITY ADJUSTMENT FACTORS

Side Channel Run Pool Study Site

Velocity Adjustment Factors

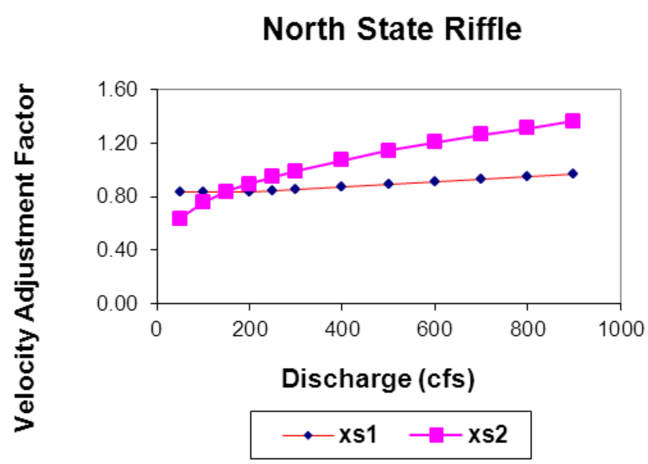
Discharge	Xsec 1	Xsec 2
50	0.74	0.41
100	0.75	0.61
150	0.78	0.75
200	0.82	0.86
250	0.85	0.96
300	0.88	1.04
400	0.95	1.19
500	1.00	1.32
600	1.06	1.43
700	1.10	1.53
800	1.15	1.63
900	1.19	1.71



North State Riffle Study Site

Velocity Adjustment Factors

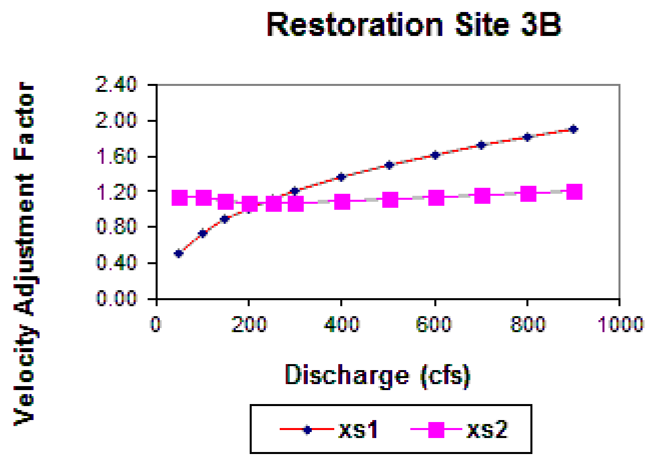
Discharge	Xsec 1	Xsec 2
50	0.84	0.64
100	0.84	0.76
150	0.84	0.84
200	0.84	0.90
250	0.85	0.95
300	0.86	0.99
400	0.88	1.07
500	0.90	1.14
600	0.92	1.21
700	0.94	1.26
800	0.95	1.31
900	0.97	1.36



Restoration Study Site 3B

Velocity Adjustment Factors

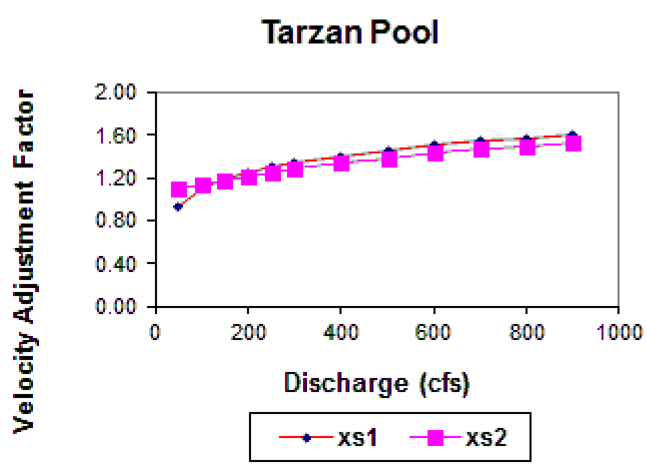
Discharge	Xsec 1	Xsec 2
50	0.50	1.14
100	0.73	1.14
150	0.89	1.09
200	1.01	1.07
250	1.12	1.07
300	1.21	1.07
400	1.37	1.09
500	1.50	1.11
600	1.61	1.13
700	1.72	1.15
800	1.82	1.18
900	1.91	1.20



Tarzan Pool Study Site

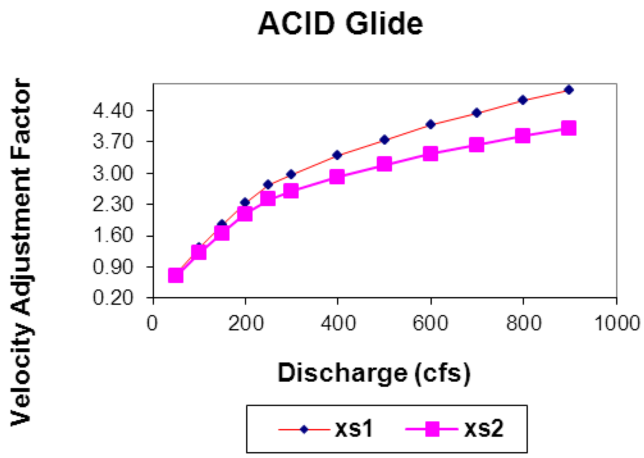
Velocity Adjustment Factors

Discharge	Xsec 1	Xsec 2
50	0.93	1.10
100	1.10	1.14
150	1.19	1.18
200	1.25	1.22
250	1.30	1.25
300	1.34	1.28
400	1.41	1.34
500	1.46	1.39
600	1.50	1.43
700	1.54	1.47
800	1.58	1.50
900	1.61	1.53



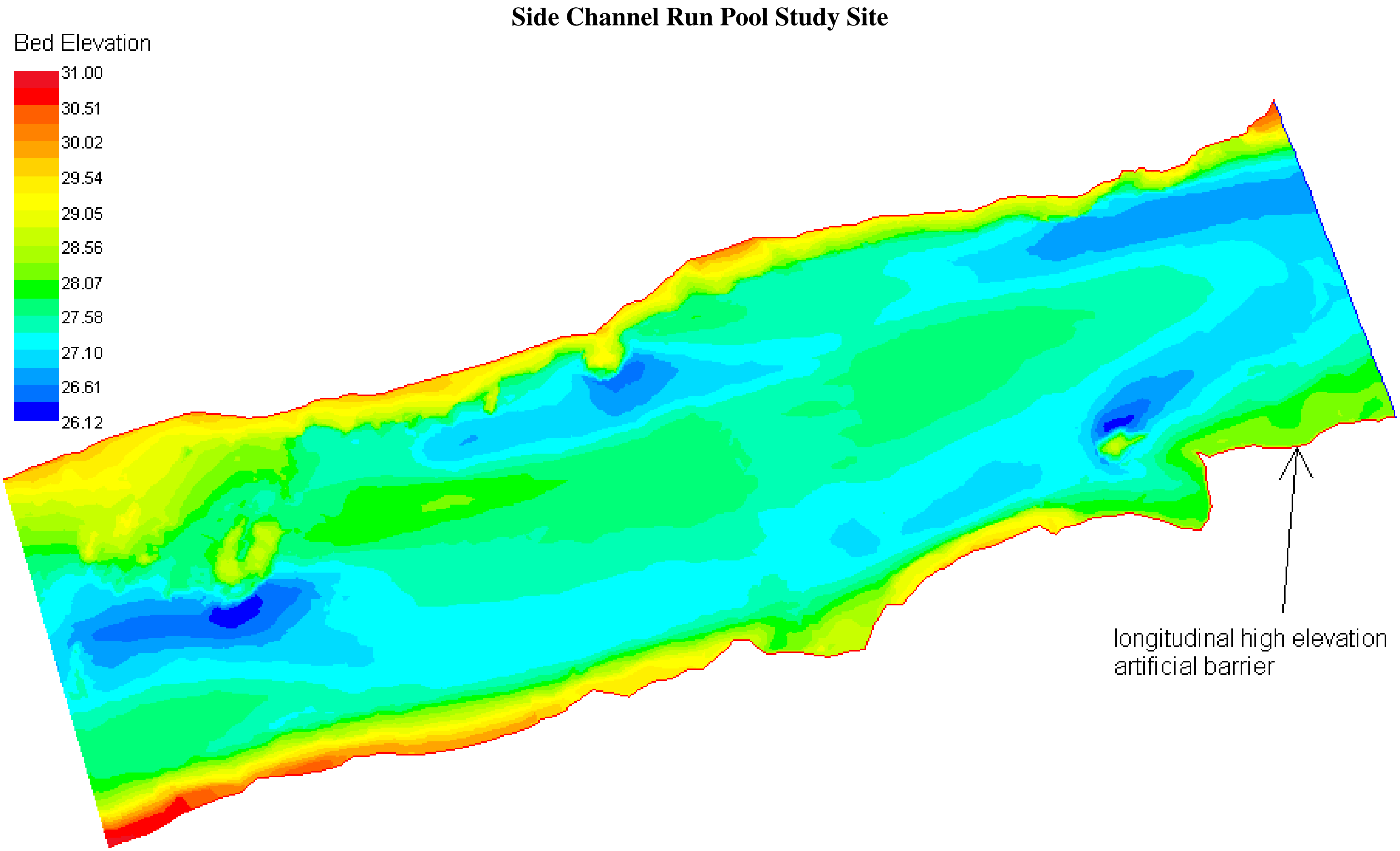
ACID Glide Study Site

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.75	0.69
100	1.32	1.20
150	1.84	1.66
200	2.33	2.08
250	2.73	2.42
300	2.97	2.60
400	3.39	2.92
500	3.76	3.19
600	4.07	3.43
700	4.36	3.64
800	4.62	3.83
900	4.86	4.01



APPENDIX E
BED TOPOGRAPHY OF STUDY SITES[27]

[27] Elevations of each site are relative to an arbitrary datum of 100 feet (30.5 m).

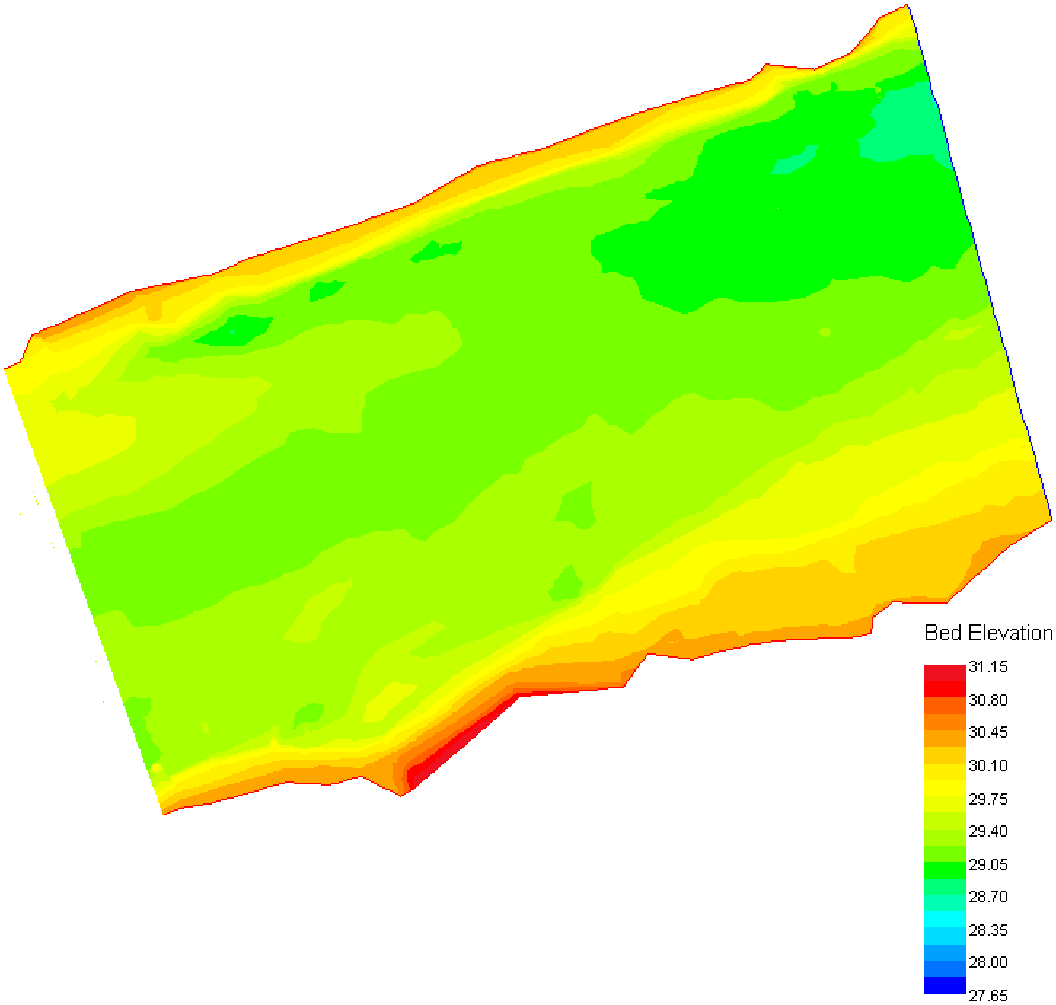


Units of Bed Elevation are meters.

Scale: 1: 634

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

North State Riffle Study Site

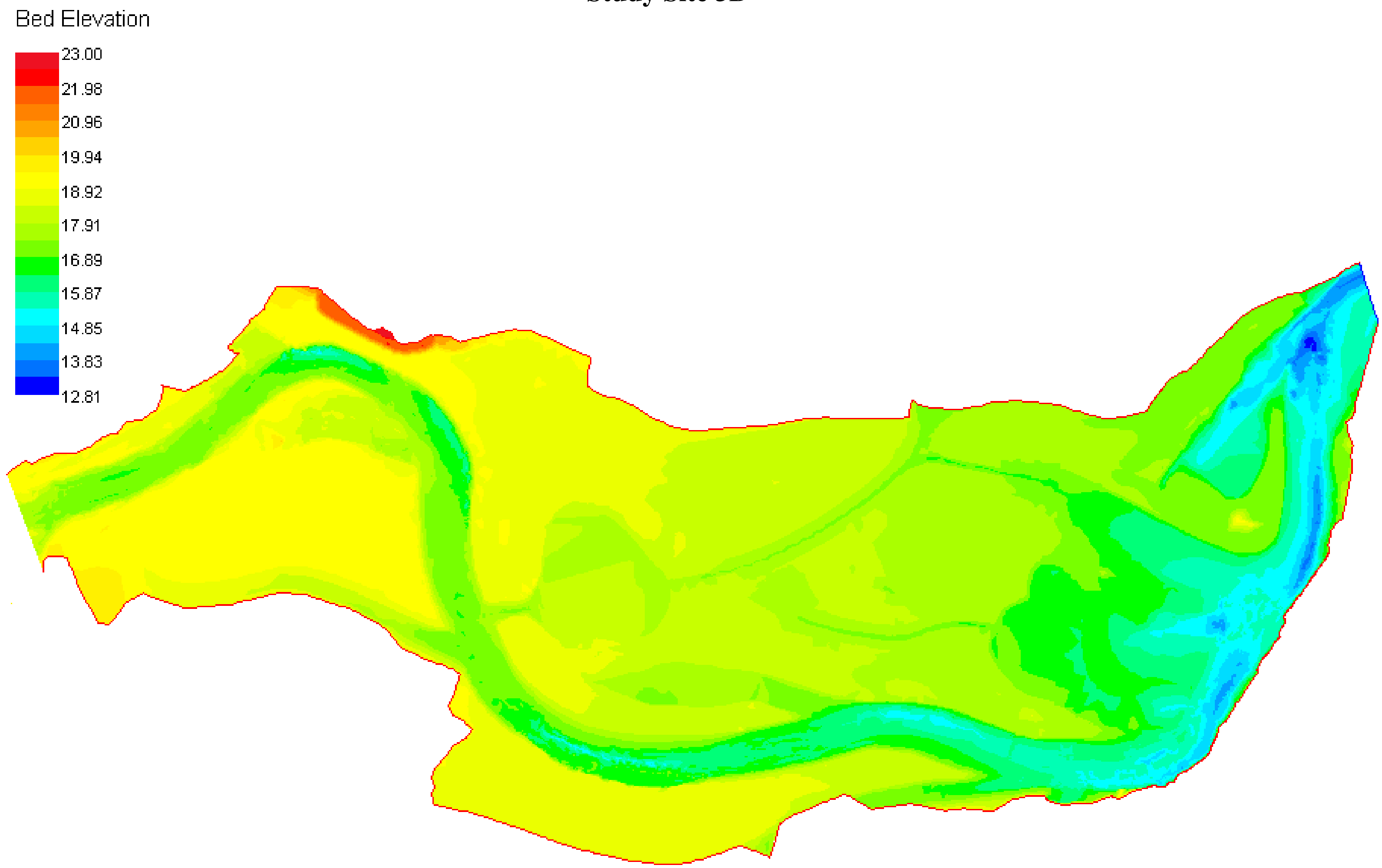


Units of Bed Elevation are meters.

Scale: 1: 512

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

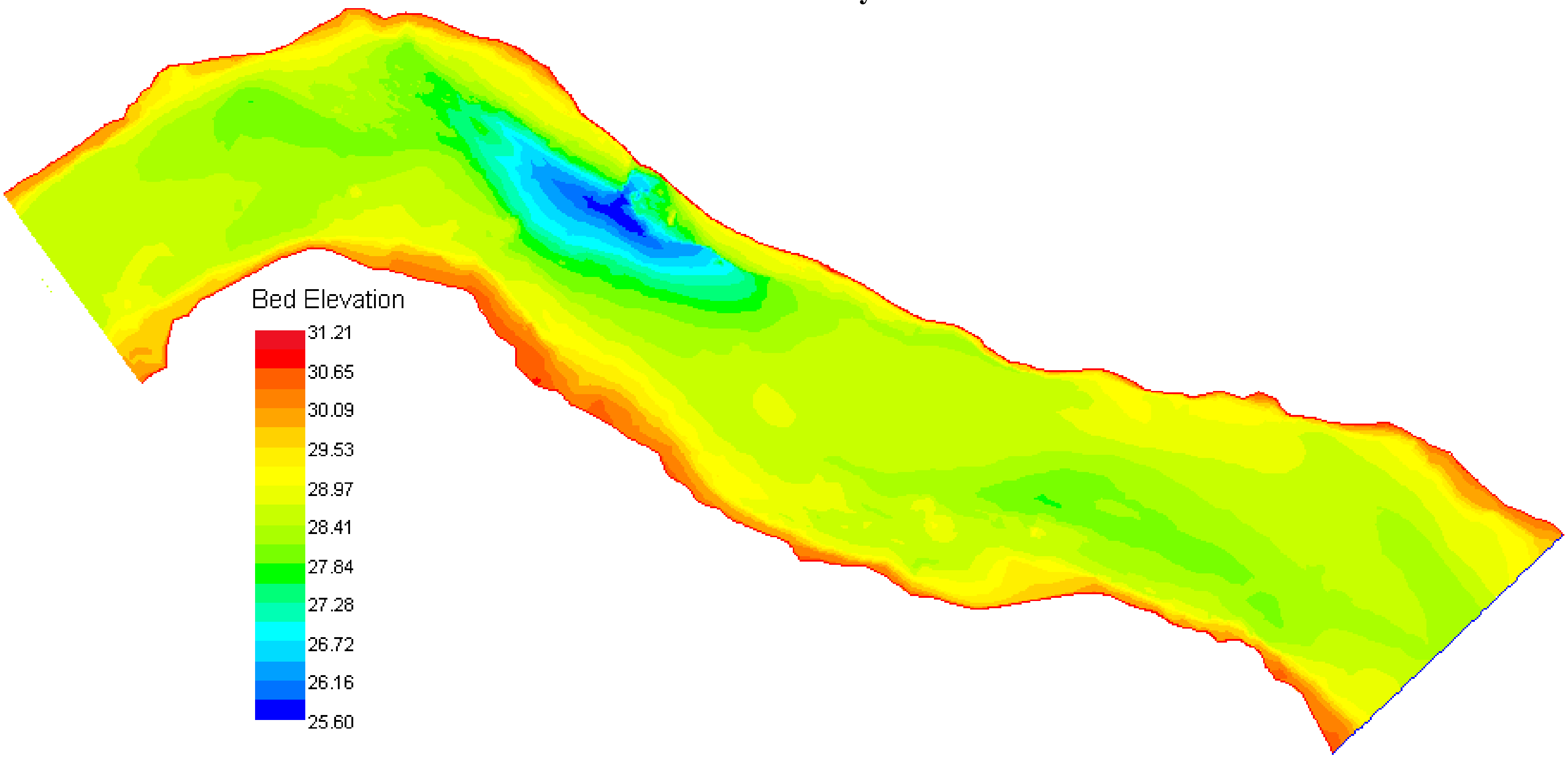
Study Site 3B



Units of Bed Elevation are meters.

