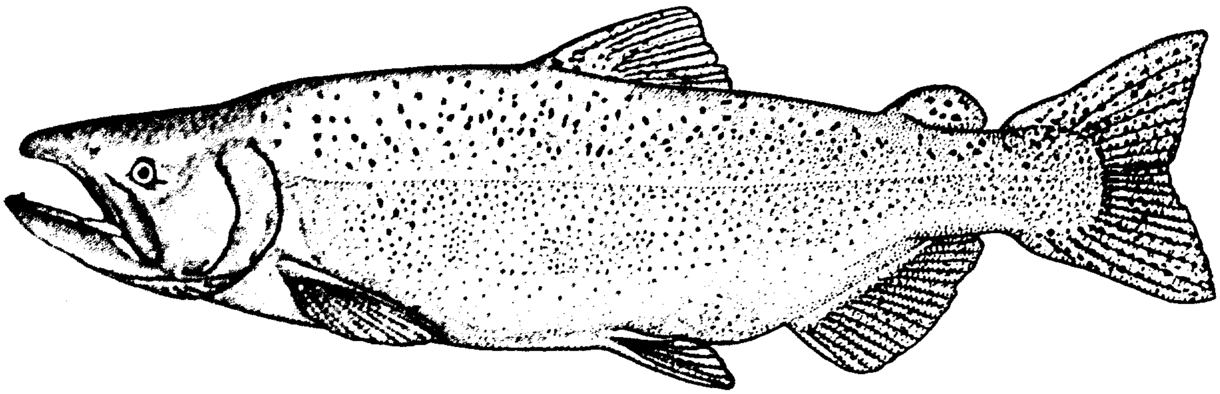
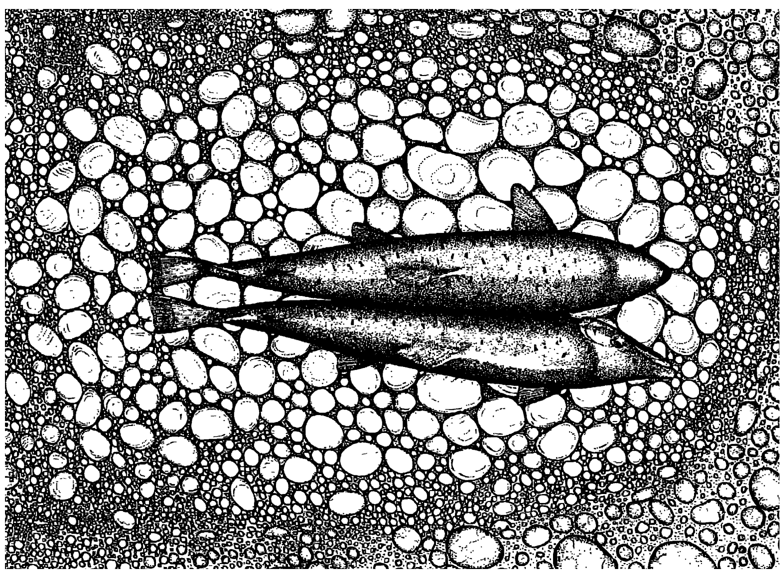
FLOW-HABITAT RELATIONSHIPS FOR SPRING-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING IN CLEAR CREEK BETWEEN WHISKEYTOWN DAM AND CLEAR CREEK ROAD





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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.

[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

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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.

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.

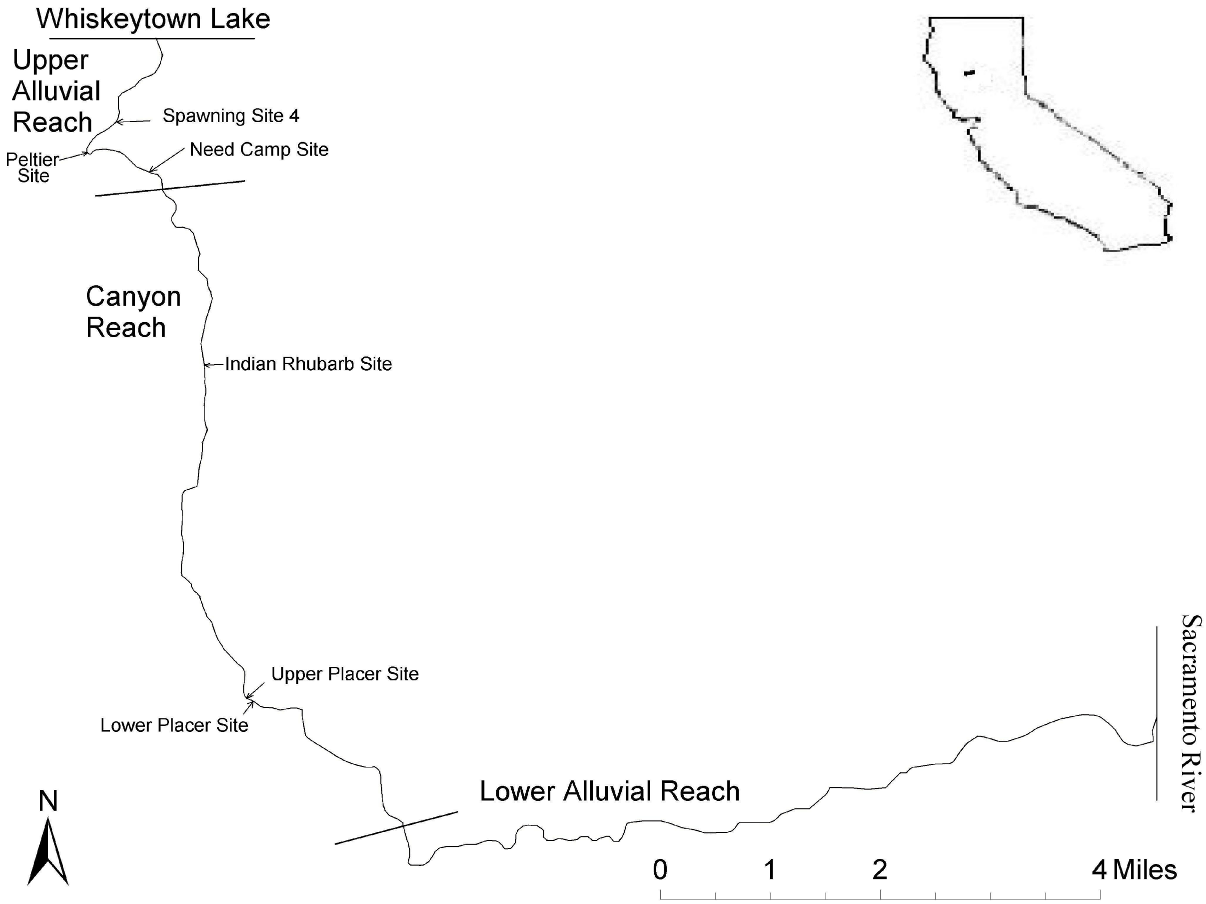
Study Site Selection

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.

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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.

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[R] 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).

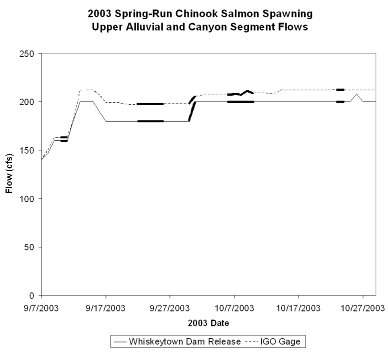
Habitat Suitability Criteria (HSC) Data Collection

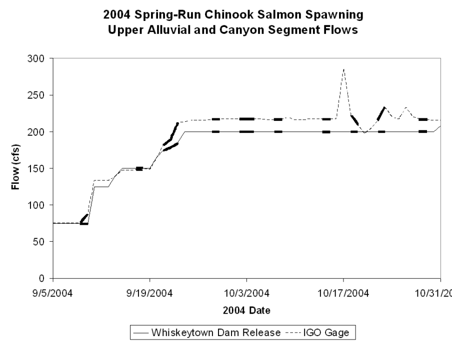
The location of depth and velocity measurements was generally about 2 to 4 feet upstream of the pit of the redd; however on rare occasions it was necessary to make measurements at a 45 degree angle upstream. The data were almost always collected within 5 feet of the pit of the redd.

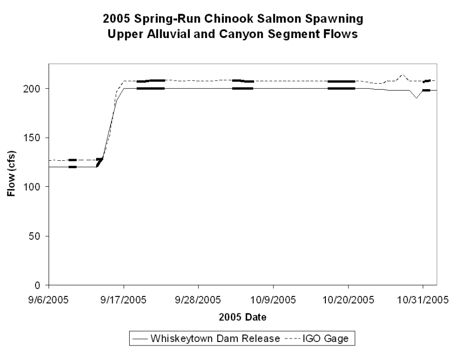
Data relative to depth, velocity, and substrate size were collected for a total of 180 spring-run Chinook salmon redds in Clear Creek on September 8-October 23, 2003, September 9-October 23, 2004 and September 6-October 21, 2005 in the Upper Alluvial and Canyon Segments. However, for some of the redds, 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

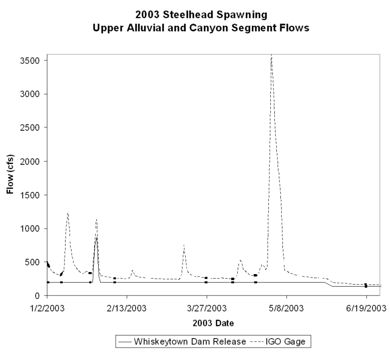
During the survey for spring-run Chinook salmon redds conducted on October 18 and 21, 2004, we measured 0 redds at Spawn Area 4, 2 redds at Peltier, 2 redds at NEED Camp, 1 redd at Indian Rhubarb, 1 redd at Lower Placer, and 1 redd at Upper Placer, for a total of 7 redds for the six study sites. While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

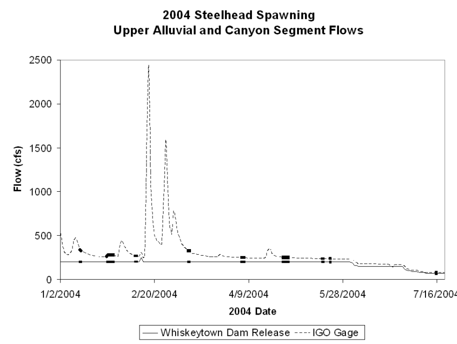
Habitat Suitability Criteria (HSC) Development

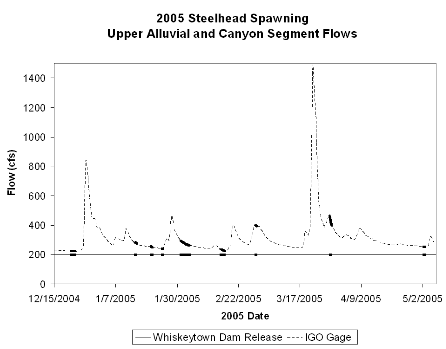
For the seven spring-run Chinook salmon occupied points (Spawn Area 4 = 0 redds, Peltier = 2 redds, NEED Camp = 2 redds, Indian Rhubarb = 1 redd, Lower Placer = 1 redd, Upper Placer = 1 redd) collected on October 18, 2004, the flows were averaged from September 1-October 18, 2004, for all the sites with 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.

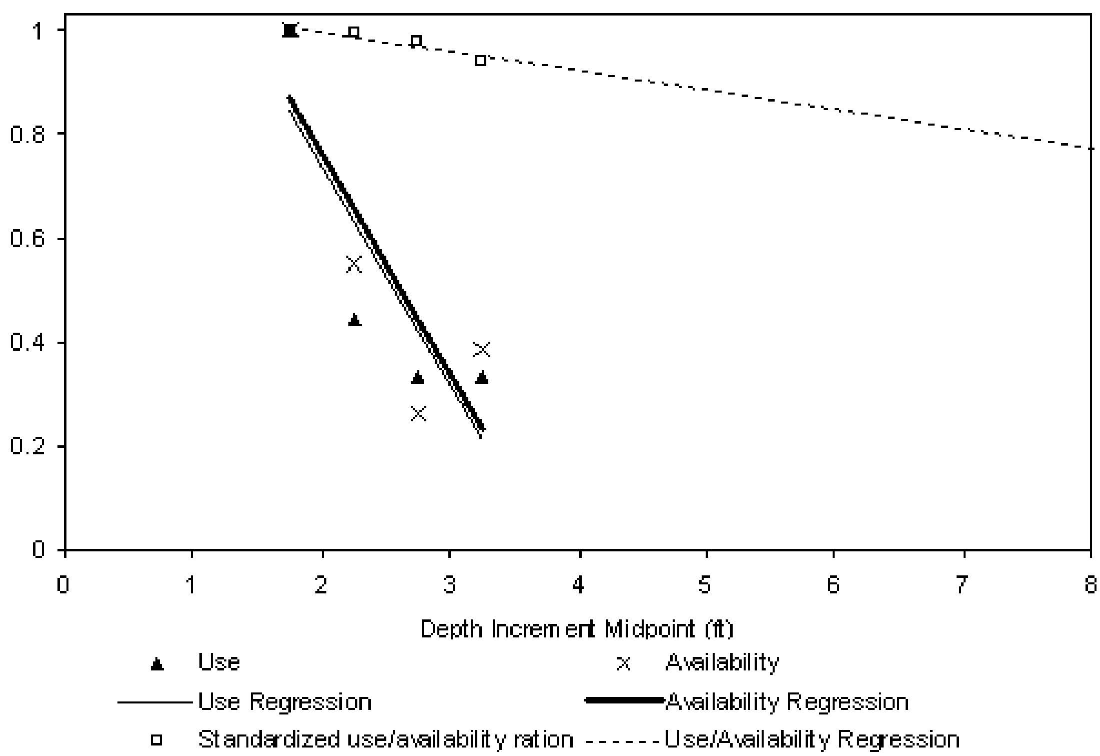


Figure 5. Spring-run Chinook salmon spawning depth HSI. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for depths of 0.8 to 7.0 feet and an optimum suitability at depths of 6.0 to 6.2 feet.

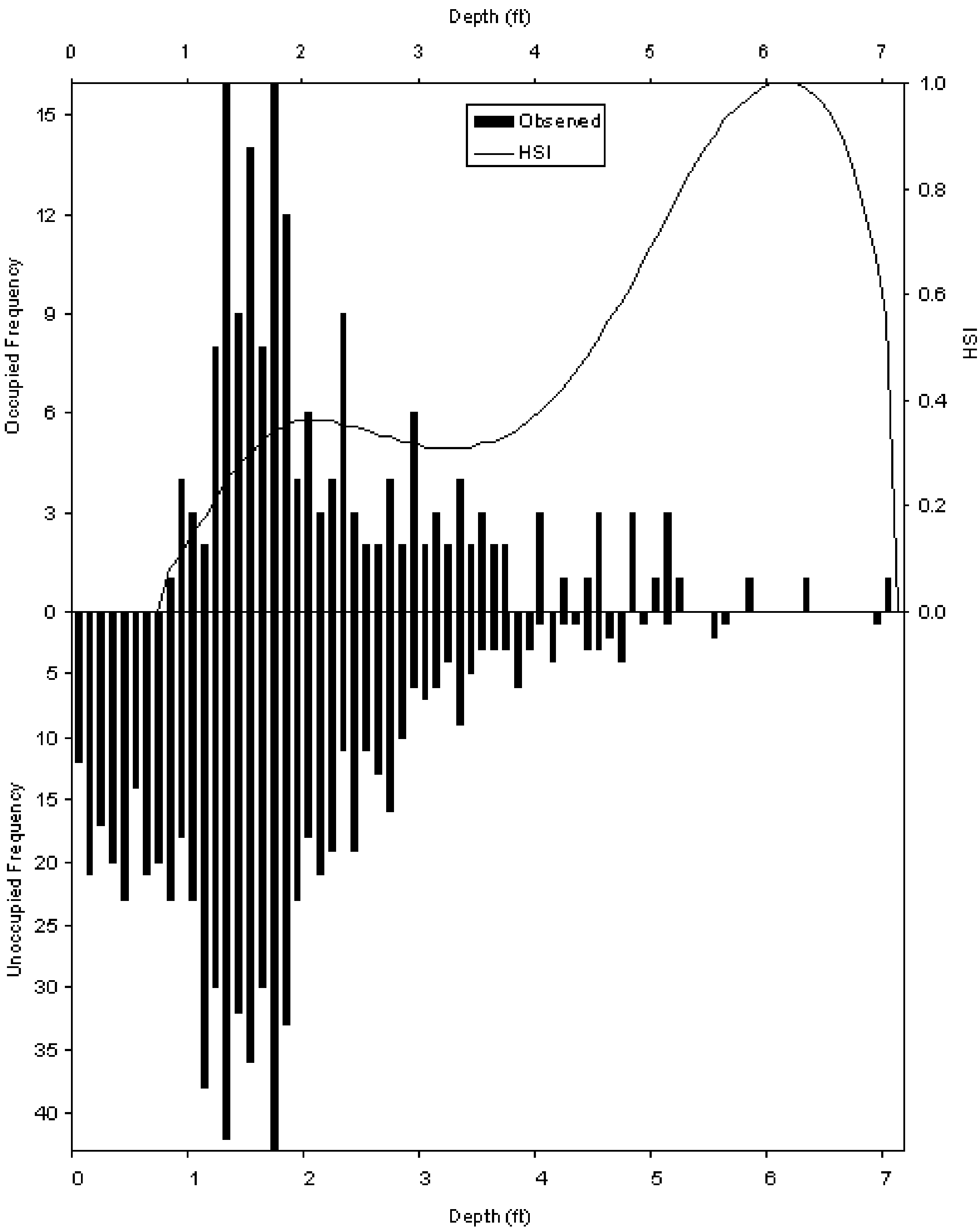


Figure 6. Spring-run Chinook salmon spawning velocity HSI. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for velocities of 0.70 to 4.40 feet/sec and an optimum suitability at velocities of 2.90 to 3.10 feet/sec.

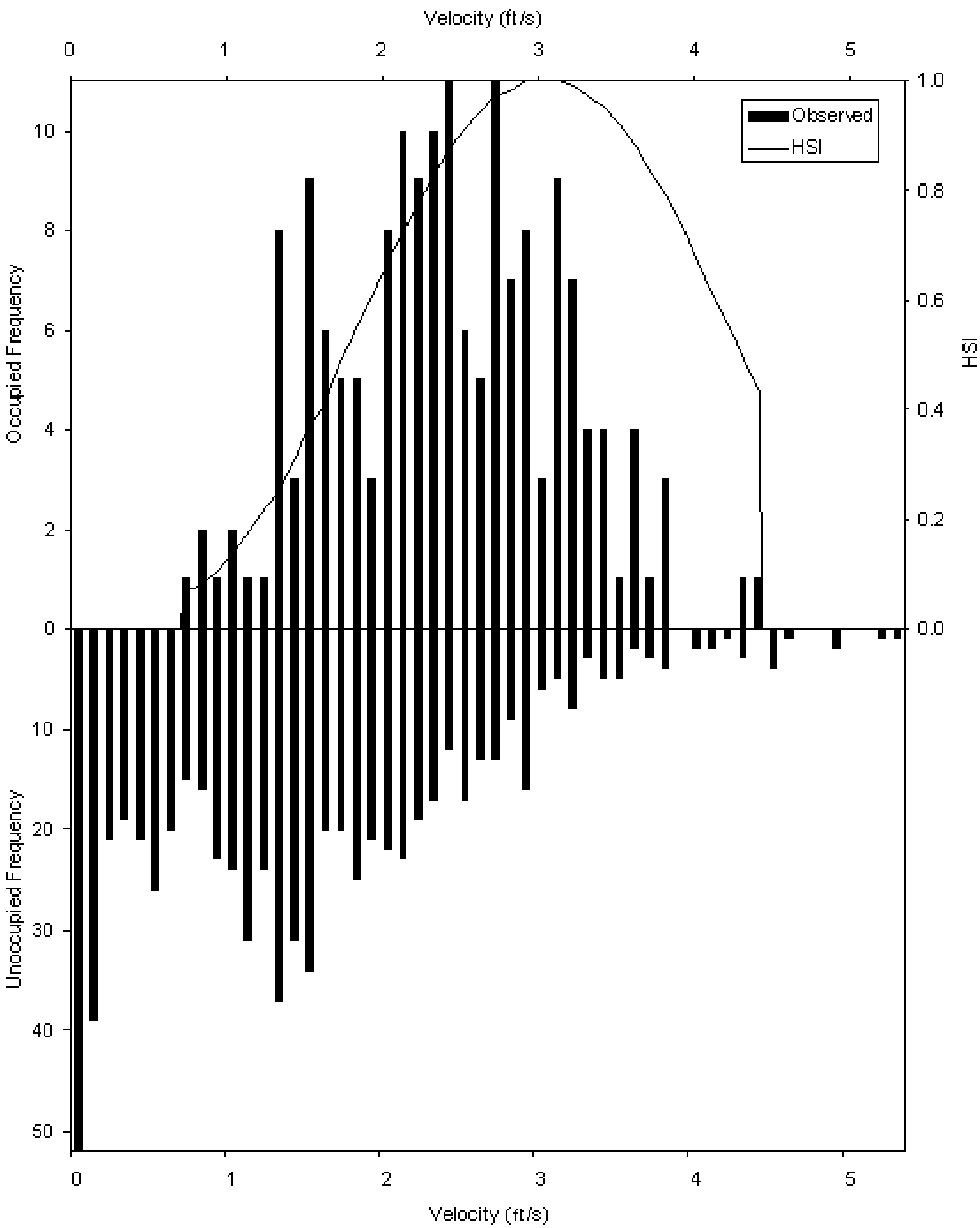


Figure 7. Steelhead/rainbow trout spawning depth HSI. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for depths of 0.4 to 28.5 feet and an optimum suitability at depths of 1.4 to 1.5 feet.