Scale: 1: 1,720

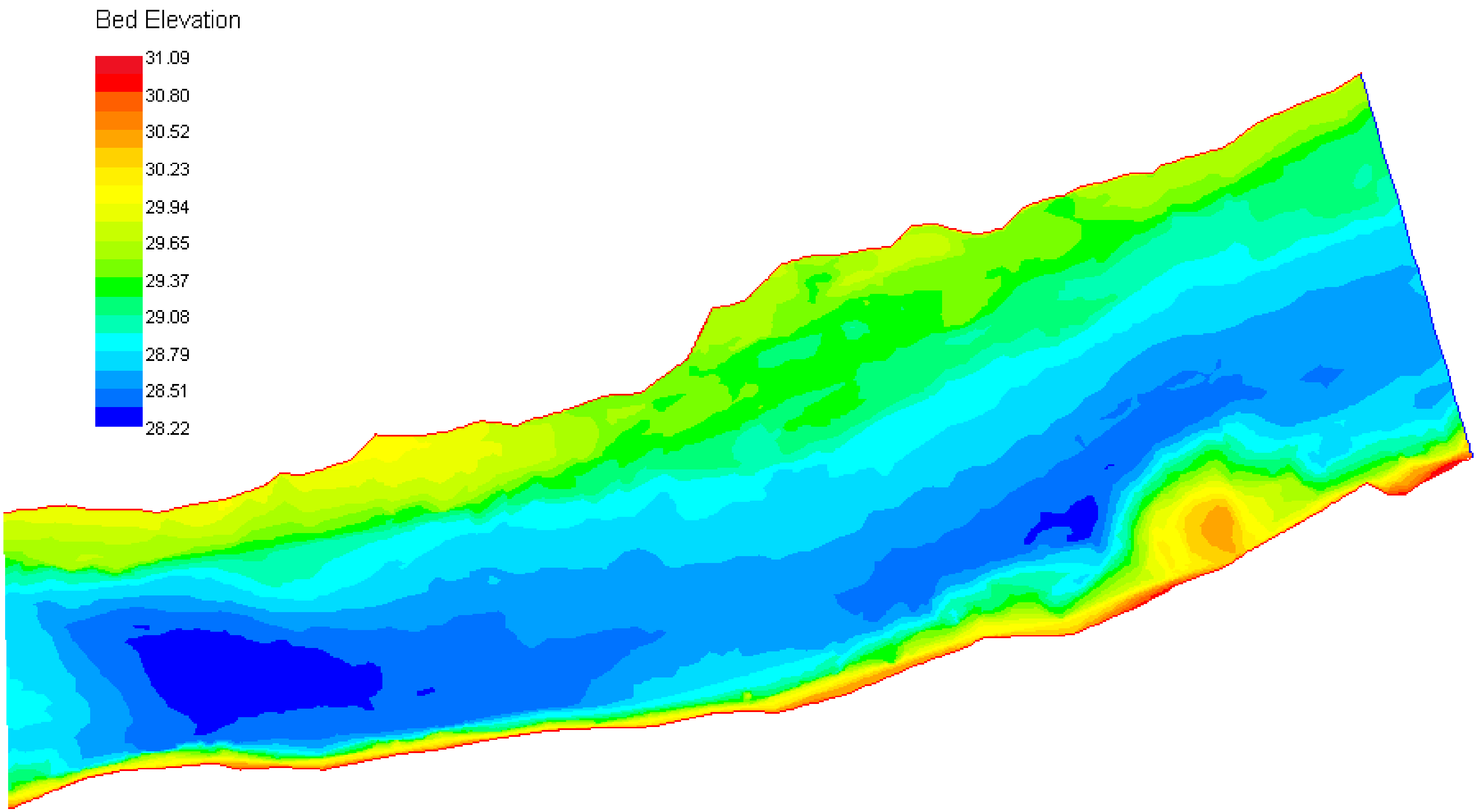
Tarzan Pool Study Site



Units of Bed Elevation are meters.

Scale: 1: 518

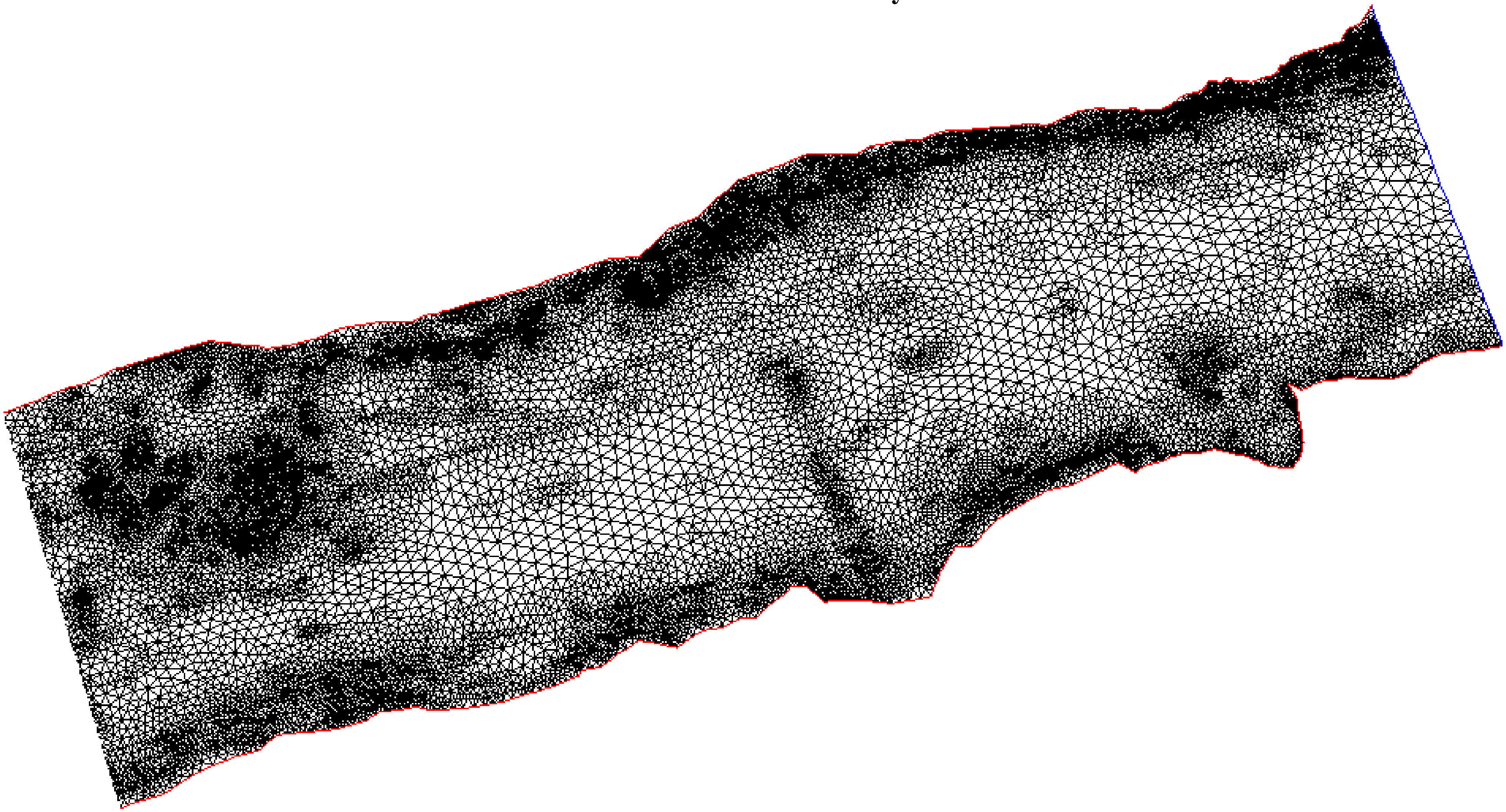
ACID Glide Study Site



Units of Bed Elevation are meters. Scale: 1: 520

APPENDIX F
COMPUTATIONAL MESHES OF STUDY SITES

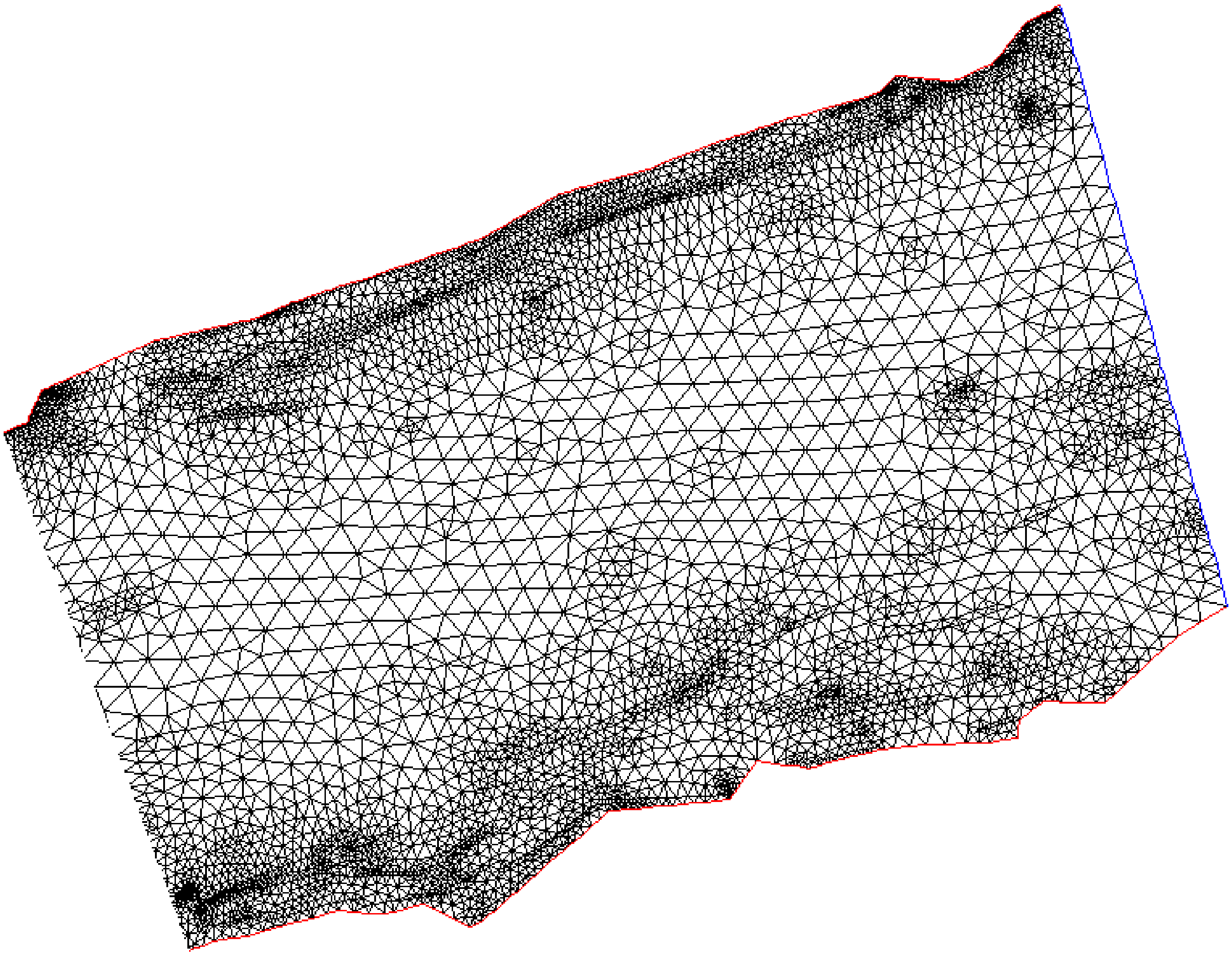
Side Channel Run Pool Study Site



Scale: 1: 634

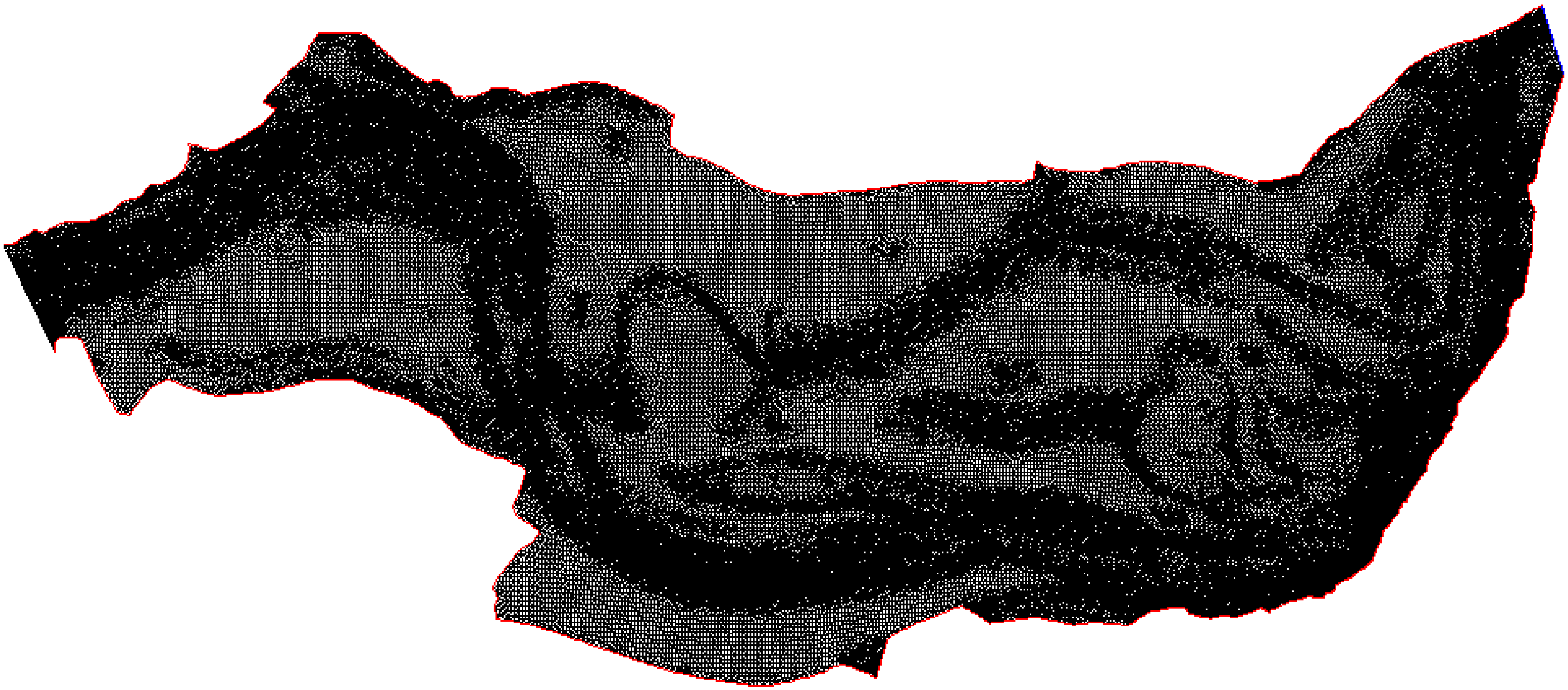
USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

North State Riffle Study Site



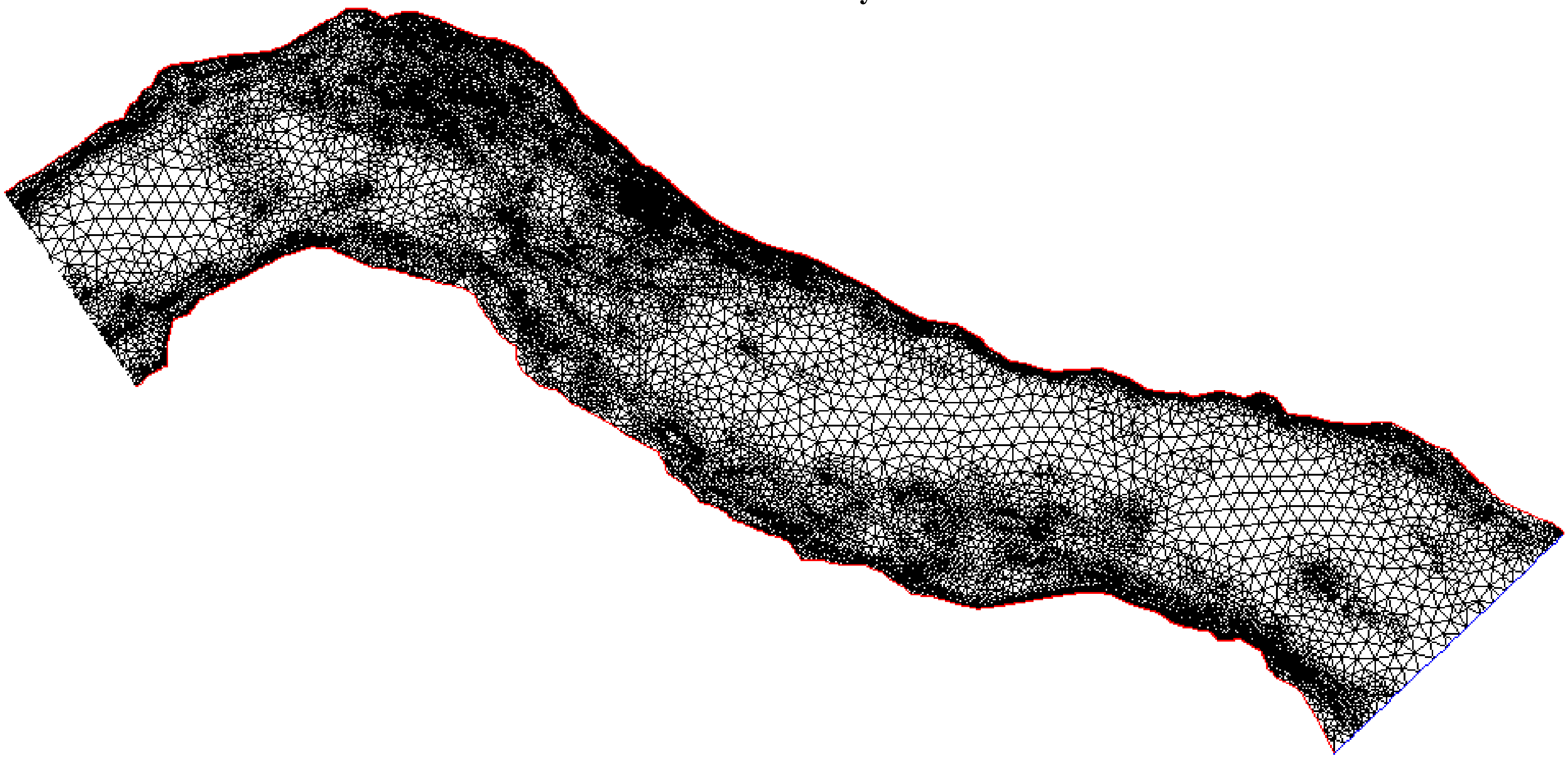
Scale: 1: 399

Study Site 3B



Scale: 1: 1,588

Tarzan Pool Study Site



Scale: 1: 518

ACID Glide Study Site

Scale: 1: 539

APPENDIX G
2-D WSEL CALIBRATION

Calibration Statistics[28]