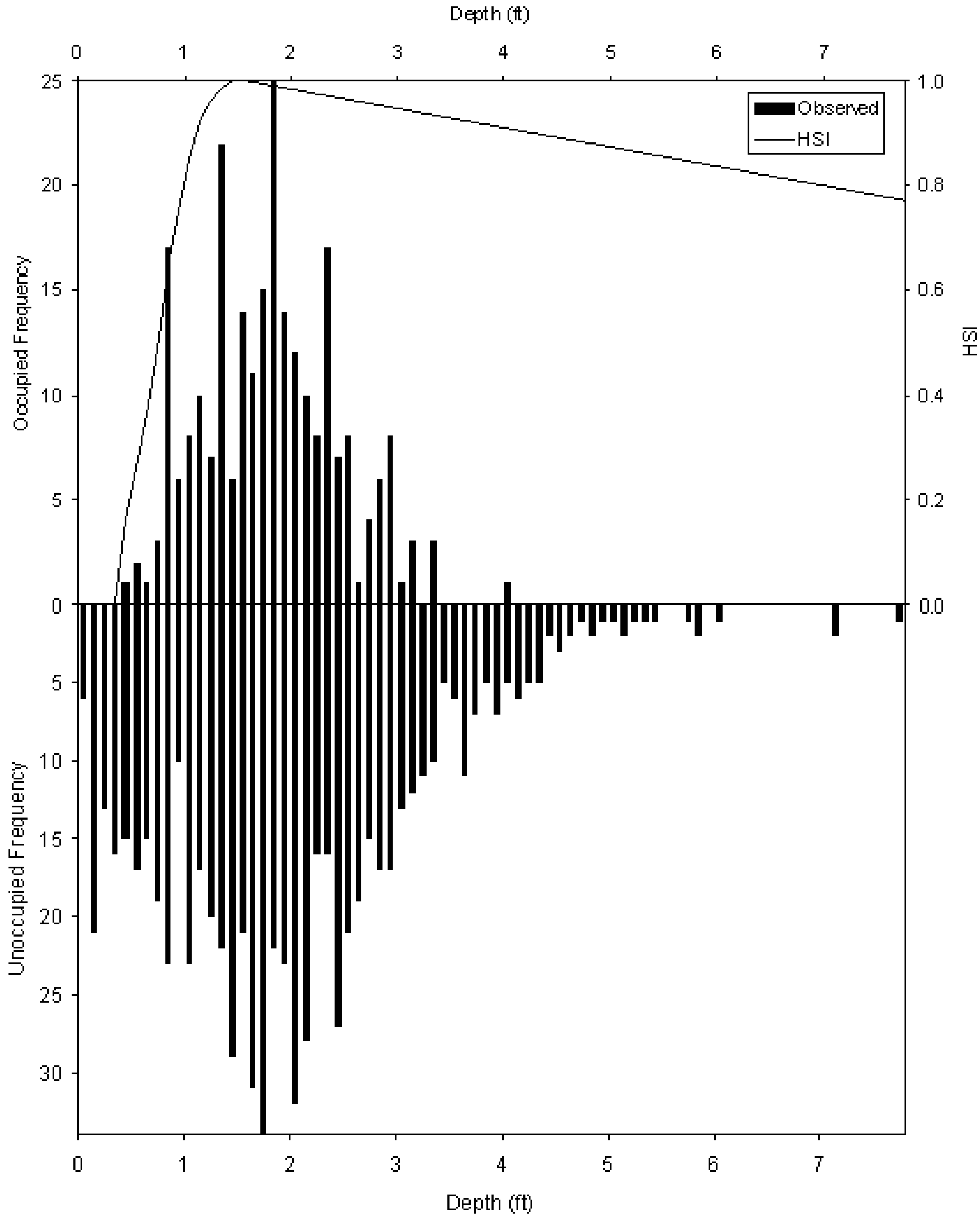


Figure 8. Steelhead/rainbow trout spawning velocity HSI. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for velocities of 0.61 to 3.89 feet/sec and an optimum suitability at velocities of 1.60 to 1.70 feet/sec.

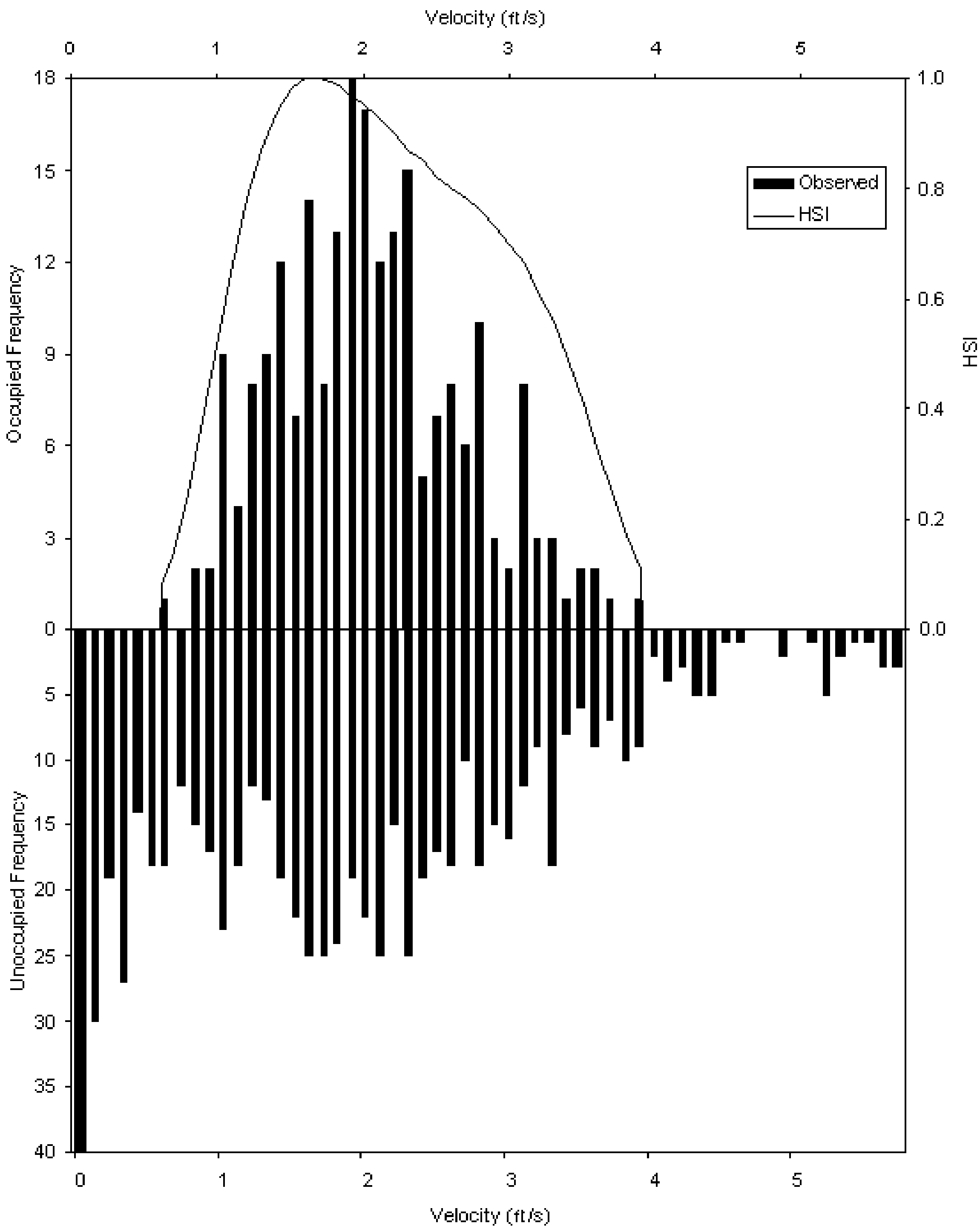


Figure 9. Spring-run Chinook salmon HSI curve for substrate. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for substrate codes 1.2 to 4.6 and an optimum suitability for substrate code 2.4.

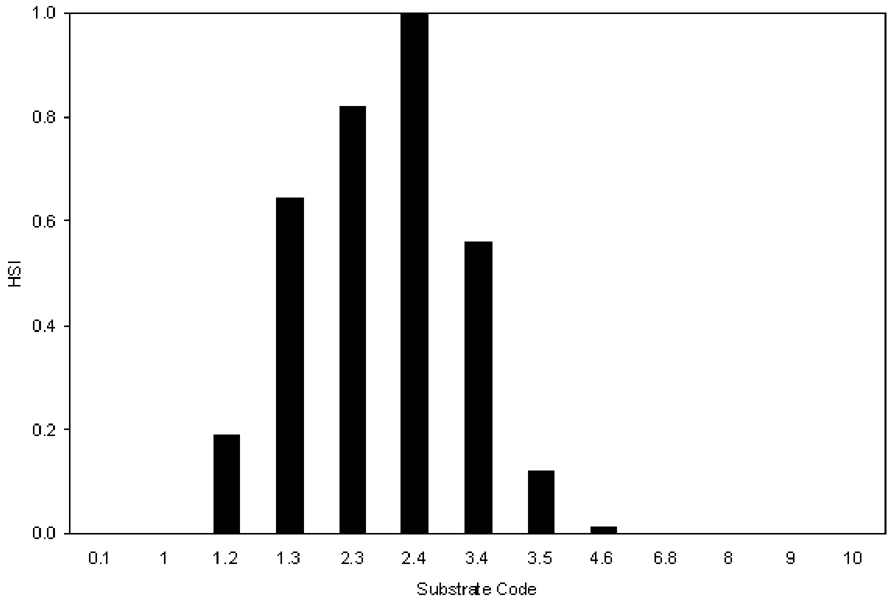
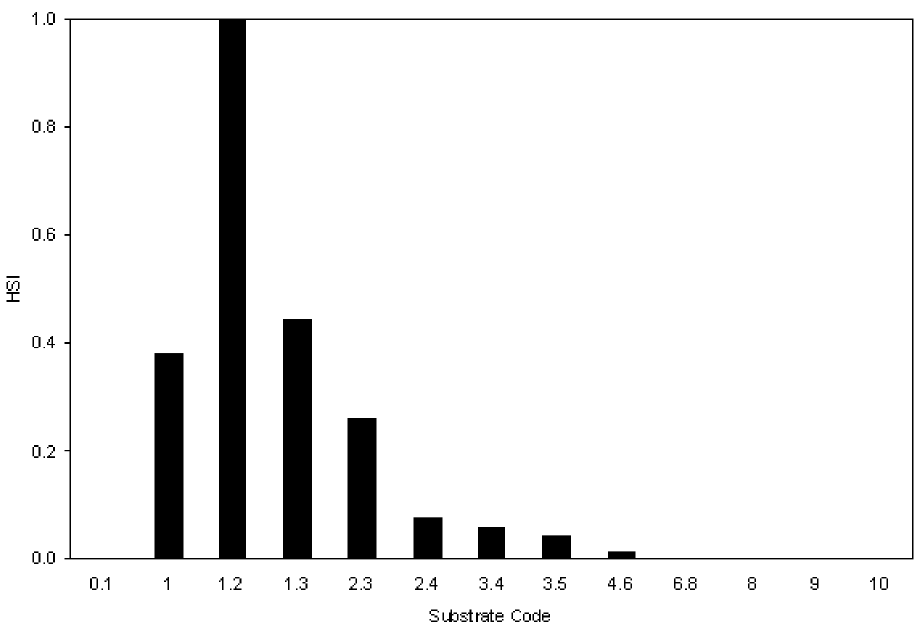


Figure 10. Steelhead/rainbow trout HSI curve for substrate. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for substrate codes 1 to 4.6 and an optimum suitability for substrate code 1.2.



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.