Site Name	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Side Channel Run Pool	74.2%	27,300	0.30	0.02%	<0.000001	2.74
North State Riffle	95.0%	11,943	0.30	0.06%	0.000006	3.07
Restoration Site 3B	77.7%	98,241	0.30	0.7%	0.000001	10.17
Tarzan Pool	90.7%	26,172	0.30	0.01%	<0.000001	8.72
ACID Glide	93.4%	18,624	0.30	0.01%	<0.000001	1.45

[28] QI = Quality Index, Net Q = Net Flow, Sol Δ = Solution change, Max F = Maximum Froude Number

Side Channel Run Pool

XSEC	BR Mult[29]	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	1.2	0.01	0.04	0.06

North State Riffle

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	0.8	0.02	0.05	0.12

Restoration Site 3B

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	0.48	0.05	0.06	0.15
2LB	0.48	0.01	0.04	0.06
2RB	0.48	0.02	0.02	0.09

Tarzan Pool

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	3.0	0.04	0.04	0.09

ACID Glide

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	1.0	0.04	0.02	0.07

[29] BR Mult = Bed Roughness Multiplier

APPENDIX H
VELOCITY VALIDATION STATISTICS

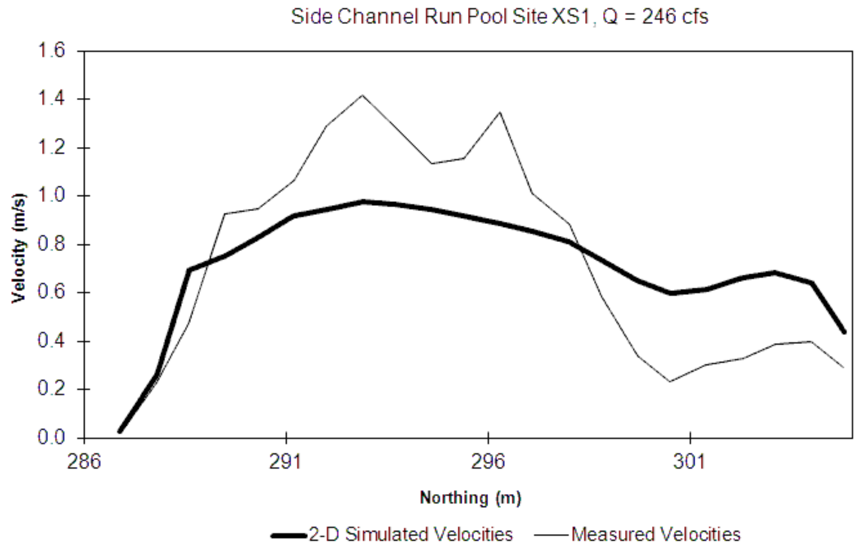
Site Name	Number of Observations	Correlation Between Measured and Simulated Velocities
Side Channel Run Pool	64	0.90
North State Riffle	92	0.88
Restoration Site 3B	116	0.52
Tarzan Pool	87	0.75
ACID Glide	91	0.84

Measured Velocities less than 3 ft/s
Difference (measured vs. pred. velocities, absolute value, ft/s)

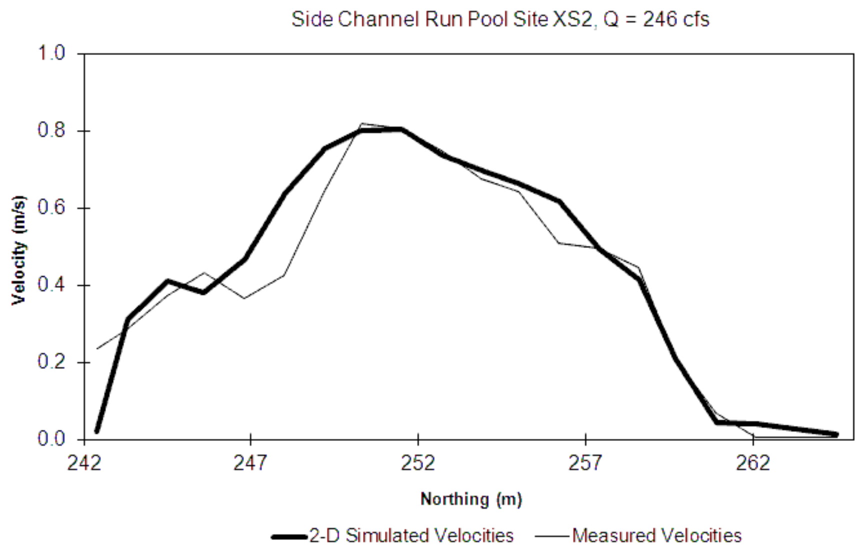
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Side Channel Run Pool	52	0.35	0.34	1.20
North State Riffle	56	0.41	0.36	1.87
Restoration Site 3B	95	1.08	1.16	6.12
Tarzan Pool	87	0.36	0.27	1.04
ACID Glide	91	0.38	0.34	1.49

Measured Velocities greater than 3 ft/s
Percent difference (measured vs. pred. velocities)

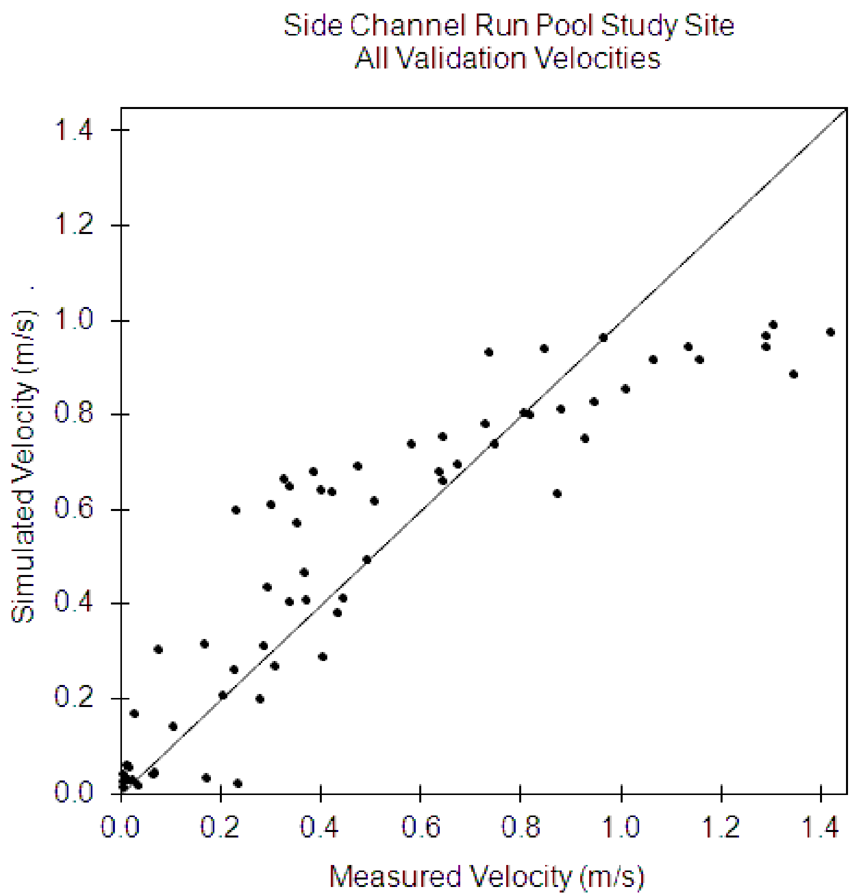
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Side Channel Run Pool	12	26%	14%	52%
North State Riffle	36	10%	10%	37%
Restoration Site 3B	21	22%	17%	55%
Tarzan Pool	0	--	--	--
ACID Glide	0	--	--	--

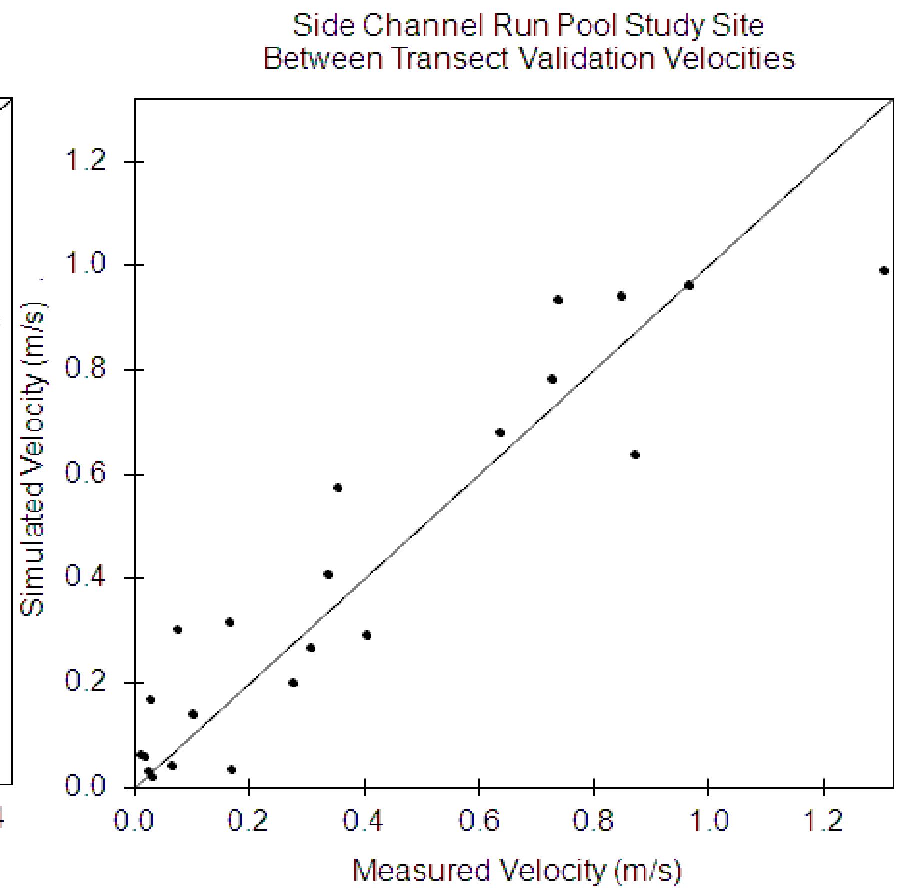


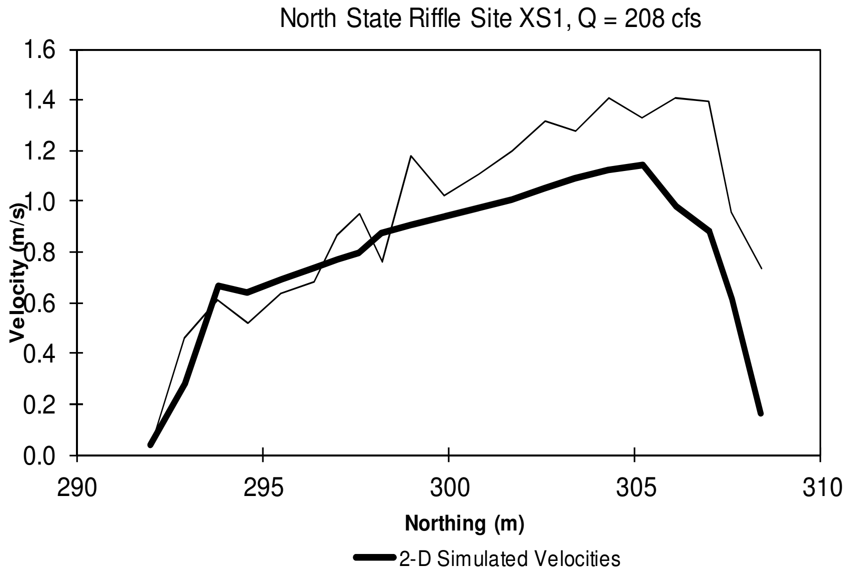
Side Channel Run Pool Site XS1, Q = 246 cfs
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Velocity (m/s)
286
291
296
301
Northing (m)
2-D Simulated Velocities
Measured Velocities

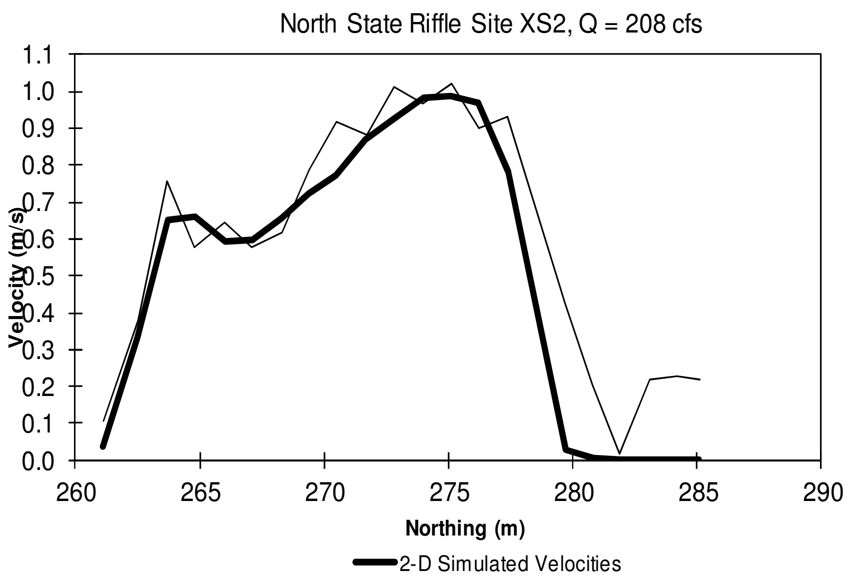


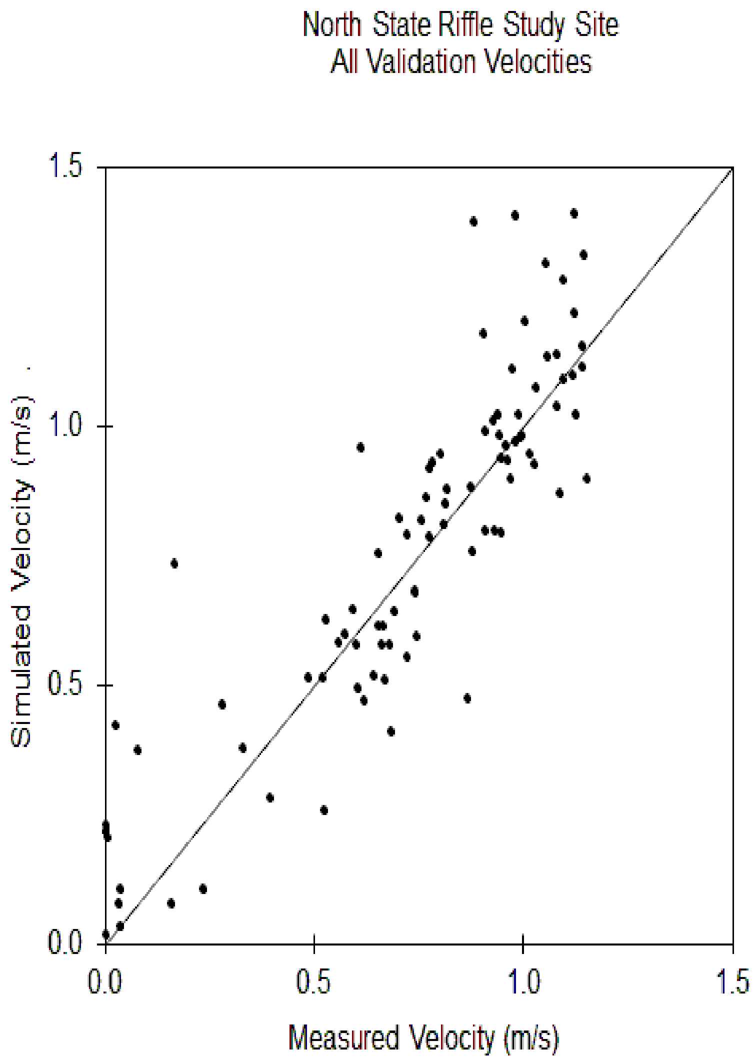
Side Channel Run Pool Site XS2, Q = 246 cfs
1.0
0.8
0.6
0.4
0.2
0.0
Velocity (m/s)
242
247
252
257
262
Northing (m)
2-D Simulated Velocities
Measured Velocities