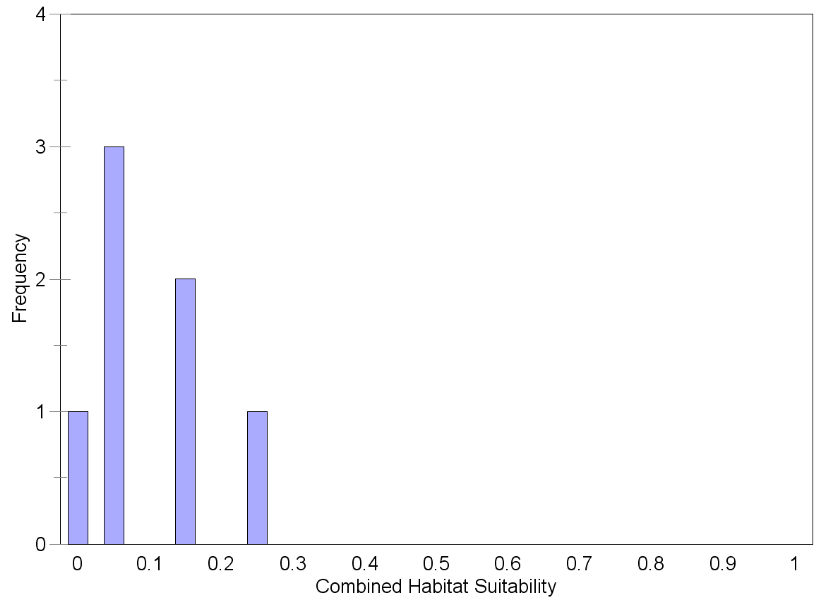


Figure 12. Spring-run Chinook salmon combined suitability for 2-D model locations without redds. The median combined suitability for unoccupied locations was 0.0000.

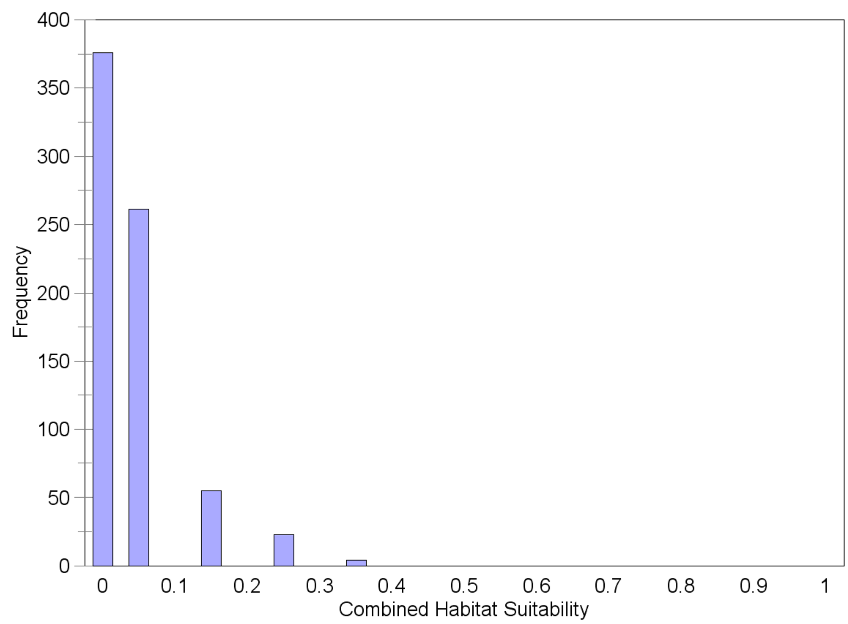


Figure 13. Steelhead/rainbow trout combined suitability for 2-D model locations with redds. The median combined suitability for occupied locations was 0.0563.

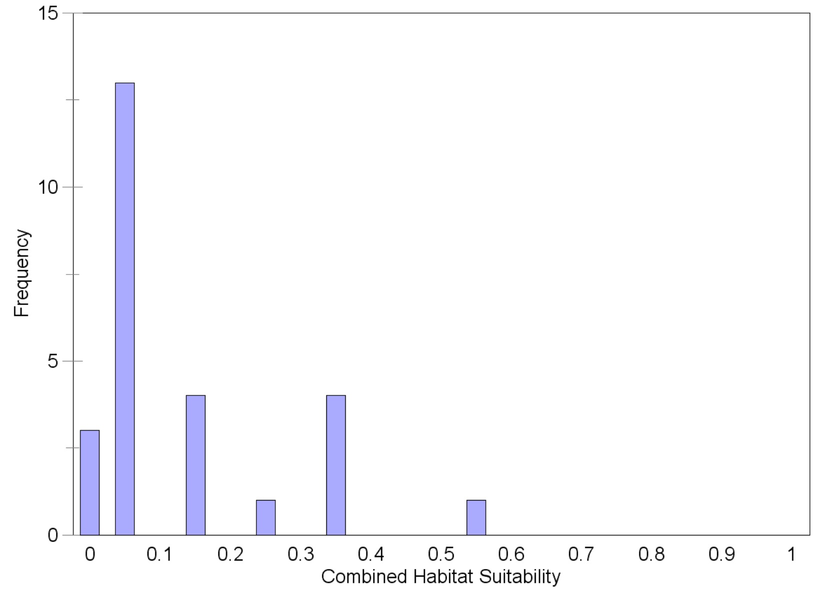
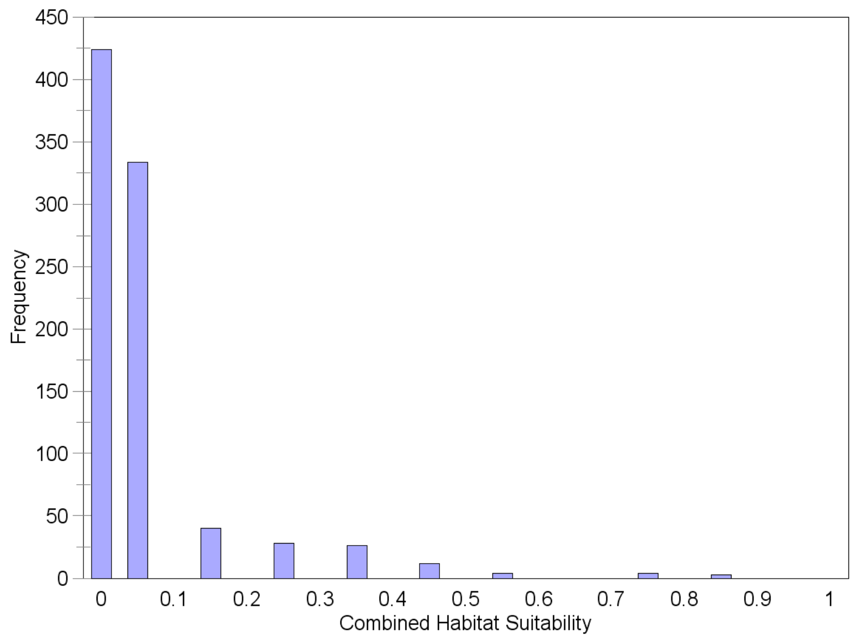


Figure 14. Steelhead/rainbow trout combined suitability for 2-D model locations without redds. The median combined suitability for unoccupied locations was 0.0008.



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.

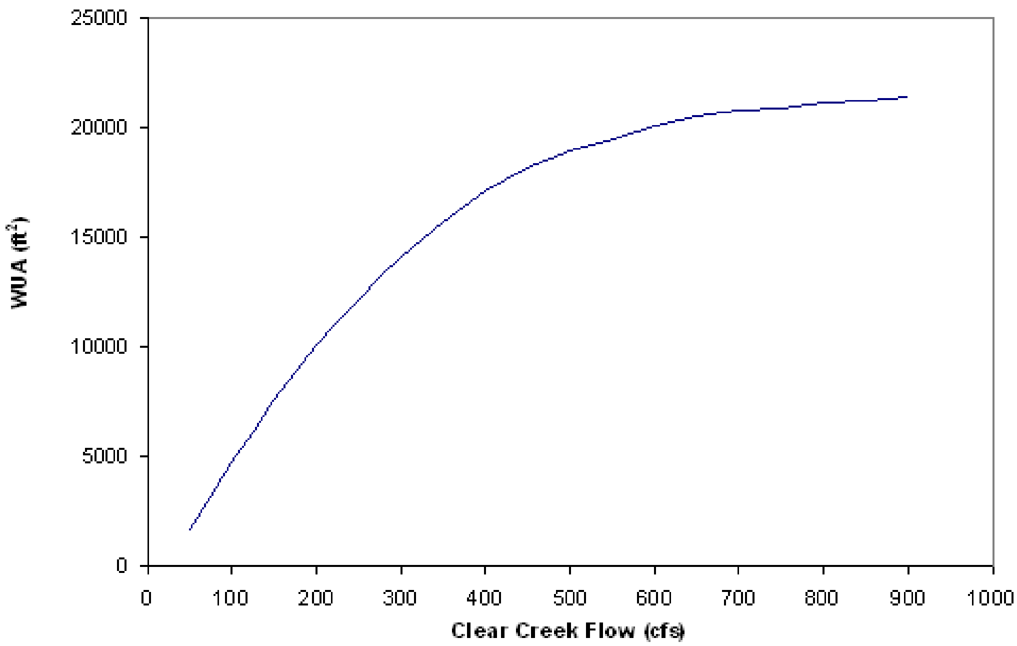


Figure 16. Spring-run Chinook salmon flow-habitat relationships, Canyon Segment. The flow with the maximum spring-run Chinook salmon spawning habitat was 650 cfs.

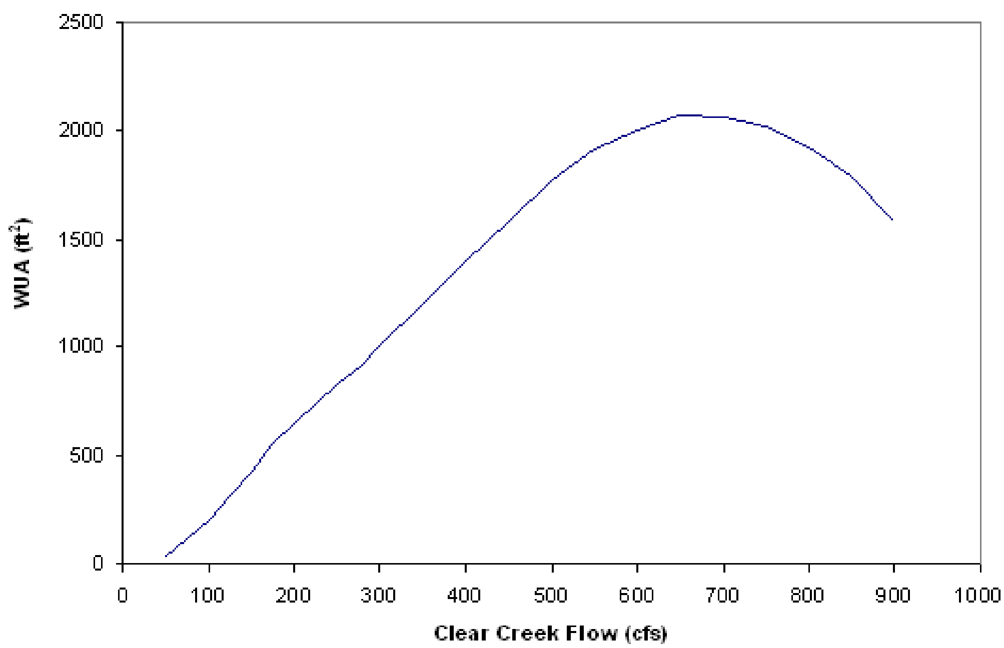


Figure 17. Steelhead/rainbow trout flow-habitat relationships, Upper Alluvial Segment. The flow with the maximum steelhead/rainbow trout spawning habitat was 350 cfs.

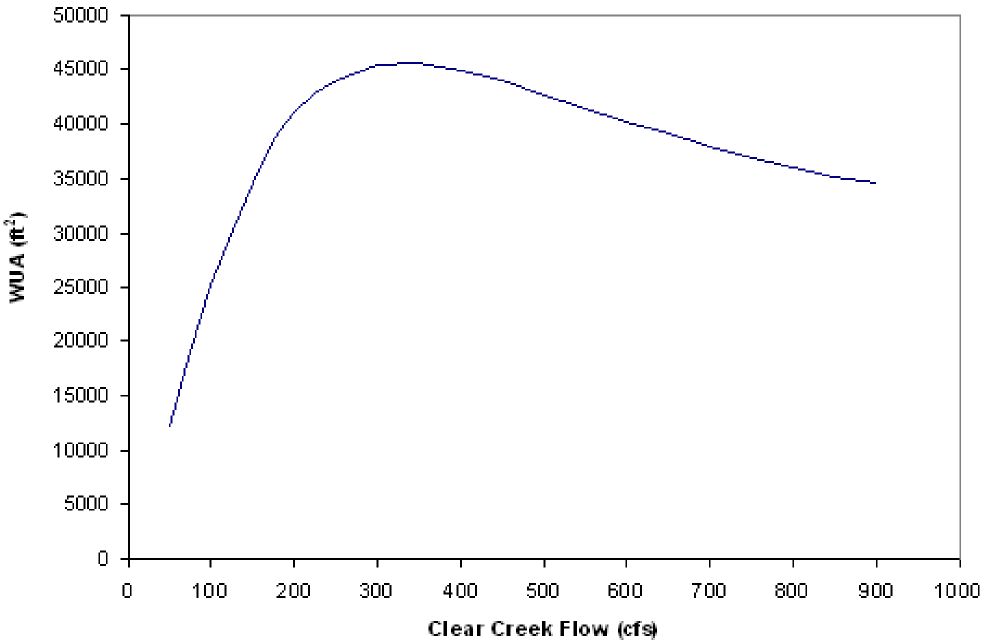


Figure 18. Steelhead/rainbow trout flow-habitat relationships, Canyon Segment**.** The flow with the maximum steelhead/rainbow trout spawning habitat was 600 cfs.

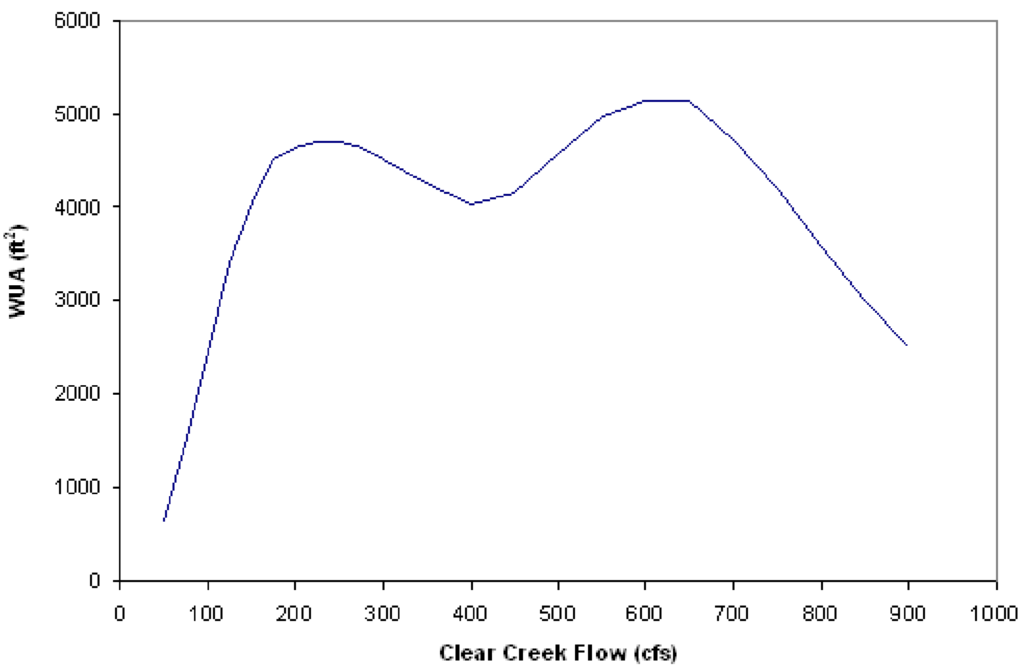


Table 8. Number of spring-run Chinook salmon redds and average flows for the six study sites for 2003 to 2005. Sites without an entry in the table for a given year did not have any spring-run Chinook salmon redds that year.

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.

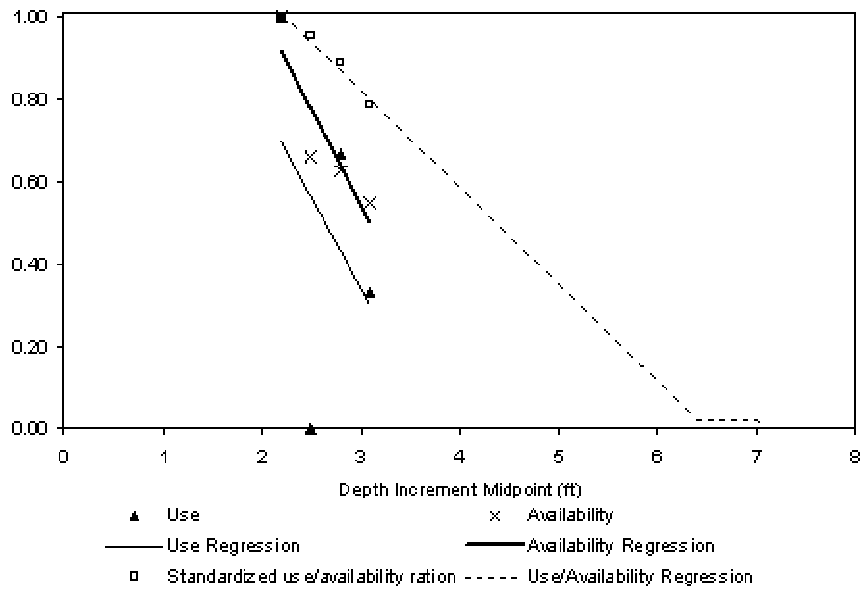


Figure 20. Original and two alternative spring-run Chinook salmon depth HSC.

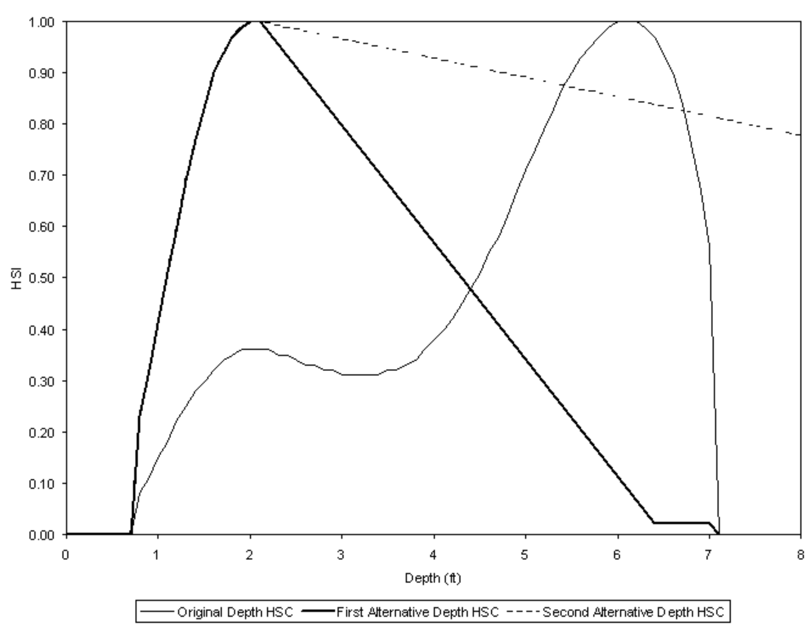
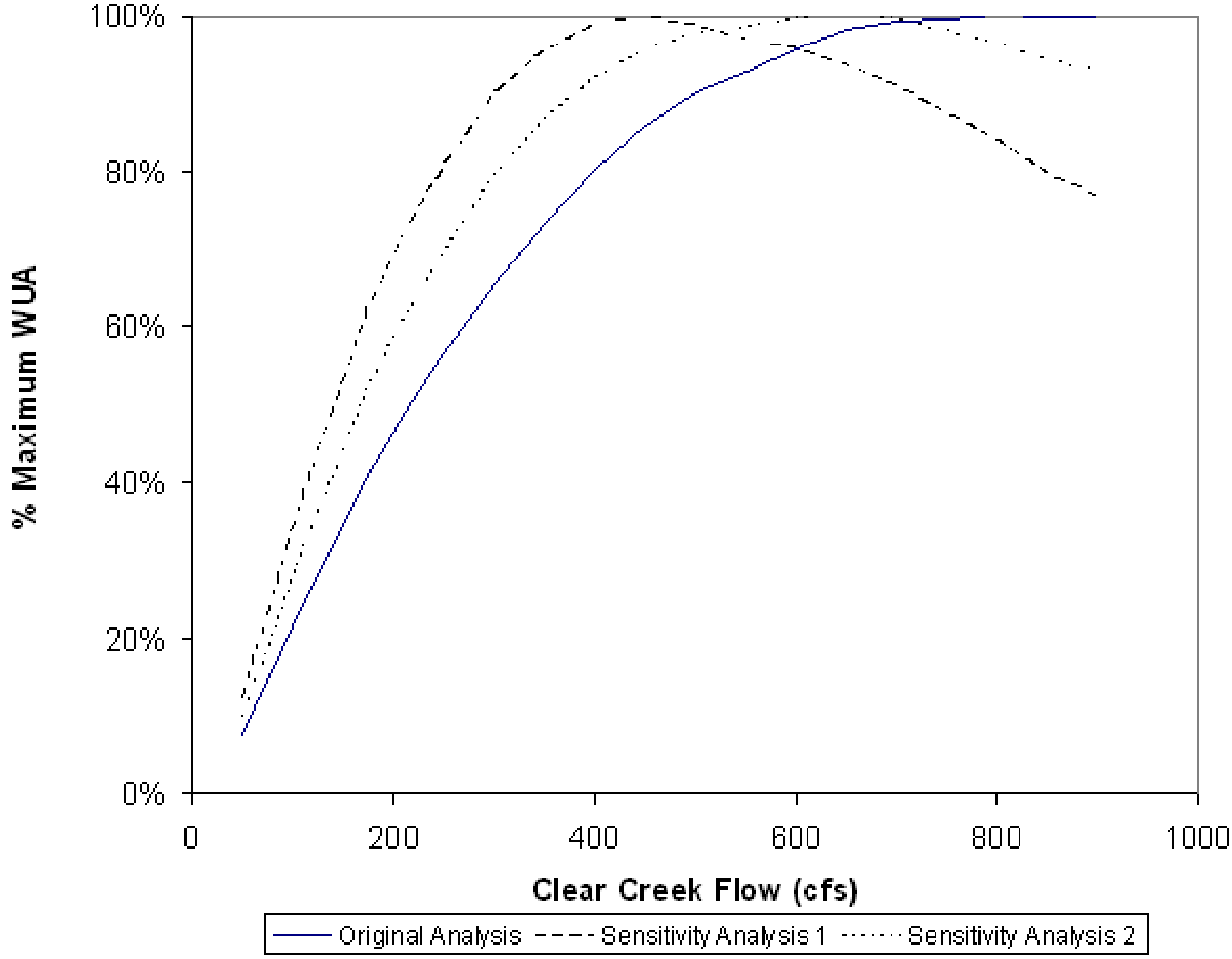


Figure 21. Flow-habitat relationships from original and two alternative spring-run Chinook salmon depth HSC. All three flow-habitat relationships show habitat increasing up to 450 cfs, but differ in pattern for flows greater than 450 cfs.