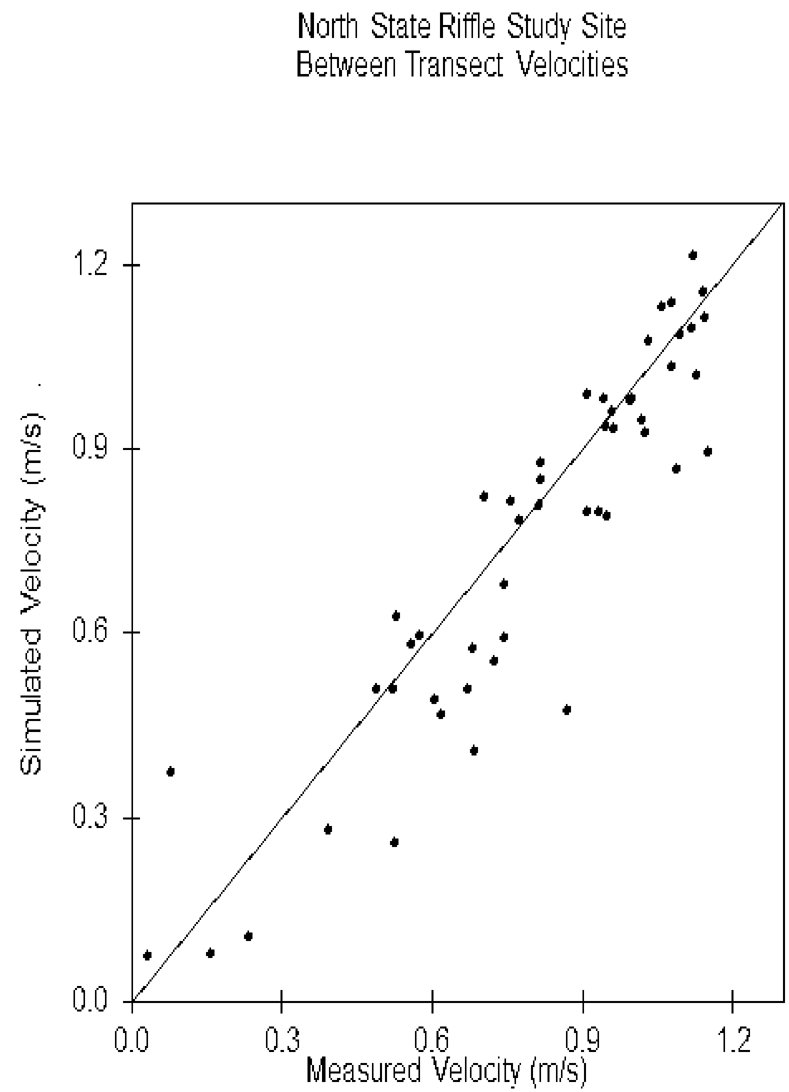

Side Channel Run Pool Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

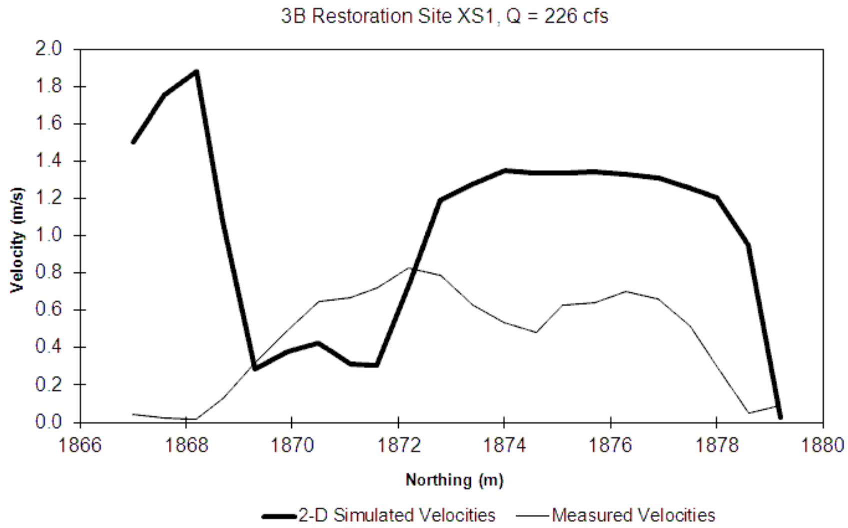

Side Channel Run Pool Study Site
Between Transect Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2

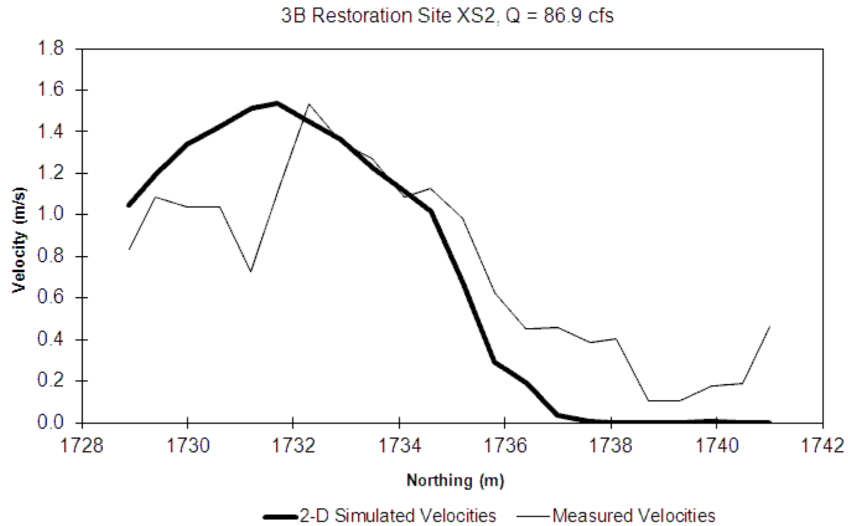

North State Riffle Site XS1, Q = 208 cfs
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Velocity (m/s)
290
295
300
305
310
Northing (m)
2-D Simulated Velocities

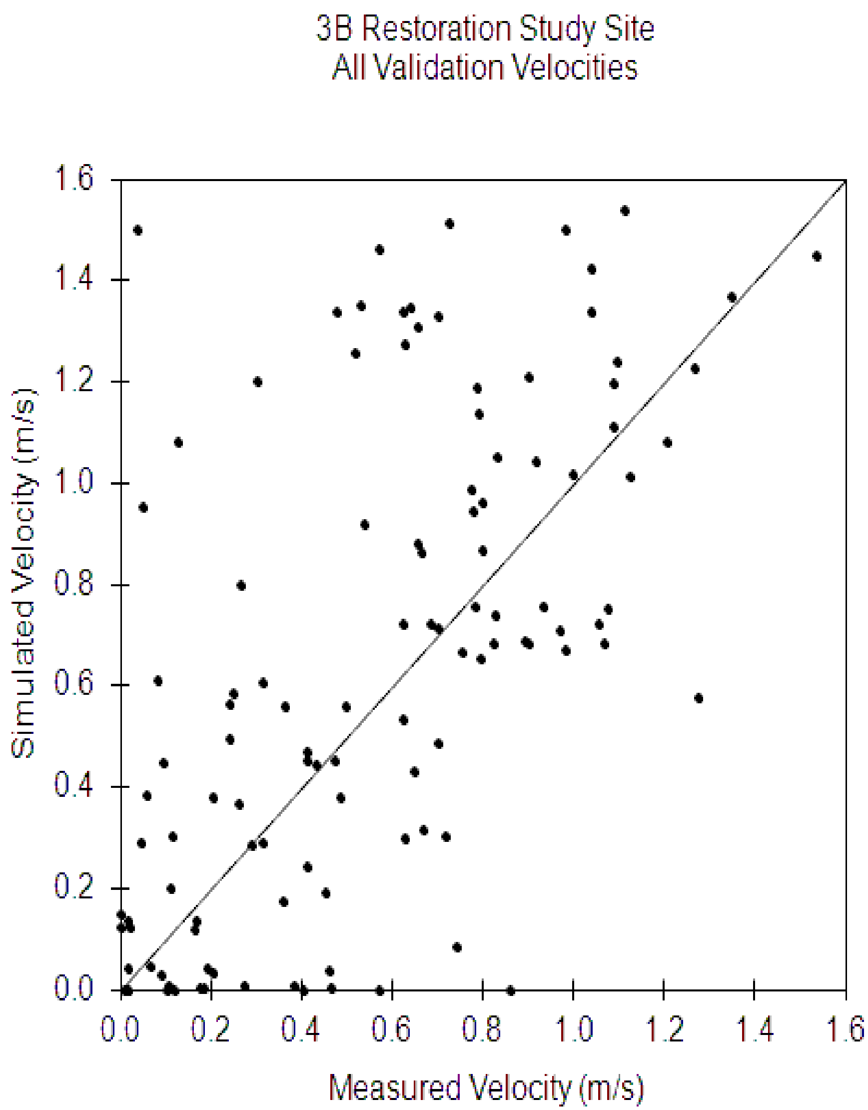

North State Riffle Site XS2, Q = 208 cfs
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Velocity (m/s)
260
265
270
275
280
285
290
Northing (m)
2-D Simulated Velocities

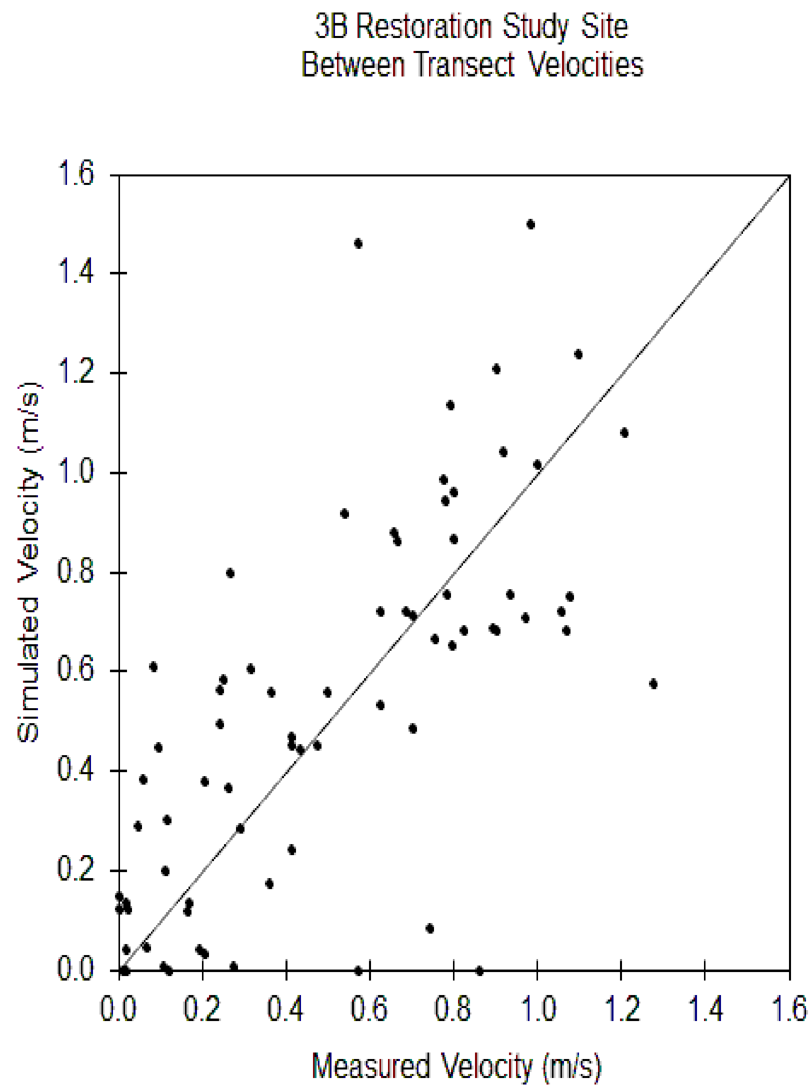

North State Riffle Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5

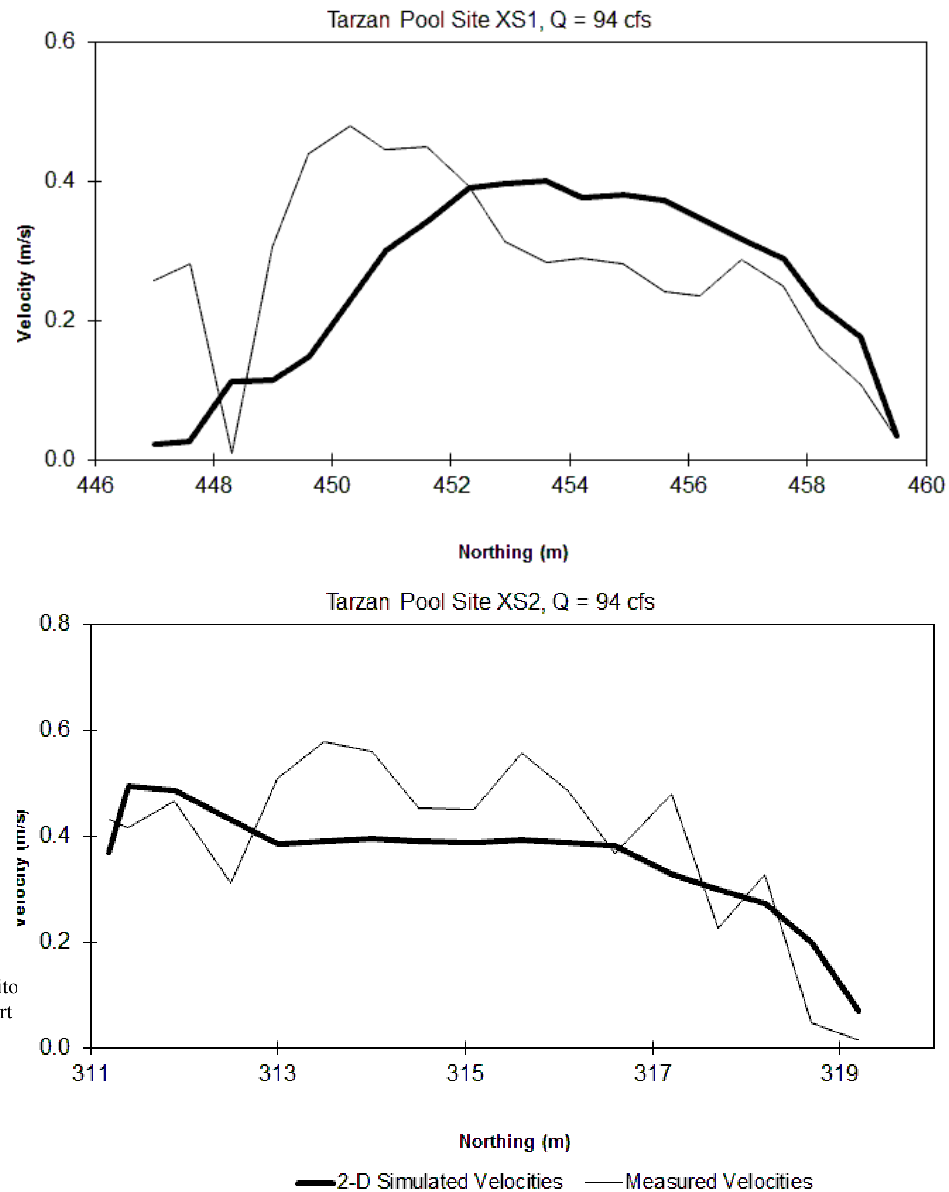

North State Riffle Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
1.2
0.9
0.6
0.3
0.0
0.0
0.3
0.6
0.9
1.2

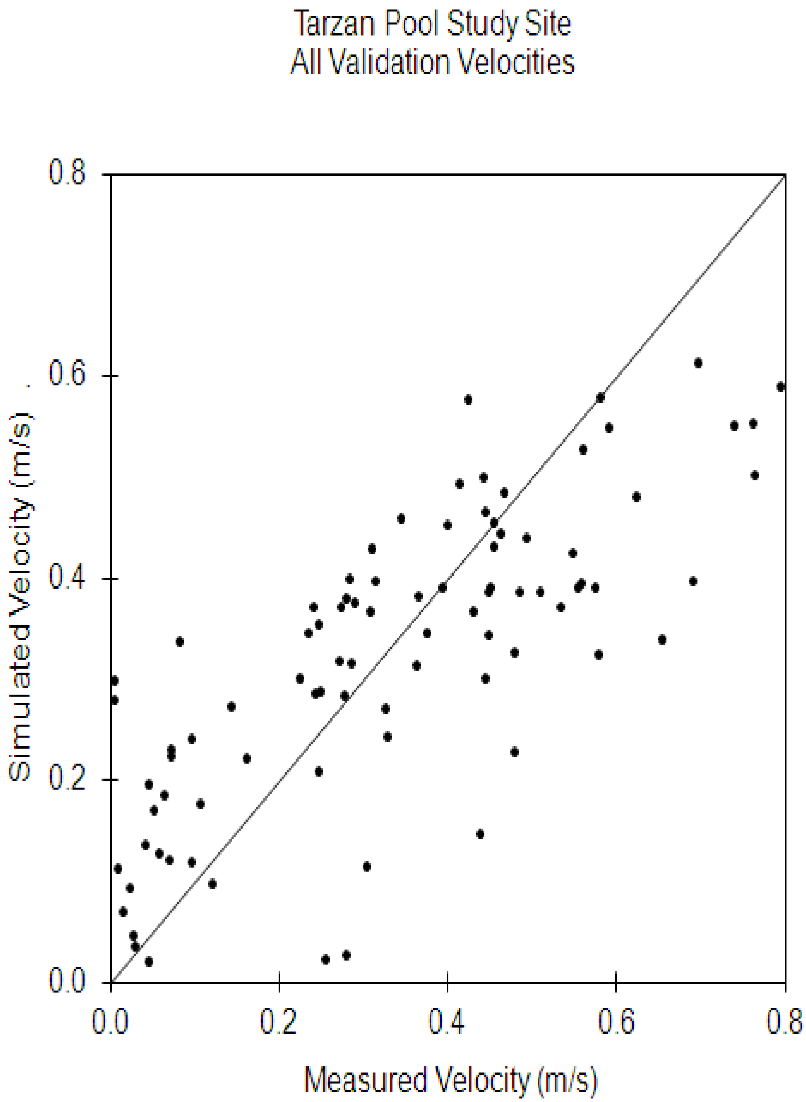

3B Restoration Site XS1, Q = 226 cfs
Velocity (m/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1866
1868
1870
1872
1874
1876
1878
1880
Northing (m)
2-D Simulated Velocities
Measured Velocities

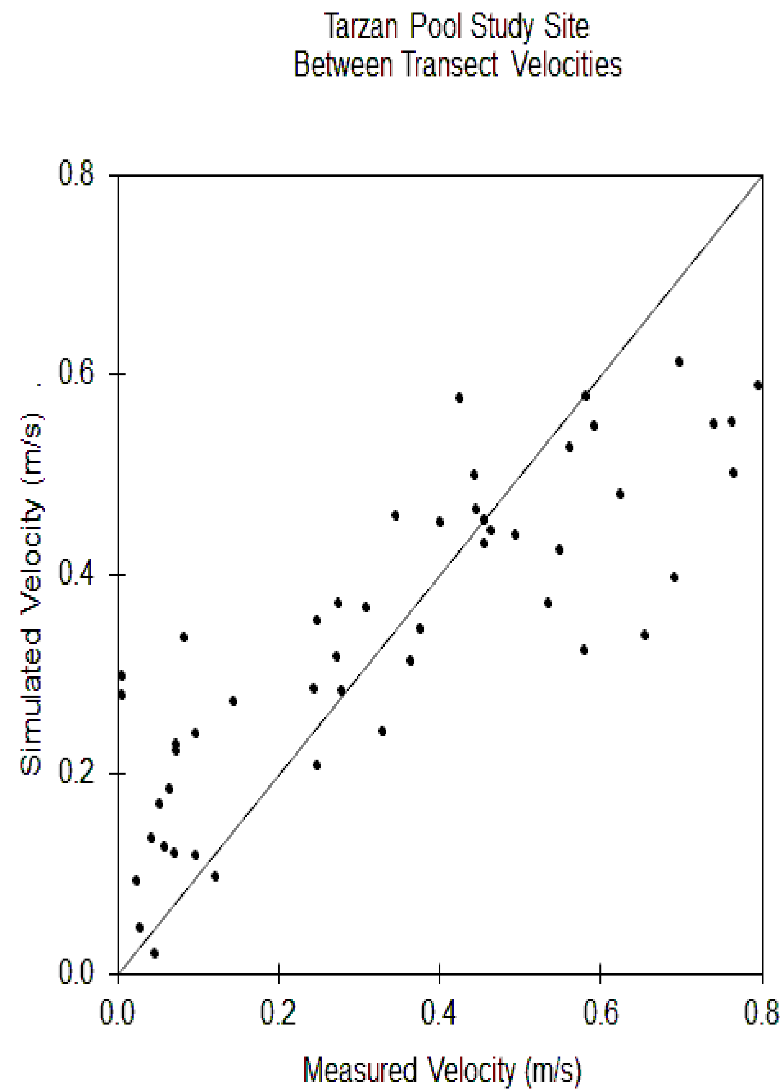

3B Restoration Site XS2, Q = 86.9 cfs
Velocity (m/s)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1728
1730
1732
1734
1736
1738
1740
1742
Northing (m)
2-D Simulated Velocities
Measured Velocities