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.

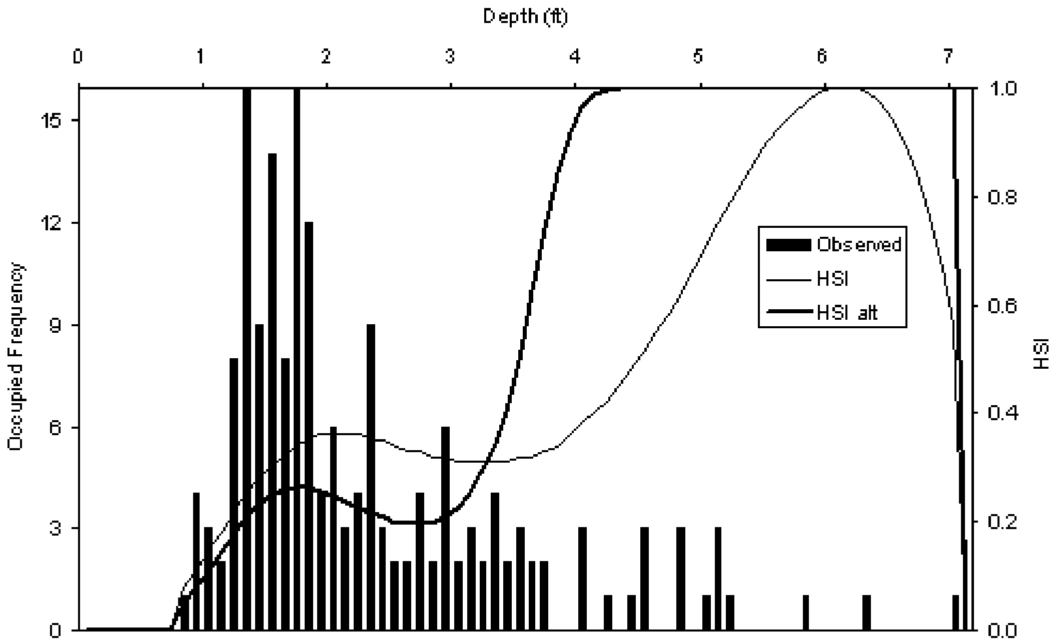


Figure 23. Comparison of spring-run Chinook salmon depth HSC from this study with an alternative depth HSC computed from data that excluded occupied and unoccupied observations with depths greater than 3.7 feet (the value of the 95th percentile unoccupied measurement).

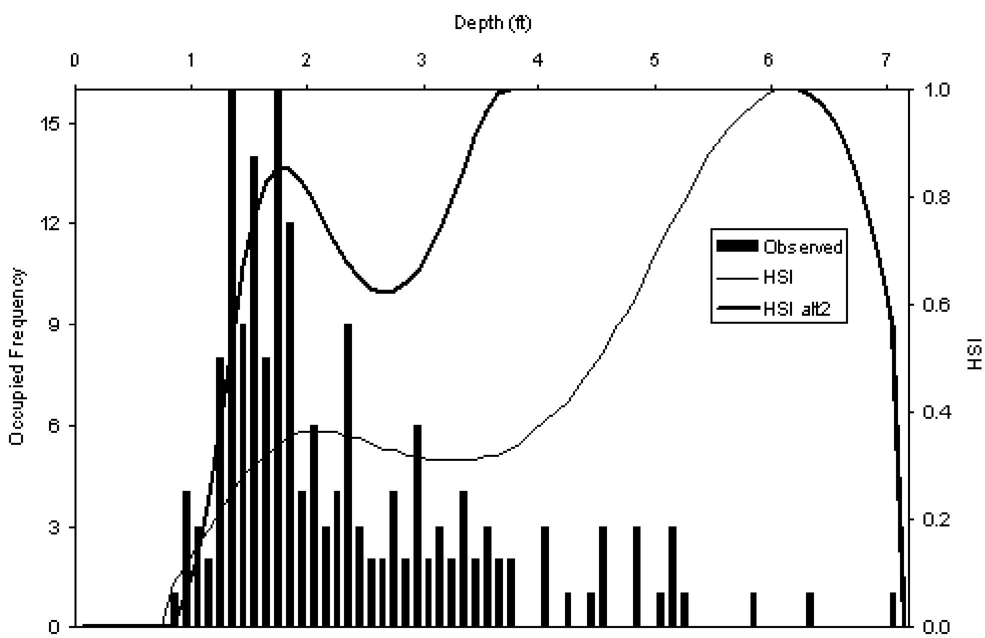


Figure 24. Comparison of depth HSC from this study. These criteria indicate that spring-run Chinook salmon selected deeper conditions than steelhead/rainbow trout.

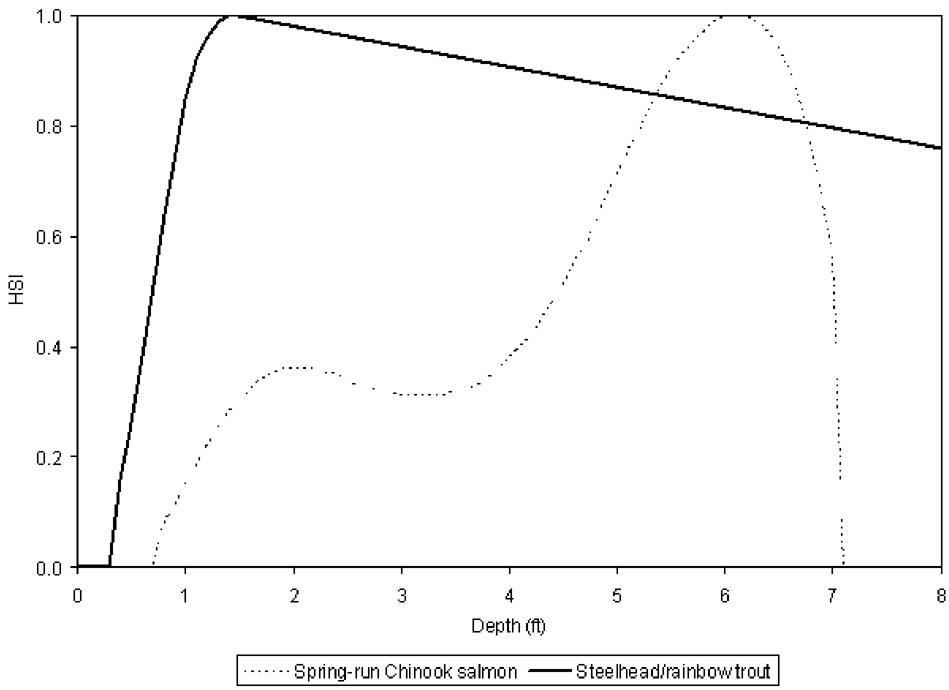


Figure 25. Comparison of velocity HSC from this study. These criteria indicate that spring-run Chinook salmon selected faster velocities than steelhead/rainbow trout.

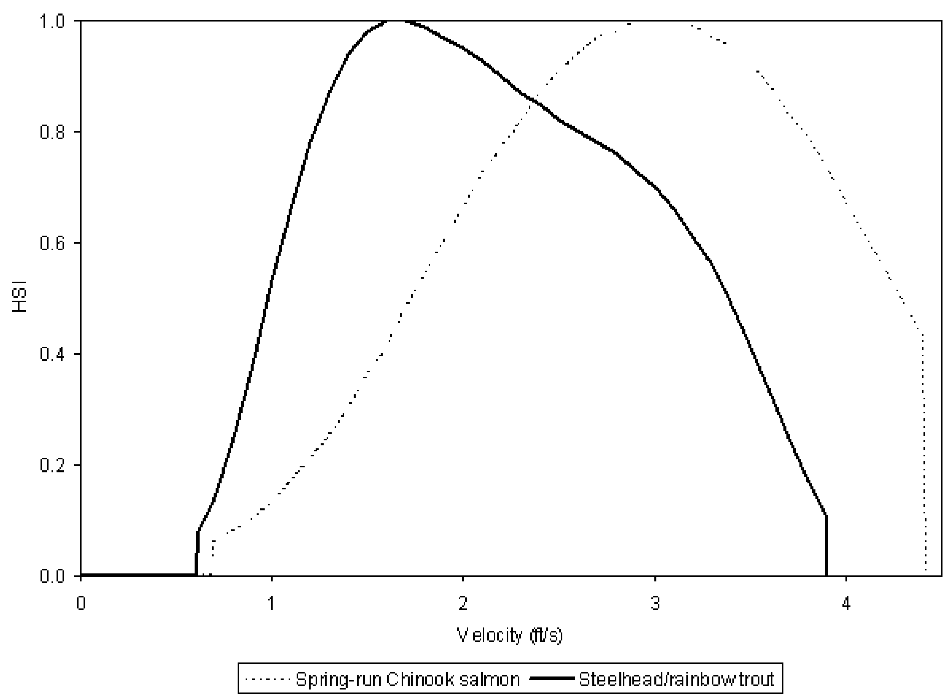
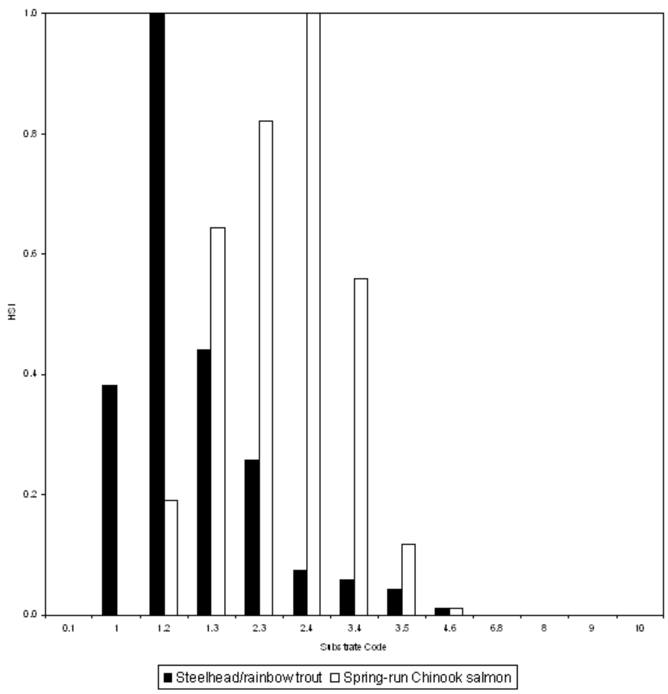


Figure 26. Comparison of substrate HSC from this study. These criteria indicate that spring-run Chinook salmon selected larger substrates than steelhead/rainbow trout.