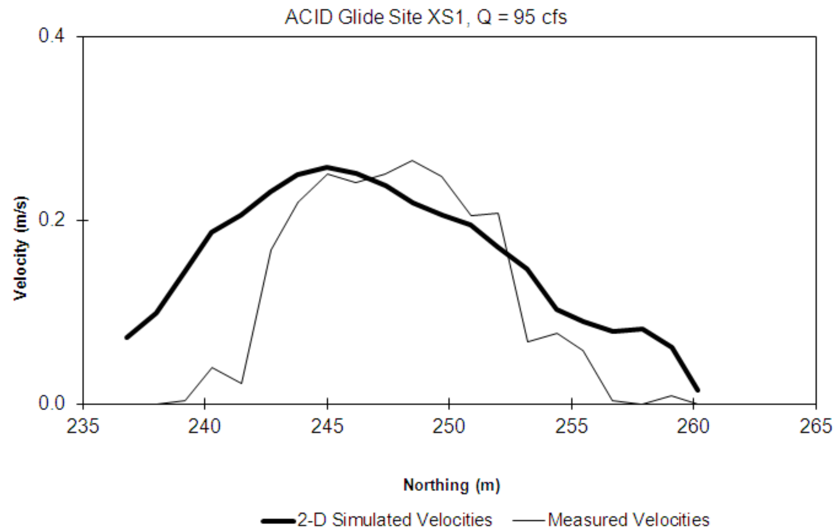

3B Restoration Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

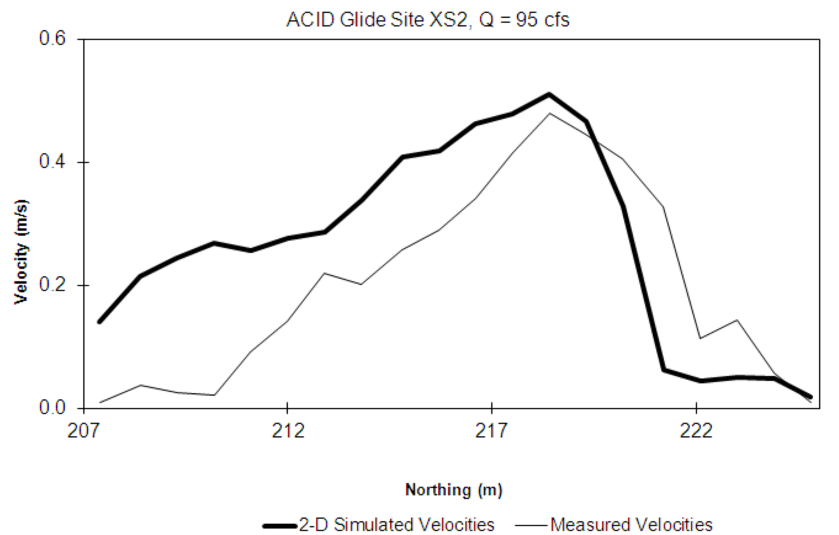

3B Restoration Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

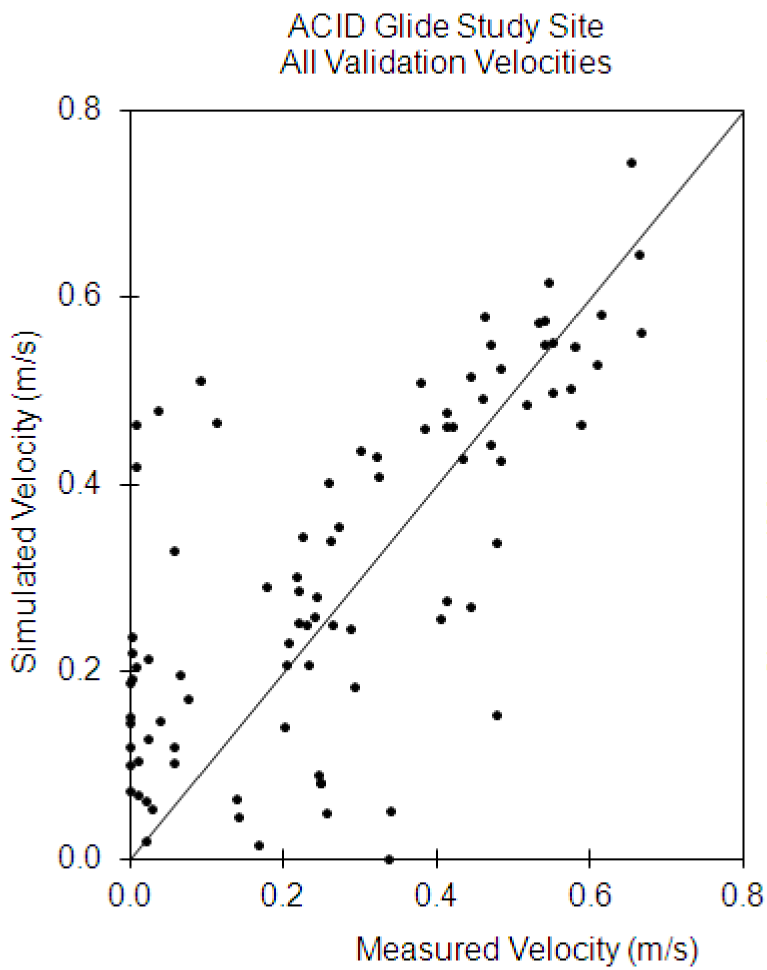

Tarzan Pool Site XS1, Q = 94 cfs
0.6
0.4
0.2
0.0
Velocity (m/s)
446
448
450
452
454
456
458
460
Northing (m)
Tarzan Pool Site XS2, Q = 94 cfs
0.8
0.6
0.4
0.2
0.0
311
313
315
317
319
Northing (m)
2-D Simulated Velocities
Measured Velocities

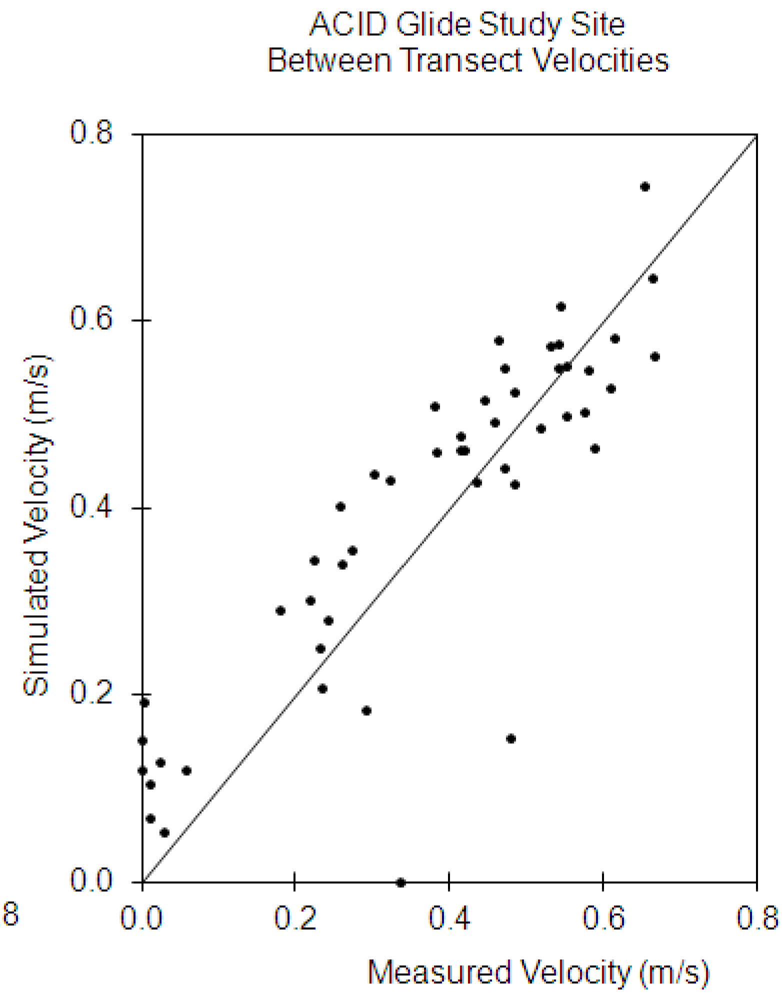

Tarzan Pool Study Site
All Validation Velocities
Simulated Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
0.0
0.2
0.4
0.6
0.8
Measured Velocity (m/s)


Tarzan Pool Study Site
Between Transect Velocities
Simulated Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
0.0
0.2
0.4
0.6
0.8
Measured Velocity (m/s)


ACID Glide Site XS1, Q = 95 cfs
0.4
0.2
0.0
Velocity (m/s)
235
240
245
250
255
260
265
Northing (m)
2-D Simulated Velocities
Measured Velocities


ACID Glide Site XS2, Q = 95 cfs
0.6
0.4
0.2
0.0
Velocity (m/s)
207
212
217
222
Northing (m)
2-D Simulated Velocities
Measured Velocities


ACID Glide Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8


ACID Glide Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8

APPENDIX I
SIMULATION STATISTICS[30]

[30] Net Q = Net Flow, Sol Δ = Solution change, Max F = Maximum Froude Number

Side Channel Run Pool

Flow (cfs)	Net Q	Sol Δ	Max F
50	10.6%	<0.000001	0.97
75	0.8%	<0.000001	0.92
100	0.6%	<0.000001	0.96
125	0.4%	<0.000001	0.97
150	0.3%	<0.000001	1.00
175	0.2%	<0.000001	1.14
200	0.2%	<0.000001	1.17
225	0.2%	<0.000001	1.25
250	0.1%	0.000006	1.08
275	0.1%	<0.000001	1.01
300	0.1%	<0.000001	1.03
350	0.04%	<0.000001	1.13
400	0.1%	<0.000001	1.61
450	0.4%	<0.000001	1.23
500	0.5%	<0.000001	1.62
550	0.5%	<0.000001	2.38
600	0.0%	0.000005	2.47
650	2.8%	0.000004	2.72
700	0.6%	0.000004	2.04
750	0.5%	<0.000001	2.31
800	0.4%	0.000006	1.84
850	0.3%	<0.000001	1.75
900	0.3%	<0.000001	1.77

North State Riffle

Flow (cfs)	Net Q	Sol Δ	Max F
50	2.2%	0.000002	1.00
75	1.2%	0.000008	0.93
100	1.2%	<0.000001	1.15
125	0.7%	0.000004	1.21
150	0.5%	<0.000001	1.11
175	0.4%	0.000005	1.03
200	0.3%	0.000003	1.00
225	0.3%	<0.000001	10.59
250	0.2%	<0.000001	11.29
275	0.2%	0.000005	8.91
300	0.2%	<0.000001	8.32
350	0.2%	<0.000001	9.23
400	0.2%	0.000009	8.39
450	0.2%	<0.000001	16.78
500	0.01%	0.000001	10.88
550	0.1%	<0.000001	8.44
600	0.1%	<0.000001	7.06
650	0.1%	<0.000001	5.79
700	0.1%	<0.000001	4.80
750	0.1%	<0.000001	3.97
800	0.1%	<0.000001	3.37
850	0.1%	<0.000001	3.05
900	0.1%	0.000006	3.07

Restoration Site 3B

Flow (cfs)	Net Q	Sol Δ	Max F
50	10.6%	0.000008	2.59
75	9.9%	0.000003	2.39
100	5.9%	0.000002	15.41
125	4.7%	0.000006	4.53
150	18.4%	0.000005	5.68
175	1.7%	0.000001	5.15
200	1.4%	0.000006	4.04
225	0.5%	0.000001	9.26
250	0.5%	0.000008	4.59
275	1.3%	<0.000001	3.83
300	0.6%	0.000005	7.36
350	2.5%	0.000001	15.31
400	4.8%	0.000002	5.98
450	0.7%	0.000003	3.91
500	7.1%	0.000008	23.66
550	5.5%	<0.000001	11.12
600	0.4%	0.000001	8.70
650	0.9%	0.000001	10.17
700	2.1%	0.000007	11.60
750	2.4%	<0.000001	12.40
800	3.3%	0.000008	10.96
850	2.1%	<0.000001	9.15
900	2.0%	0.000009	7.73

Tarzan Pool

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.5%	<0.000001	0.39
75	0.3%	<0.000001	0.48
100	0.3%	<0.000001	0.47
125	0.2%	<0.000001	0.53
150	0.1%	<0.000001	0.73
175	0.1%	<0.000001	0.63
200	0.1%	<0.000001	1.22
225	0.1%	<0.000001	1.09
250	0.1%	<0.000001	1.30
275	0.1%	<0.000001	1.08
300	0.1%	0.000006	3.47
350	0.04%	<0.000001	1.49
400	0.1%	<0.000001	1.84
450	0.04%	<0.000001	279
500	0.03%	<0.000001	0.82
550	0.03%	<0.000001	0.89
600	0.03%	<0.000001	27.04
650	0.03%	<0.000001	15.22
700	0.02%	<0.000001	21.52
750	0.01%	<0.000001	21.73
800	0.01%	<0.000001	8.58
850	0.01%	<0.000001	6.09
900	0.01%	<0.000001	8.72

ACID Glide

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.1%	0.000001	0.47
75	0.1%	<0.000001	0.41
100	0.1%	0.000003	0.49
125	0.1%	<0.000001	0.49
150	0.07%	<0.000001	0.68
175	0.05%	<0.000001	0.73
200	0.05%	<0.000001	0.71
225	0.03%	<0.000001	0.84
250	0.03%	<0.000001	0.94
275	0.03%	<0.000001	0.73
300	0.03%	<0.000001	0.73
350	0.03%	<0.000001	0.72
400	0.02%	<0.000001	1.06
450	0.01%	<0.000001	0.87
500	0.09%	0.000001	1.24
550	0.01%	<0.000001	1.47
600	0.01%	<0.000001	1.58
650	0.01%	<0.000001	1.45
700	0.02%	<0.000001	1.13
750	0.02%	<0.000001	1.08
800	0.02%	<0.000001	1.03
850	0.02%	<0.000001	0.99
900	0.02%	<0.000001	0.95

APPENDIX J
HABITAT SUITABILITY CRITERIA

Fall-run Chinook Salmon Fry Rearing

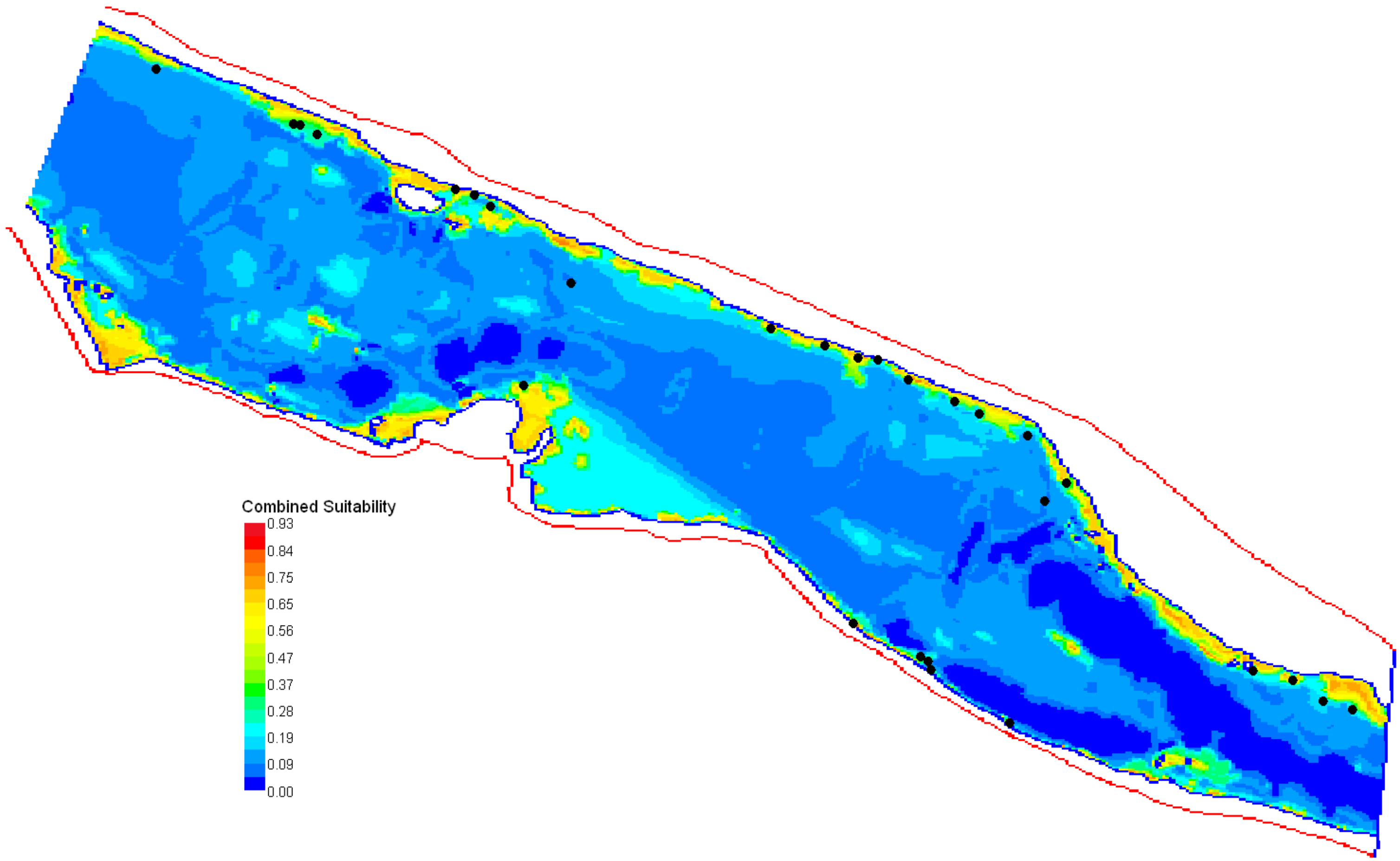
Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.70
0.10	0.99	0.1	0.94	0.1	0.33	3.60	1.00
0.20	0.97	0.2	0.97	1	0.33	100	1.00
0.30	0.93	0.3	0.98	2	0.33		
0.40	0.88	0.4	1.00	3	1.00		
0.50	0.82	0.5	1.00	3.7	1.00		
0.60	0.76	0.6	1.00	4	1.00		
0.70	0.69	0.7	0.99	4.7	1.00		
0.80	0.62	0.8	0.99	5	1.00		
0.90	0.56	0.9	0.97	5.7	1.00		
1.00	0.50	1.0	0.96	7	0.33		
1.10	0.45	1.1	0.94	8	1.00		
1.20	0.41	1.2	0.92	9	1.00		
1.30	0.38	4.7	0.92	9.7	1.00		
1.40	0.35	4.8	0.91	10	0.33		
2.50	0.34	4.9	0.90	11	0.00		
2.60	0.34	5.0	0.89	100	0.00		
2.70	0.32	5.1	0.87				
2.80	0.30	5.2	0.84				
2.90	0.27	5.3	0.80				
3.00	0.23	5.4	0.76				
3.10	0.18	5.5	0.70				
3.11	0.17	5.6	0.64				
3.12	0.00	5.7	0.57				
100	0.00	5.8	0.49				
		5.9	0.41				
		6.0	0.33				
		6.1	0.00				
		100	0.00				

Fall-run Chinook Salmon 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	0.51
0.10	0.94	0.4	0.00	0.1	0.33	4.65	1.00
0.20	0.88	0.5	0.30	1	1.00	100	1.00
0.30	0.82	0.6	0.33	2	0.33		
0.40	0.77	0.7	0.37	3	0.33		
0.50	0.72	0.8	0.40	3.7	1.00		
0.60	0.68	1.6	0.72	4	1.00		
2.10	0.67	1.7	0.75	4.7	1.00		
2.20	0.67	1.8	0.79	5	1.00		
2.30	0.65	2.1	0.88	5.7	1.00		
2.40	0.63	2.5	0.96	7	0.33		
2.50	0.59	2.9	1.00	8	1.00		
2.60	0.53	3.2	1.00	9	1.00		
2.70	0.47	3.6	0.96	9.7	1.00		
2.80	0.39	3.7	0.94	10	0.33		
2.90	0.30	3.8	0.93	11	0.00		
3.00	0.22	3.9	0.90	100	0.00		
3.06	0.18	4.0	0.88				
3.07	0.00	4.2	0.82				
100	0.00	4.3	0.79				
		4.4	0.76				
		4.5	0.73				
		5.3	0.41				
		5.4	0.00				
		100	0.00				

APPENDIX K
RIVER2D COMBINED SUITABILITY OF FRY AND JUVENILE LOCATIONS

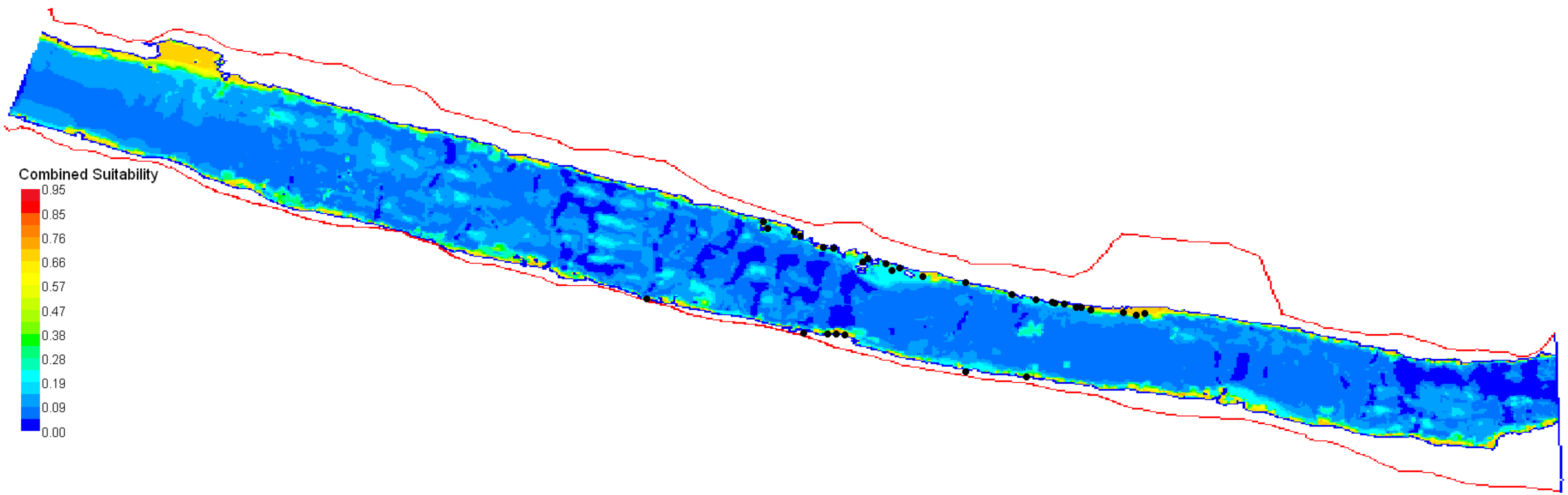
UPPER ISOLATION STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 230 CFS



Fry locations: ●

Scale: 1: 917

LOWER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 229 CFS



Fry locations: ●

Scale: 1: 1,481

USFWS, SFWO, Restoration and Monitoring Program
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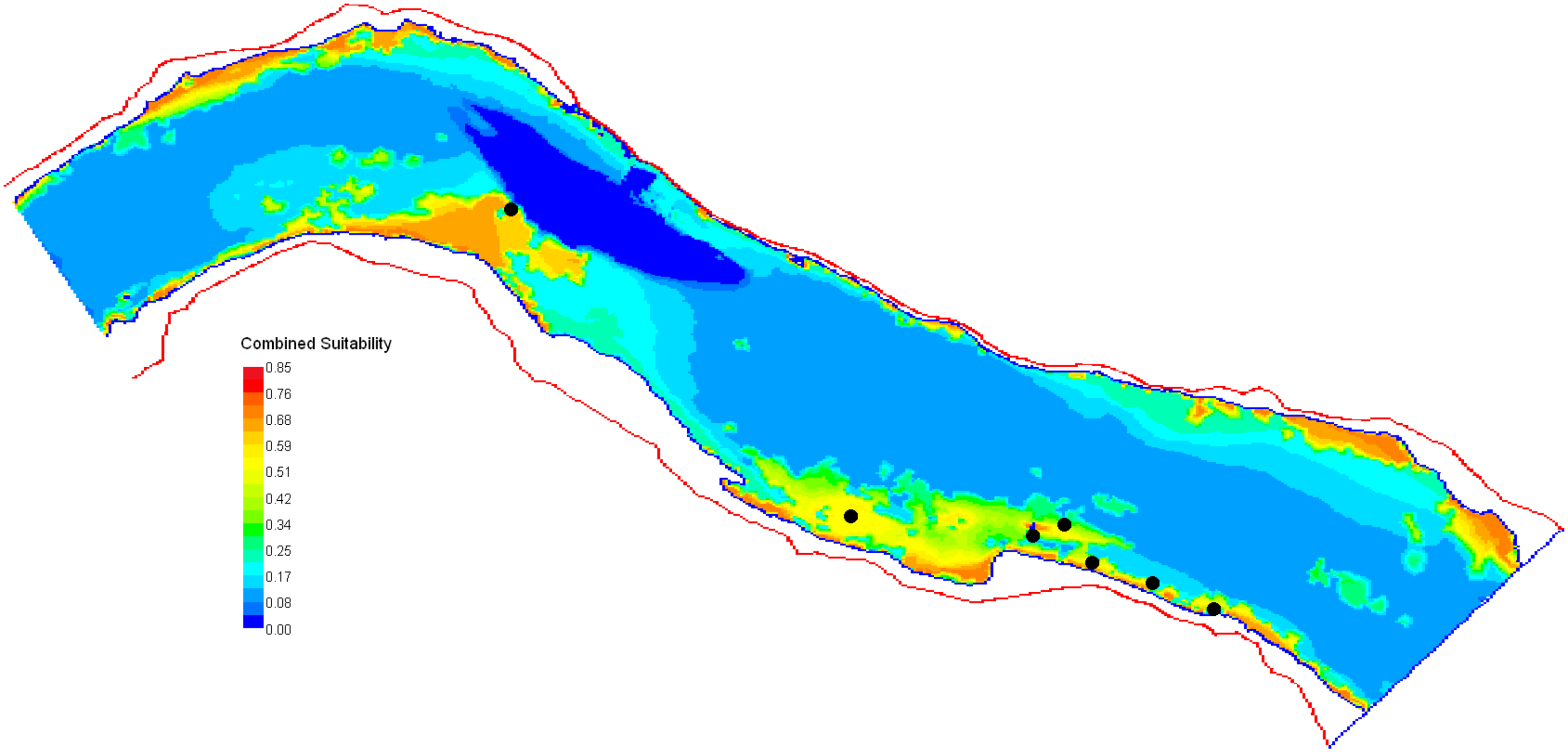
TARZAN POOL STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 168 CFS

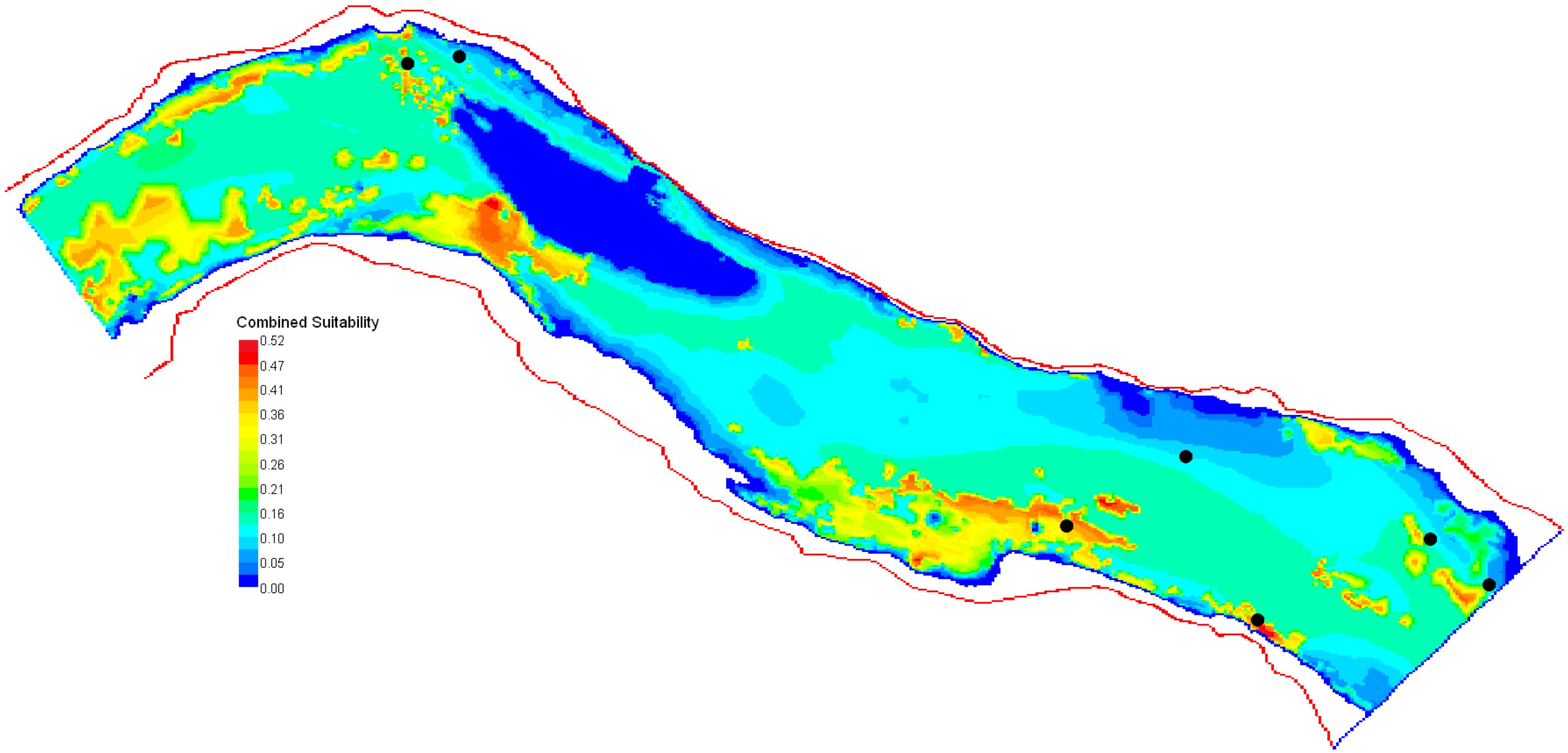


Fry locations: ●

Scale: 1: 518

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

TARZAN POOL STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 168 CFS



Juvenile locations: ●

Scale: 1: 518

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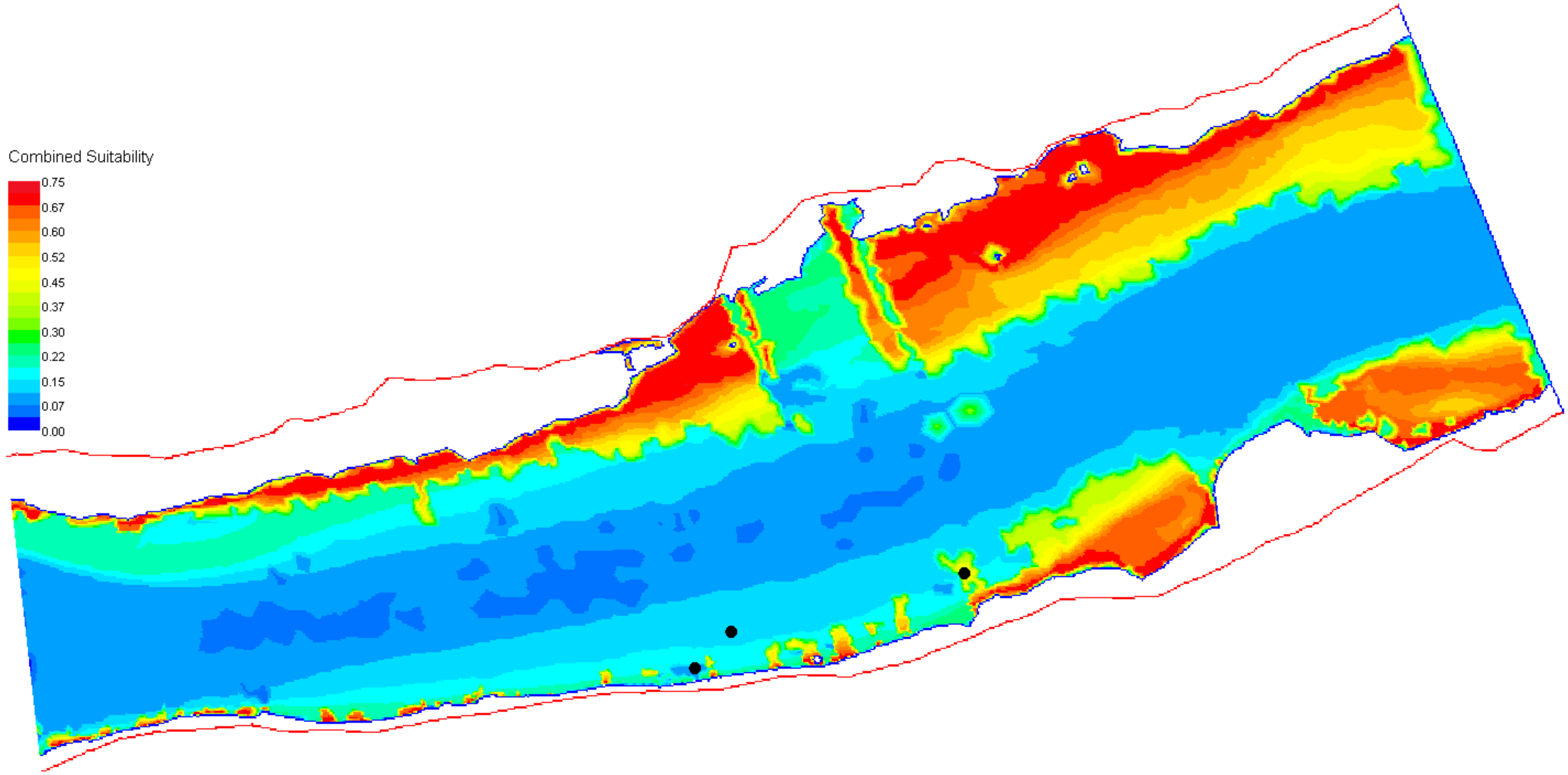
ACID GLIDE STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING[31], FLOW = 168 CFS

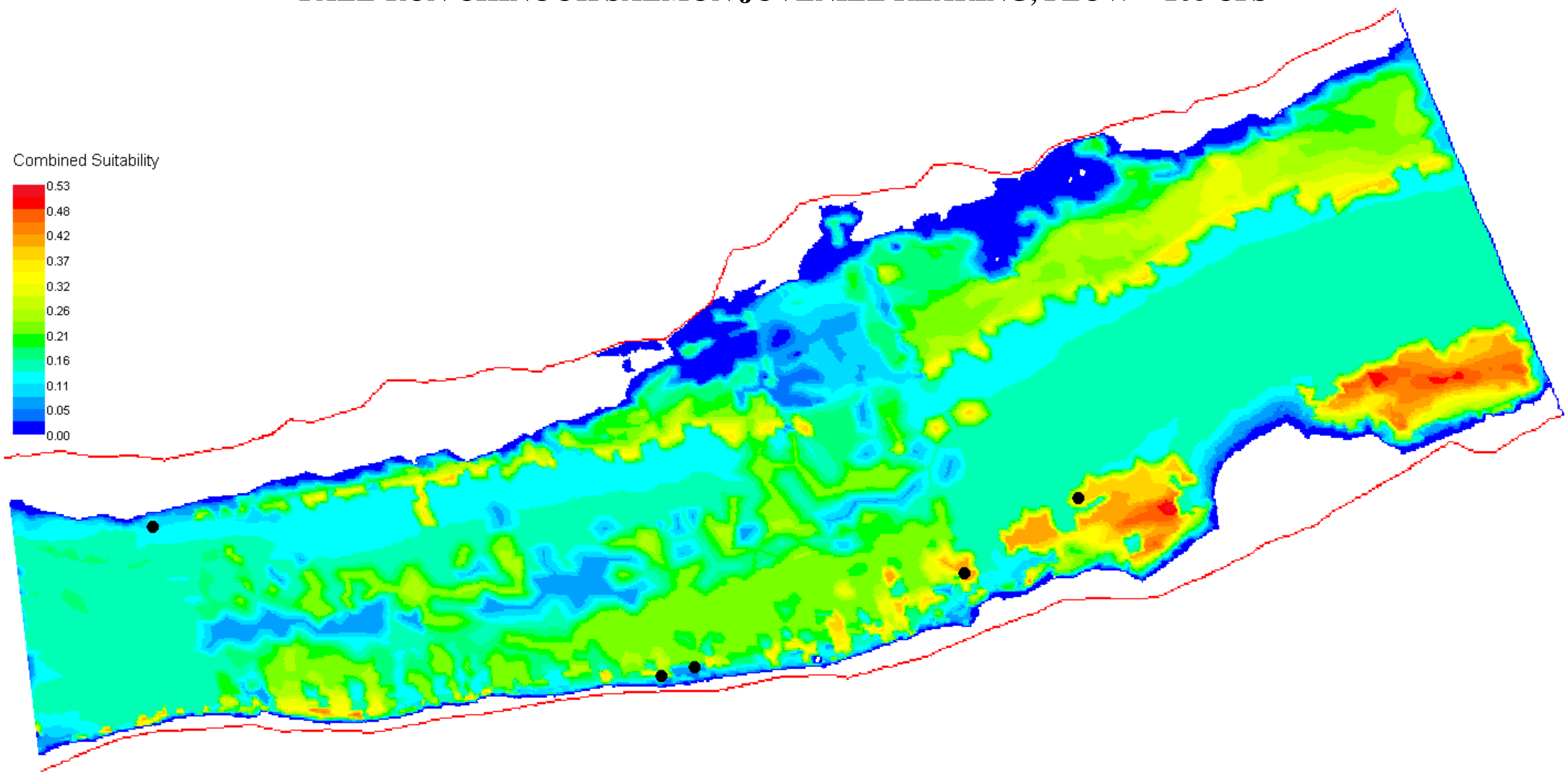


Fry locations: ●

Scale: 1: 527

31 The pattern of suitability in the upper center is due to a rectilinear patch of no cover (with a fry suitability of 0.33), with aquatic vegetation (with a fry suitability of 1.0) located both downstream and upstream of the area without cover.