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.

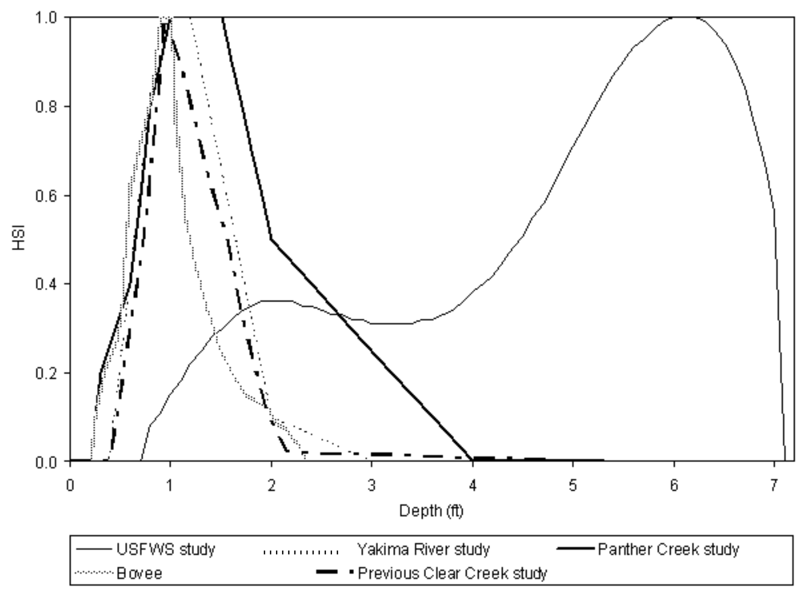


Figure 28. Comparison of spring-run Chinook salmon velocity HSC from this study with other spring-run Chinook salmon spawning velocity HSC and the fall-run Chinook salmon spawning velocity HSC used in the previous instream flow study on Clear Creek. The criteria from this study show a shift to more suitability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

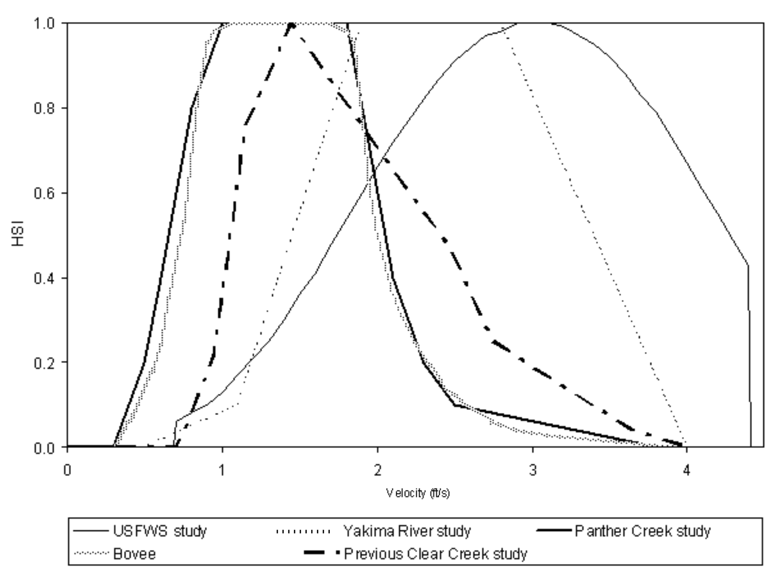


Figure 29. Comparison of steelhead/rainbow trout depth HSC from this study with other steelhead/rainbow trout spawning depth HSC. The criteria from this study show a higher suitability at greater depths than the criteria from other studies.

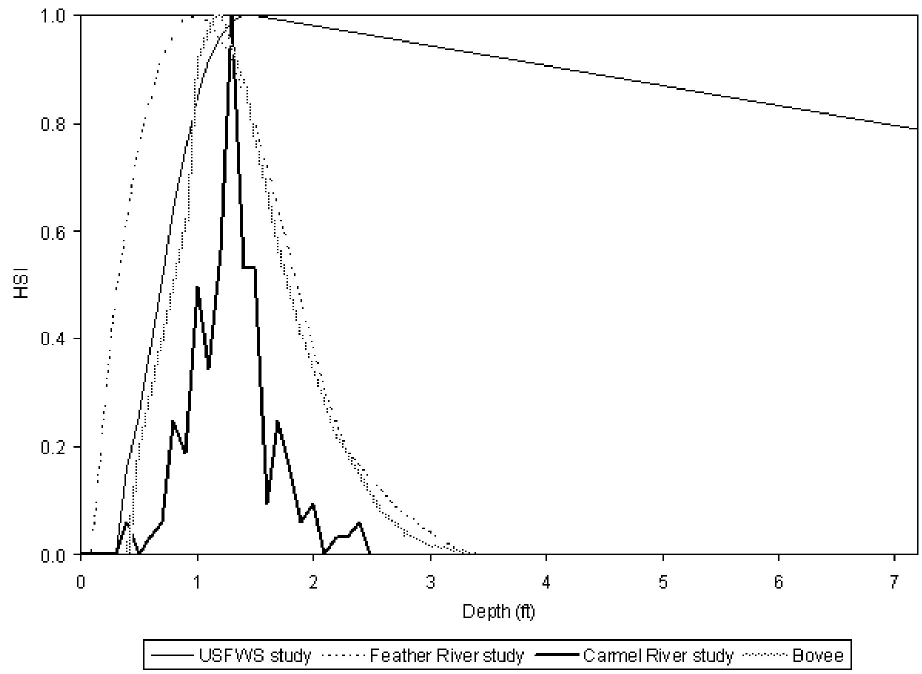


Figure 30. Comparison of steelhead/rainbow trout velocity HSC from this study with other steelhead/rainbow trout spawning velocity HSC. The criteria from this study show suitability extending to higher velocities than for other studies.

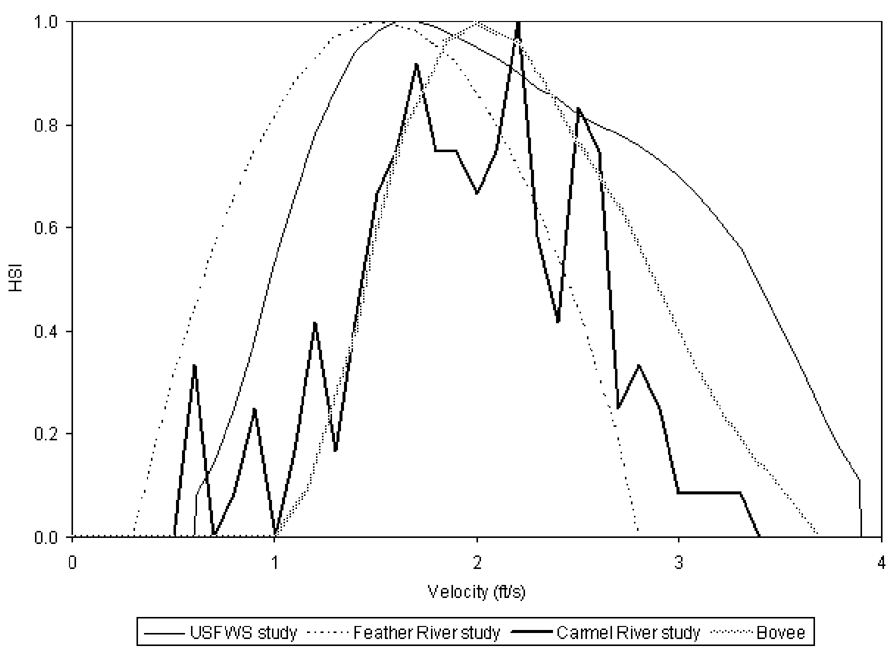
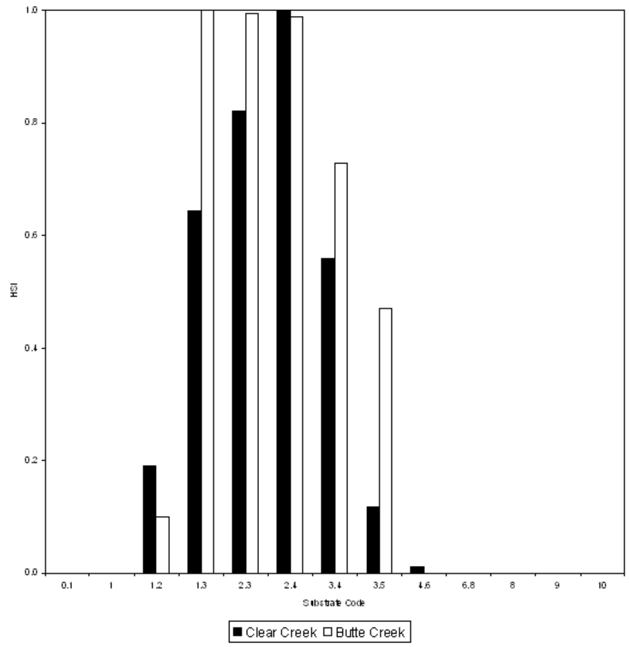


Figure 31. Comparison of spring-run Chinook salmon substrate HSC from this study with other spring-run Chinook salmon spawning substrate HSC.



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.

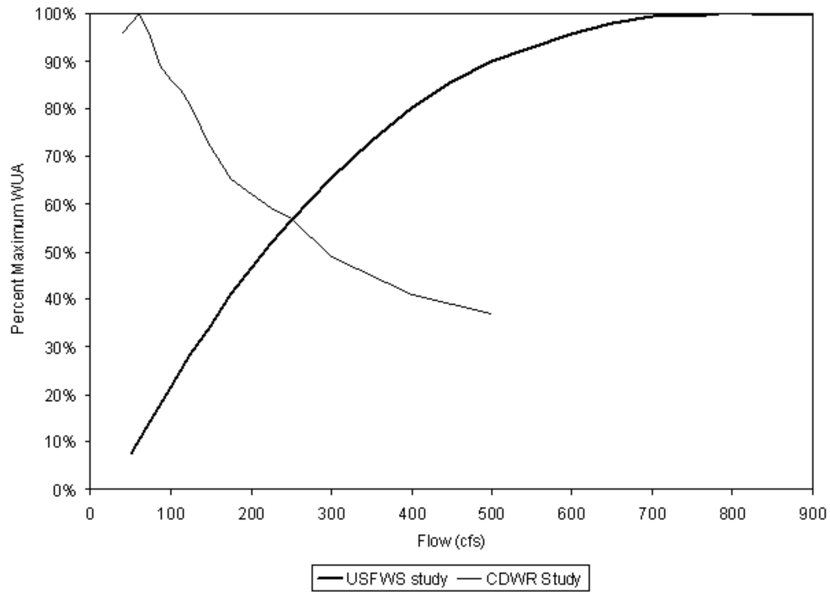


Figure 30. Comparison of steelhead/rainbow trout flow-habitat relationships from California Department of Water Resources (1985) and for the combined Upper Alluvial and Canyon Segments from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources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