ACID GLIDE STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 168 CFS



Juvenile locations: ●

Scale: 1: 505

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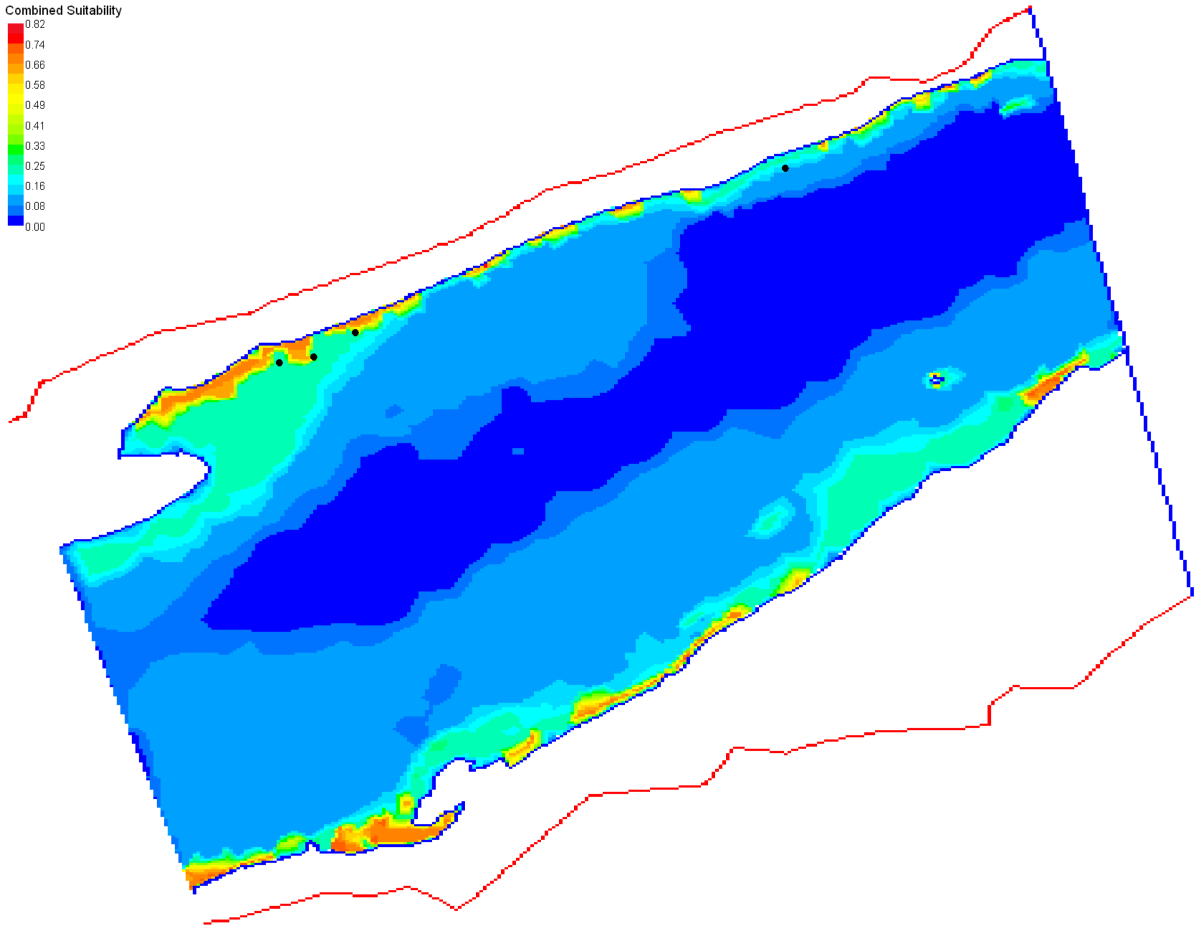
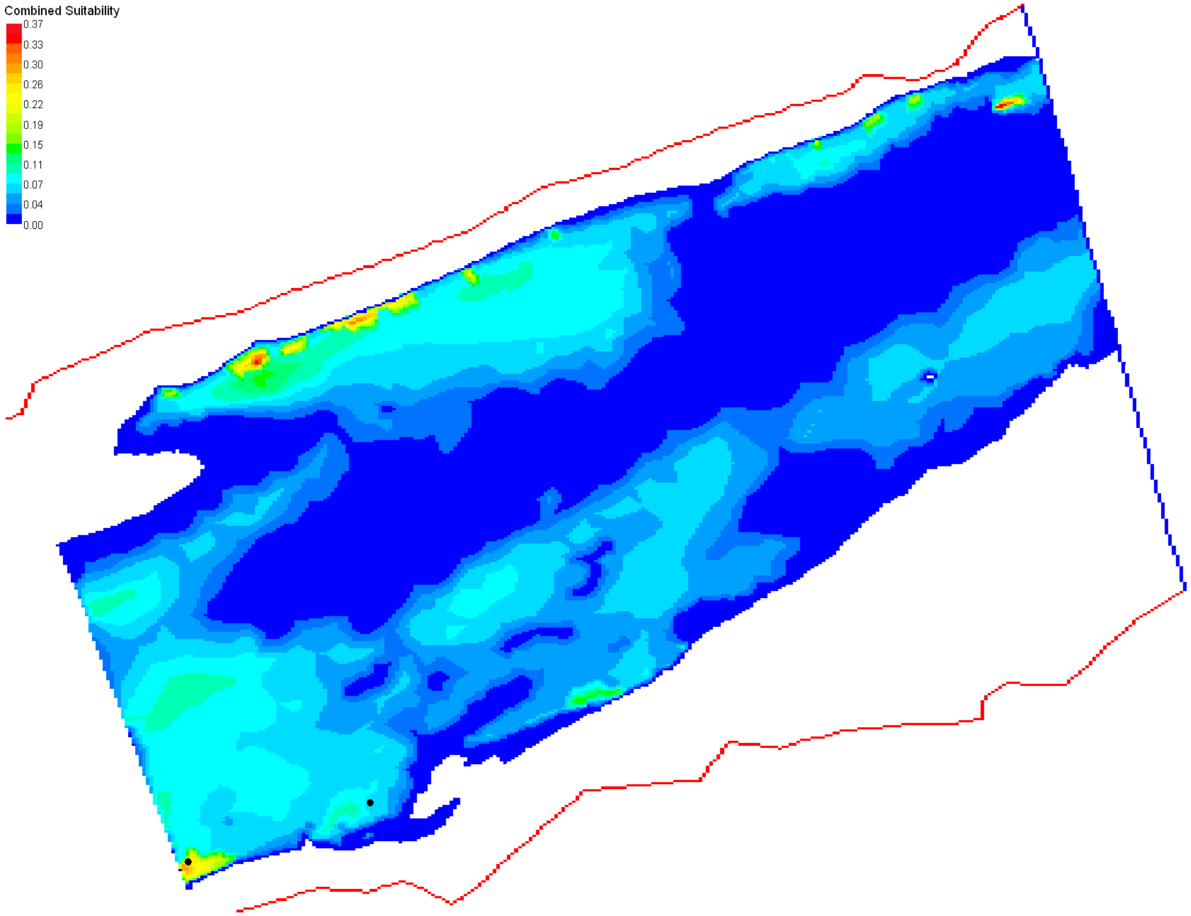
NORTH STATE RIFFLE STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 172 CFS



Fry locations: ●

Scale: 1: 452

NORTH STATE RIFFLE STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 172 CFS



Juvenile locations: ●

Scale: 1: 452

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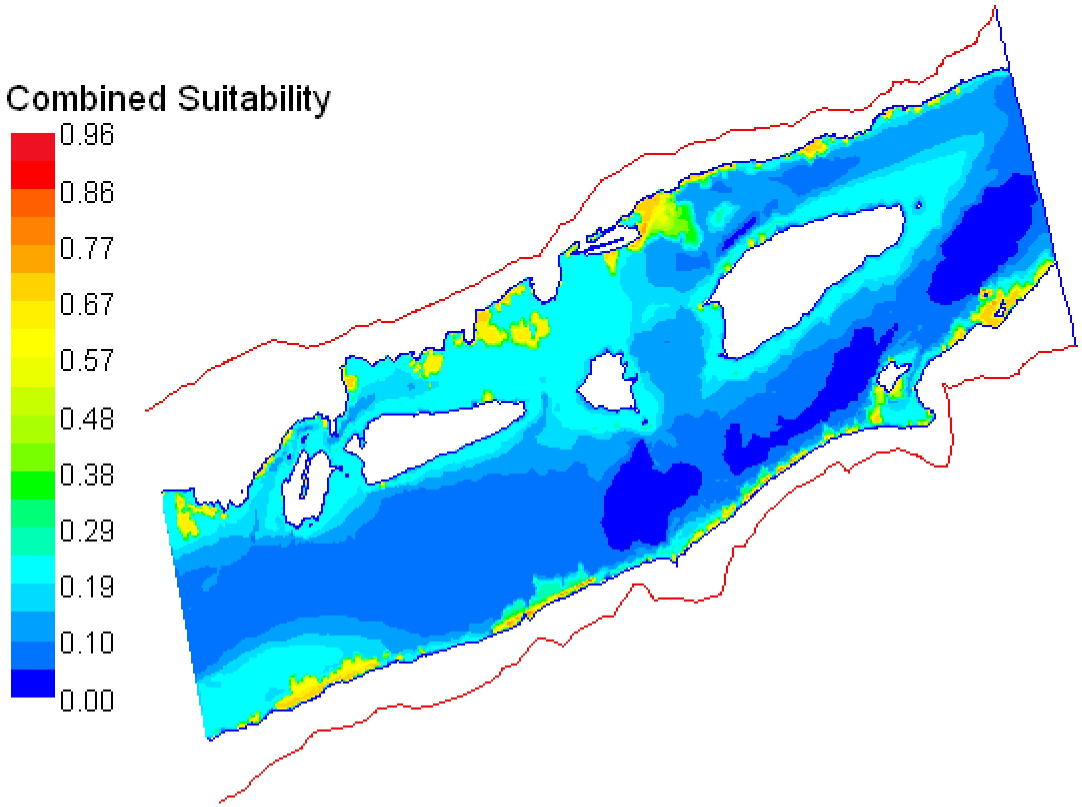
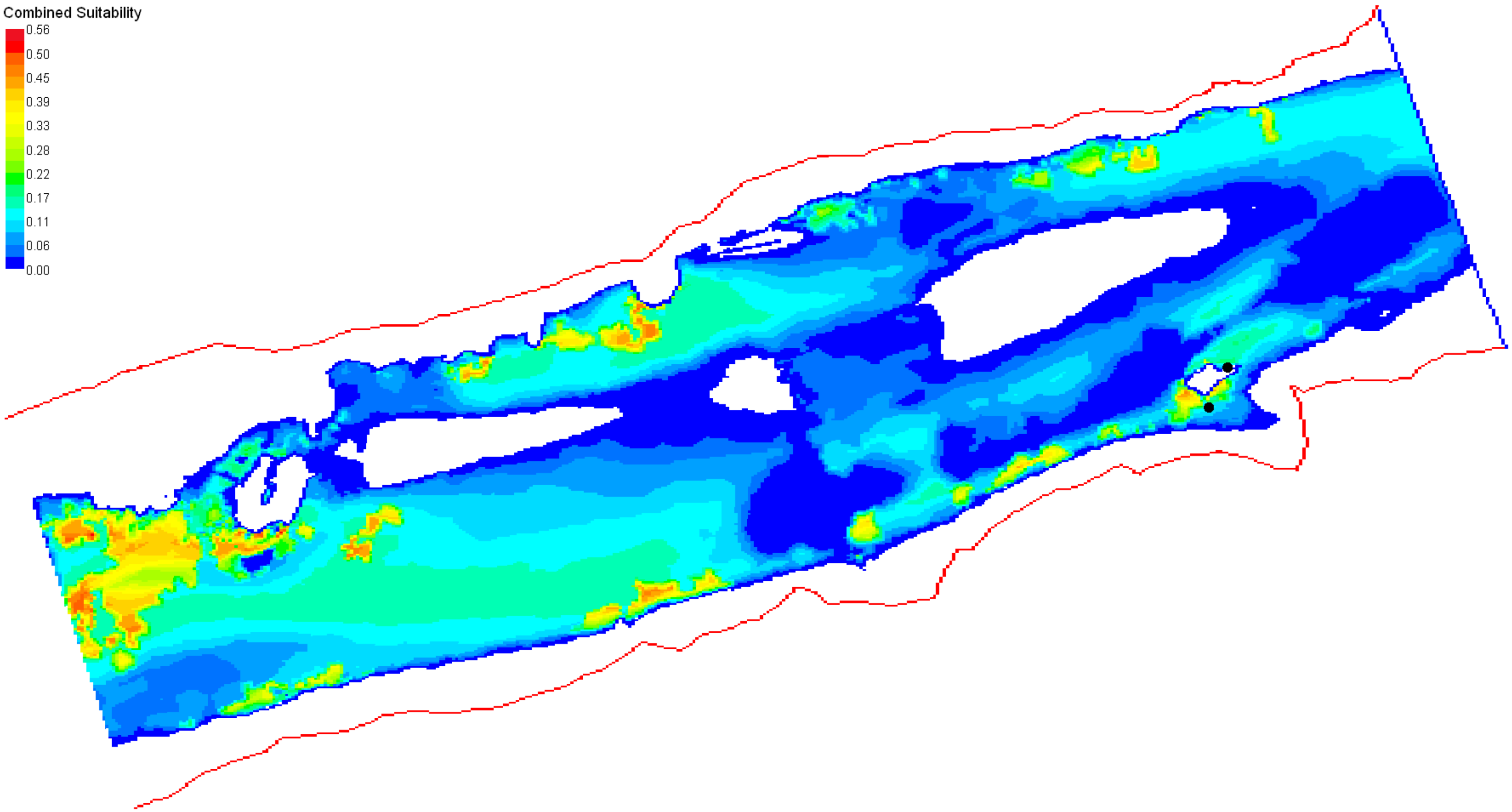
SIDE CHANNEL RUN POOL STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 173 CFS



Fry locations: ●

Scale: 1: 761

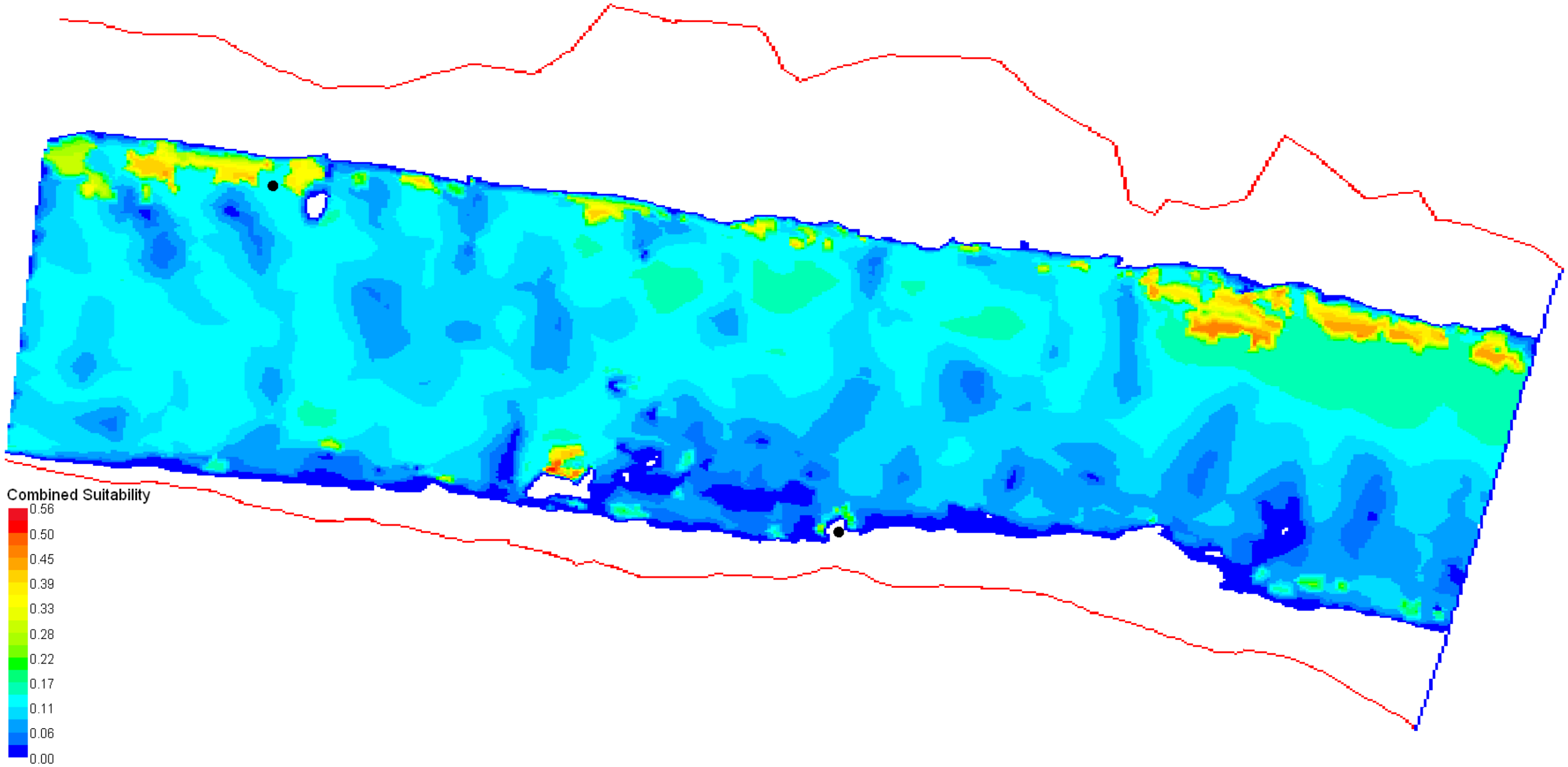
SIDE CHANNEL RUN POOL STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 173 CFS



Juvenile locations: ●

Scale: 1: 634

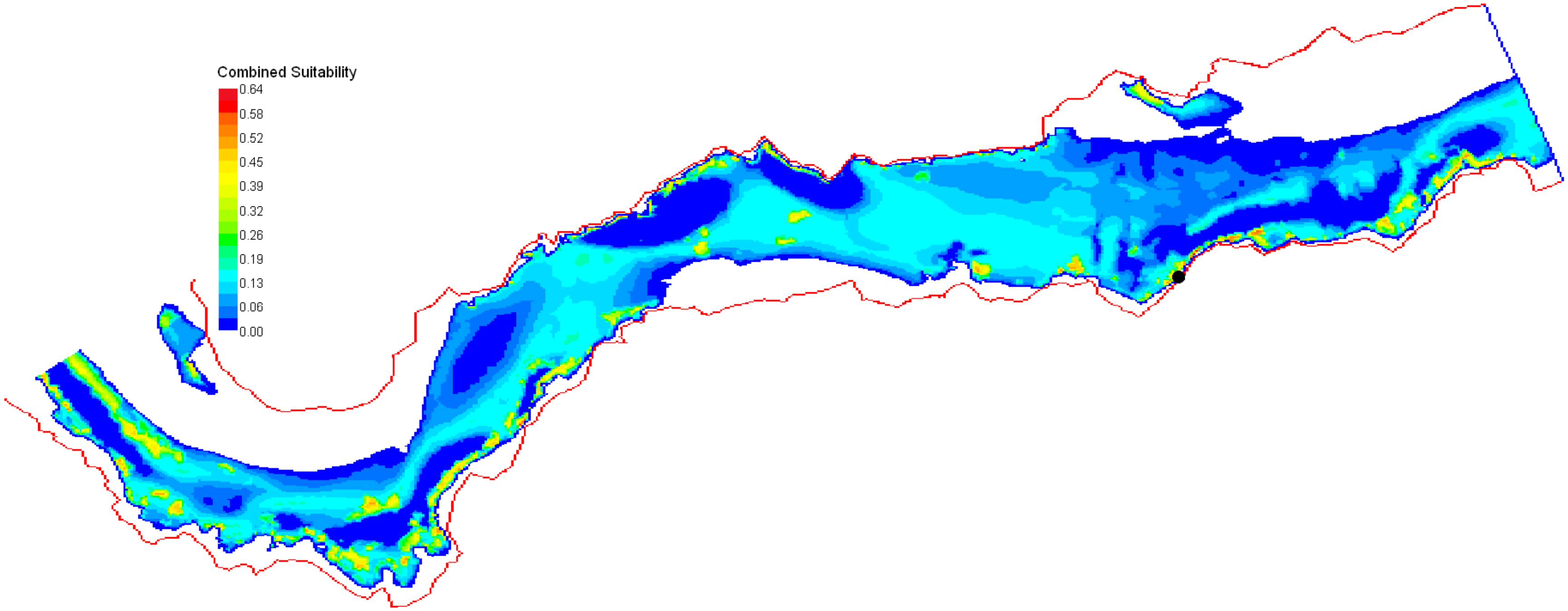
UPPER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 153 CFS



Juvenile locations: ●

Scale: 1: 471

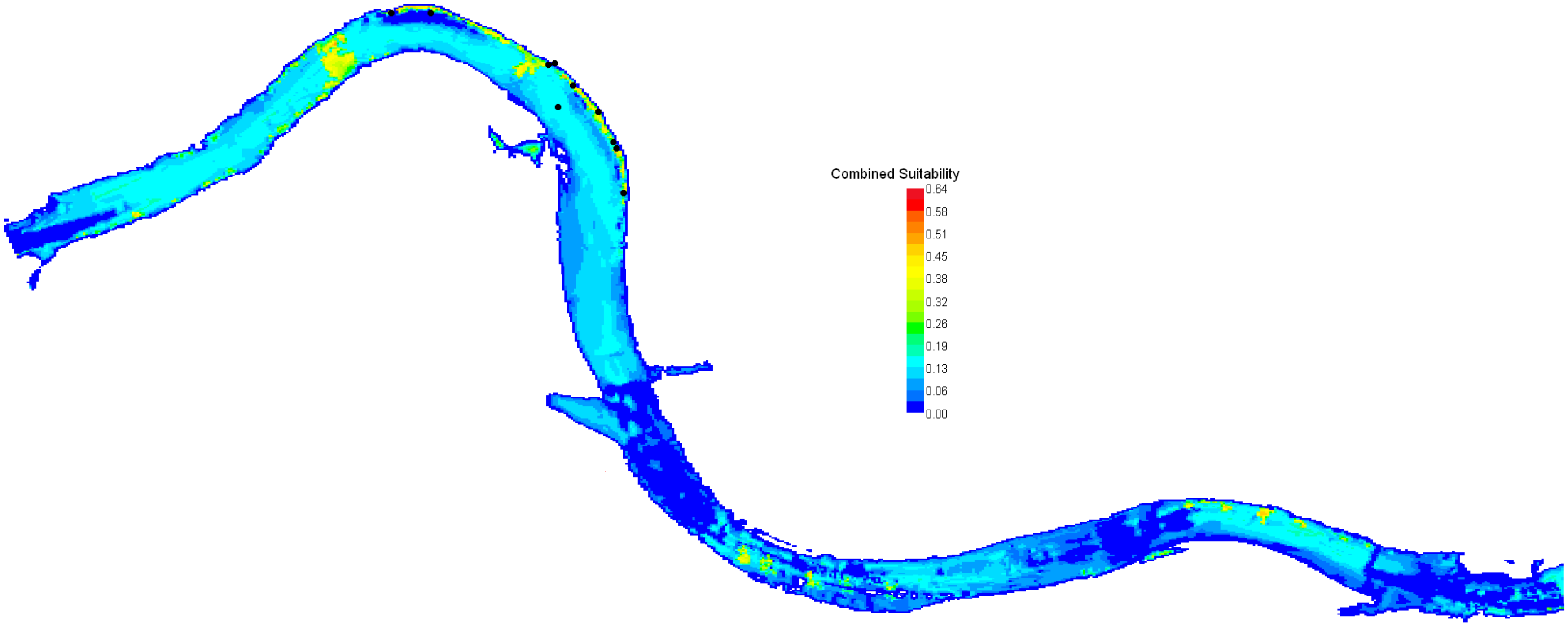
LOWER GORGE STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 204 CFS



Juvenile locations: ●

Scale: 1: 1,276

3B STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 189 CFS



Juvenile locations: ●

Scale: 1: 2,944

APPENDIX L
HABITAT MODELING RESULTS

Spring-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	2,640	1,856	1,882	6,140	2,407
75	2,700	1,864	1,720	5,996	2,352
100	2,868	1,887	1,576	6,010	2,320
125	2,973	1,925	1,546	6,098	2,348
150	2,940	1,950	1,392	6,019	2,323
175	2,854	1,958	1,253	5,891	2,294
200	2,765	1,935	1,138	5,668	2,348
225	2,743	2,055	976	5,645	2,412
250	2,646	2,034	960	5,738	2,634
275	2,496	1,890	958	5,862	2,961
300	2,475	1,769	948	5,761	3,070
350	2,516	1,689	1,043	5,833	2,851
400	2,329	1,704	1,123	6,171	2,847
450	2,317	1,724	1,127	6,331	2,887
500	2,328	1,787	1,123	6,535	2,896
550	2,300	1,896	1,129	6,850	2,958
600	2,404	2,011	1,159	7,255	3,059
650	2,466	2,097	1,229	7,687	3,201
700	2,623	2,042	1,386	8,173	3,484
750	2,787	1,896	1,507	8,803	3,778
800	3,002	1,840	1,601	9,885	4,131
850	3,117	1,861	1,783	11,198	4,319
900	3,067	1,876	1,962	12,650	4,366

Spring-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	1,089	784	18,228	731	1,144	127,116
75	1,097	867	17,536	737	1,251	126,494
100	1,118	977	17,041	726	1,407	127,924
125	1,135	985	16,923	756	1,655	130,415
150	1,156	934	16,981	749	1,655	129,286
175	1,244	807	17,177	757	1,666	130,070
200	1,346	730	17,823	783	1,686	131,919
225	1,414	691	18,684	747	1,765	133,275
250	1,430	695	19,441	751	1,883	134,972
275	1,571	731	20,605	907	1,930	141,192
300	1,716	761	21,914	844	2,019	143,221
350	1,742	795	23,529	882	2,062	142,856
400	1,825	826	24,899	961	1,935	146,002
450	1,886	830	25,873	1,010	1,836	149,028
500	1,929	804	27,156	1,051	1,830	152,636
550	1,951	754	27,971	1,102	1,798	155,903
600	1,941	720	29,483	1,130	1,821	162,051
650	1,989	700	30,803	1,144	1,837	168,225
700	2,128	717	32,506	1,178	1,827	176,777
750	2,215	765	34,676	1,173	1,816	184,361
800	2,293	833	37,393	1,198	1,822	196,658
850	2,348	939	41,297	1,266	1,762	211,735
900	2,266	1,051	45,562	1,380	1,715	226,197

Fall-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	6,042	7,208	5,511	29,006	10,804
75	6,309	7,113	5,411	27,803	10,875
100	6,291	7,021	5,235	26,400	10,661
125	6,080	6,944	5,127	25,032	10,233
150	5,794	6,939	4,983	23,884	9,771
175	5,576	6,938	4,825	22,875	9,299
200	5,511	6,886	4,705	22,096	8,994
225	5,346	6,790	4,660	21,445	8,782
250	5,257	6,654	4,633	20,965	8,604
275	5,139	6,535	4,641	20,552	8,497
300	5,024	6,493	4,659	20,179	8,401
350	4,908	6,318	4,647	19,398	8,274
400	4,710	6,262	4,649	18,738	8,316
450	4,476	6,259	4,681	18,089	8,120
500	4,458	6,243	4,671	17,129	7,805
550	4,472	6,153	4,614	16,351	7,482
600	4,476	5,925	4,674	15,708	6,926
650	4,537	5,843	4,661	15,248	6,934
700	4,548	5,748	4,622	14,831	6,676
750	4,575	5,645	4,579	14,398	6,423
800	4,461	5,539	4,414	13,814	6,169
850	4,305	5,492	4,353	13,294	6,021
900	4,259	5,452	4,349	12,997	5,863

Fall-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	5,592	2,188	50,950	6,800	8,857	536,166
75	5,863	2,138	49,438	6,702	8,756	528,779
100	5,934	2,025	48,539	6,504	8,526	515,513
125	5,965	1,877	48,095	6,312	8,232	501,845
150	5,930	1,750	47,989	6,163	7,941	490,718
175	5,779	1,670	48,020	5,951	7,619	478,203
200	5,685	1,631	48,679	5,838	7,401	470,453
225	5,688	1,585	49,495	5,740	7,218	463,637
250	5,618	1,591	50,233	5,644	7,166	458,051
275	5,561	1,597	51,454	5,563	7,137	454,405
300	5,471	1,557	52,547	5,491	7,157	450,992
350	5,296	1,466	54,026	5,361	7,171	444,511
400	5,113	1,370	55,187	5,295	7,127	440,975
450	4,819	1,302	55,181	5,690	7,062	438,123
500	4,509	1,230	56,956	5,188	7,005	425,804
550	4,385	1,198	57,376	5,158	6,900	418,842
600	4,303	1,218	57,925	5,611	6,774	417,735
650	4,162	1,258	59,303	5,218	6,633	410,118
700	4,080	1,331	61,244	4,941	6,449	404,258
750	3,955	1,362	63,424	4,773	6,450	400,288
800	3,886	1,367	65,884	4,572	5,962	393,976
850	3,778	1,308	69,603	4,424	5,687	390,482
900	3,669	1,230	73,549	4,333	5,465	389,928

Steelhead/rainbow trout fry rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	1,452	939	1,071	7,741	2,273
75	1,542	921	1,012	7,127	2,247
100	1,532	920	923	6,514	2,187
125	1,471	891	870	5,831	2,045
150	1,417	918	810	5,456	1,900
175	1,399	981	725	5,093	1,766
200	1,357	963	669	4,875	1,672
225	1,341	944	649	4,697	1,597
250	1,332	896	640	4,479	1,562
275	1,357	877	643	4,322	1,551
300	1,375	849	640	4,232	1,554
350	1,434	851	612	4,044	1,530
400	1,516	874	571	3,840	1,602
450	1,516	947	571	3,783	1,734
500	1,541	1,013	554	3,857	1,625
550	1,676	1,092	554	3,755	1,482
600	1,749	1,064	585	3,658	1,460
650	1,794	1,051	661	3,696	1,422
700	1,834	1,073	720	3,894	1,415
750	1,943	1,063	796	3,959	1,445
800	1,949	1,076	887	4,019	1,465
850	1,875	1,042	925	4,020	1,482
900	1,851	1,018	1,022	4,017	1,476

Steelhead/rainbow trout fry rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	1,105	526	10,284	1,268	1,782	110,573
75	1,203	483	9,921	1,134	1,716	107,877
100	1,219	451	9,825	1,017	1,667	102,746
125	1,182	415	9,728	938	1,630	96,754
150	1,122	398	9,795	890	1,590	93,114
175	1,075	385	9,940	837	1,539	89,942
200	1,036	379	10,230	787	1,493	87,201
225	1,022	387	10,677	770	1,455	85,807
250	1,022	418	10,998	736	1,416	84,039
275	1,008	432	11,308	699	1,351	83,164
300	978	439	12,001	663	1,306	83,079
350	911	432	13,110	599	1,296	82,580
400	879	416	13,702	558	1,270	82,669
450	850	415	14,371	639	1,220	85,798
500	798	429	15,205	506	1,190	85,039
550	774	414	15,576	477	1,140	84,361
600	790	393	16,191	536	1,066	86,183
650	757	424	16,928	510	1,041	87,029
700	706	461	17,706	493	1,068	88,024
750	693	512	18,545	496	1,068	90,407
800	695	533	19,862	489	1,003	93,064
850	674	523	21,600	477	908	94,319
900	674	483	24,020	484	823	97,105

Spring-run Chinook salmon and Steelhead/rainbow trout juvenile rearing
WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	2,325	1,456	903	4,476	1,487
75	3,085	1,893	1,171	5,863	1,930
100	3,757	2,262	1,407	7,041	2,309
125	4,340	2,590	1,616	8,134	2,675
150	4,867	2,874	1,822	9,125	3,006
175	5,326	3,163	2,039	10,174	3,355
200	5,694	3,391	2,217	11,022	3,638
225	6,028	3,590	2,380	11,826	3,903
250	6,285	3,776	2,535	12,579	4,149
275	6,500	3,930	2,680	13,282	4,378
300	6,671	4,070	2,814	13,943	4,601
350	6,891	4,306	3,062	15,154	5,000
400	7,008	4,484	3,272	16,240	5,364
450	7,023	4,616	3,448	17,170	5,687
500	7,059	4,731	3,612	18,023	5,995
550	6,990	4,817	3,741	18,723	6,245
600	6,939	4,897	3,832	19,308	6,448
650	6,897	4,931	3,909	19,790	6,618
700	6,734	4,938	3,965	20,180	6,759
750	6,632	4,930	4,002	20,489	6,870
800	6,432	4,896	4,024	20,747	6,945
850	6,252	4,888	4,026	20,900	7,009
900	6,064	4,891	4,011	21,006	7,028

Spring-run Chinook salmon and Steelhead/rainbow trout juvenile rearing
WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	900	418	7,639	735	751	84,765
75	1,183	555	9,735	948	956	109,949
100	1,439	678	11,587	1,138	1,149	131,778
125	1,686	782	13,185	1,306	1,327	151,521
150	1,929	860	14,585	1,460	1,496	169,463
175	2,185	931	16,111	1,622	1,687	188,198
200	2,394	996	17,281	1,748	1,844	203,305
225	2,587	1,066	18,372	1,861	1,991	217,275
250	2,769	1,119	19,440	1,965	2,115	230,218
275	2,943	1,171	20,418	2,057	2,225	241,875
300	3,106	1,221	21,243	2,141	2,329	252,459
350	3,399	1,308	22,708	2,281	2,515	270,939
400	3,656	1,389	23,979	2,387	2,674	286,641
450	3,876	1,461	24,877	2,041	2,812	294,252
500	4,071	1,519	25,767	2,528	2,935	310,507
550	4,234	1,564	26,247	2,553	3,029	318,737
600	4,383	1,600	26,416	2,048	3,109	319,283
650	4,504	1,631	26,654	2,147	3,168	325,605
700	4,621	1,657	26,807	2,241	3,212	330,086
750	4,690	1,678	26,857	2,298	3,212	333,135
800	4,756	1,692	26,758	2,327	3,251	334,596
850	4,791	1,702	26,586	2,323	3,256	334,724
900	4,794	1,691	26,393	2,212	3,243	332,802

Fall-run Chinook salmon juvenile rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	3,172	4,231	2,075	9,724	3,512
75	3,809	4,529	2,470	11,038	3,938
100	4,182	4,791	2,781	12,188	4,230
125	4,309	4,963	3,088	13,184	4,488
150	4,444	5,074	3,330	14,050	4,709
175	4,535	5,143	3,598	14,892	4,934
200	4,656	5,165	3,799	15,530	5,122
225	4,657	5,150	4,006	16,069	5,297
250	4,514	5,116	4,177	16,510	5,448
275	4,346	5,091	4,337	16,801	5,569
300	4,105	5,084	4,482	16,989	5,671
350	3,660	4,964	4,699	16,957	5,788
400	3,328	4,789	4,846	16,481	5,831
450	3,011	4,599	4,912	15,675	5,794
500	2,821	4,396	4,832	14,536	5,644
550	2,773	4,197	4,630	13,501	5,439
600	2,667	4,048	4,423	12,522	5,388
650	2,524	3,932	4,089	11,580	4,837
700	2,369	3,875	3,720	10,646	4,443
750	2,241	3,736	3,353	9,758	4,066
800	2,120	3,665	2,985	8,891	3,733
850	2,096	3,609	2,707	8,155	3,477
900	2,045	3,579	2,494	7,603	3,234

Fall-run Chinook salmon juvenile rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	2,410	433	19,585	2,910	4,554	224,915
75	2,700	524	21,195	3,295	4,558	248,454
100	2,906	568	22,735	3,613	4,637	267,634
125	3,075	579	24,021	3,884	4,735	283,272
150	3,214	581	25,125	4,114	4,844	296,863
175	3,333	582	26,045	4,321	4,970	308,968
200	3,412	570	26,704	4,496	5,087	318,200
225	3,489	541	27,187	4,649	5,206	325,414
250	3,514	464	27,456	4,780	5,367	330,224
275	3,574	516	27,698	4,890	5,533	334,768
300	3,595	499	27,933	4,985	5,684	337,862
350	3,553	457	27,962	5,121	5,952	338,627
400	3,426	433	27,899	5,197	6,156	334,869
450	3,244	423	26,985	4,327	6,292	315,866
500	3,105	400	27,342	5,157	6,335	315,769
550	3,065	392	26,752	5,035	6,269	304,825
600	3,088	390	25,790	4,015	6,114	284,289
650	3,053	390	25,664	3,910	5,916	273,178
700	3,052	378	25,720	3,825	5,681	263,294
750	2,960	356	25,880	3,740	5,681	253,609
800	2,898	333	26,064	3,613	5,183	242,998
850	2,793	306	26,375	3,435	4,948	234,032
900	2,658	287	26,669	3,269	4,745	226,215