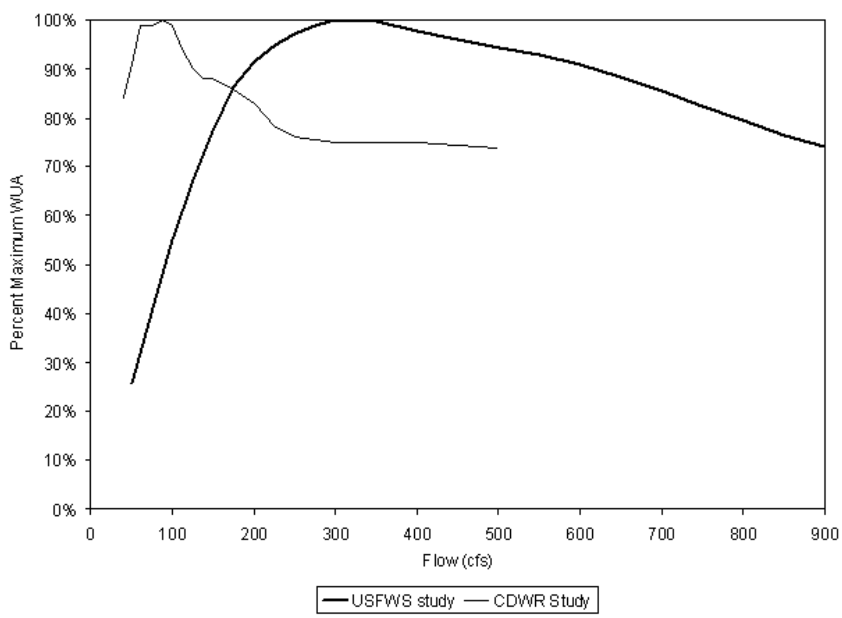


Figure 31. Comparison of fall-run Chinook salmon flow-habitat relationship from California Department of Water Resources (1985) and spring-run Chinook salmon flow-habitat relationship for the Canyon Segment from this study. This study predicts the peak habitat at a higher flow than the California Department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

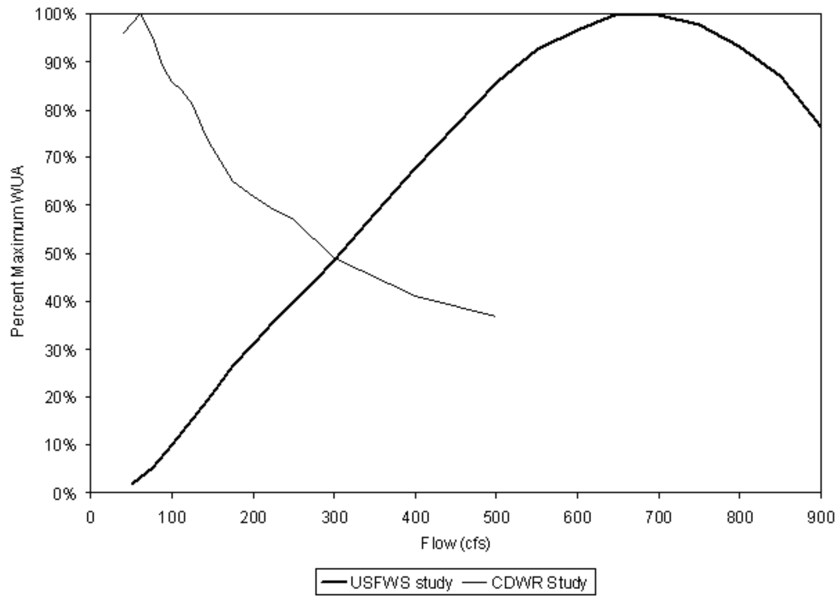
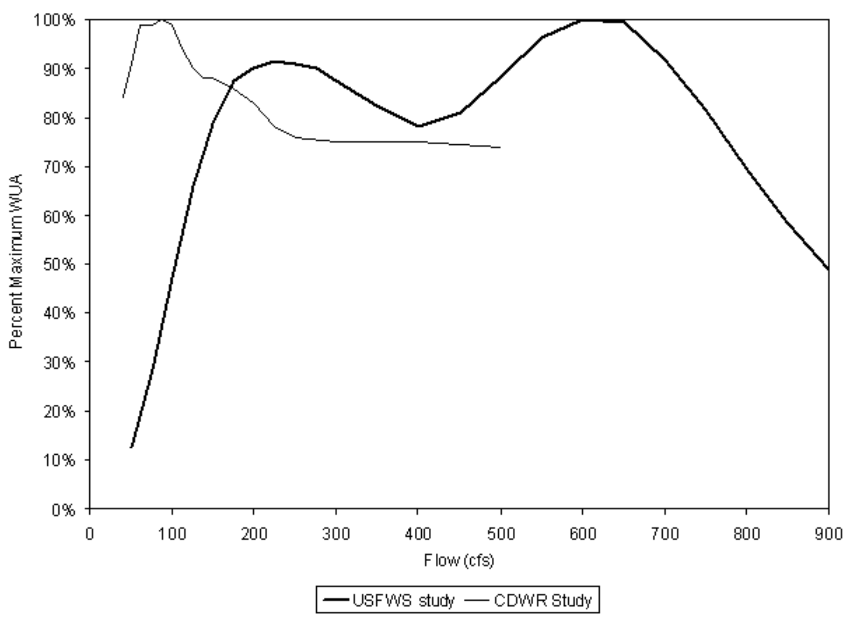


Figure 32. Comparison of steelhead/rainbow trout flow-habitat relationships from California Department of Water Resources (1985) and for the Canyon Segment from this study. This study predicts the peak habitat at a higher flow than the California Department of Water Resources (1985) study.



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.

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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

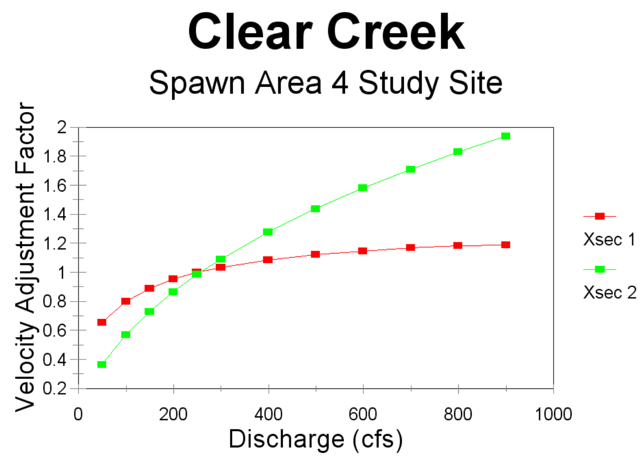
XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 72 cfs	255 cfs	454 cfs	666 cfs	Difference (measured vs. pred. WSELs) 72 cfs	255 cfs	454 cfs	666 cfs
1	---	4.50	14.0	3.0	0.0	1.0	0.09	0.05	0.00	0.03

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

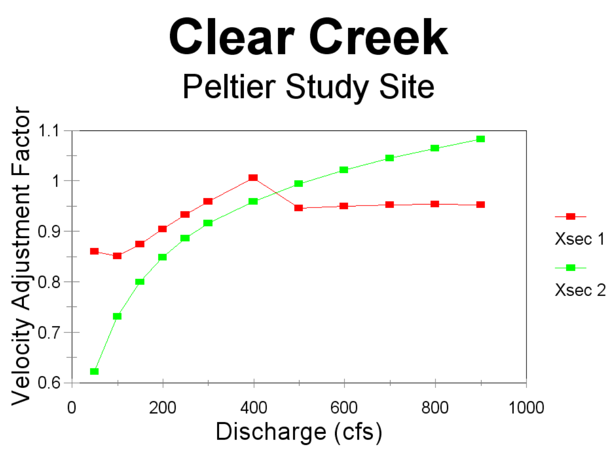
Spawn Area 4

	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



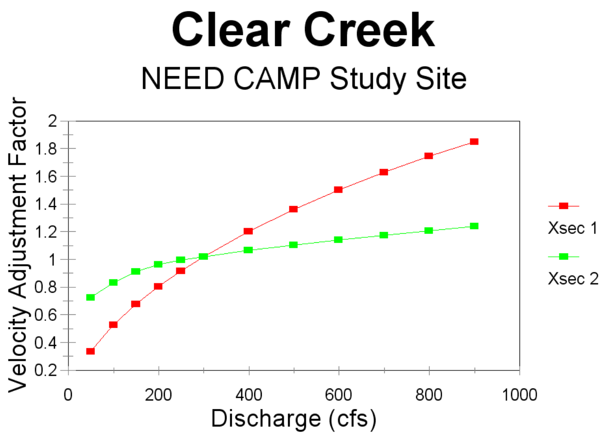
Peltier

	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



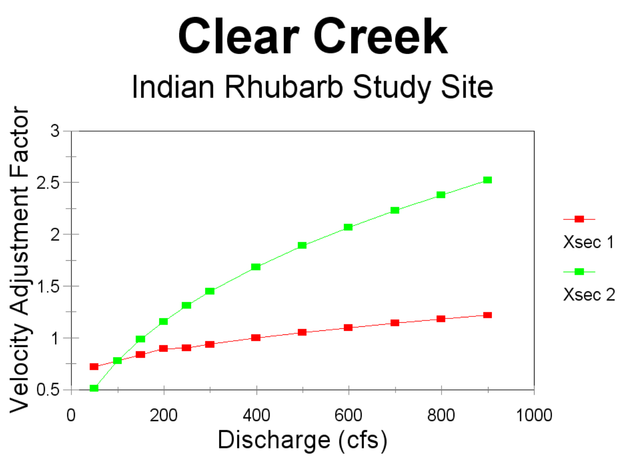
NEED Camp

	Velocity Adjustment Factors	
Discharge	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



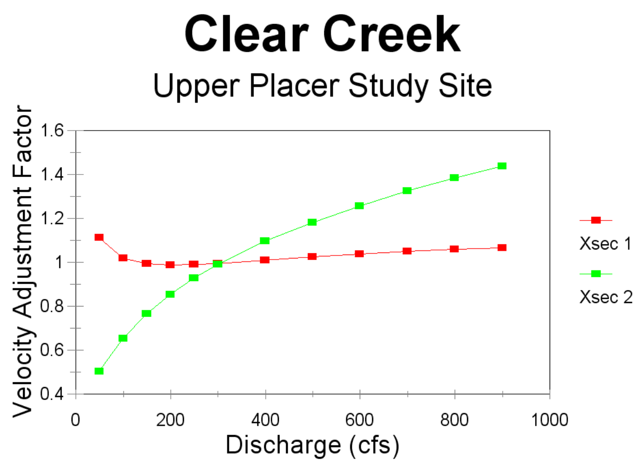
Indian Rhubarb

	Velocity Adjustment Factors	
Discharge	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



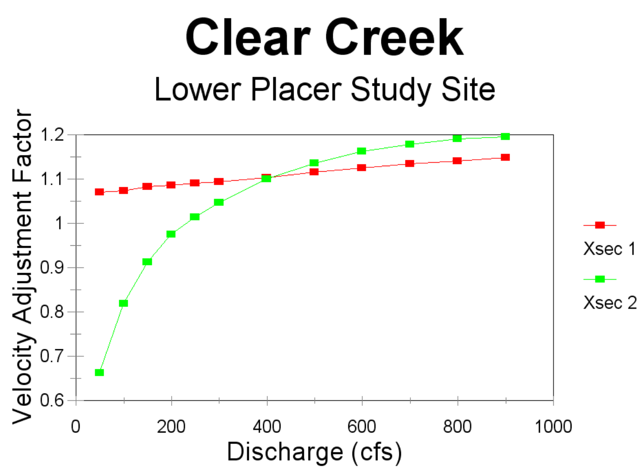
Upper Placer

	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



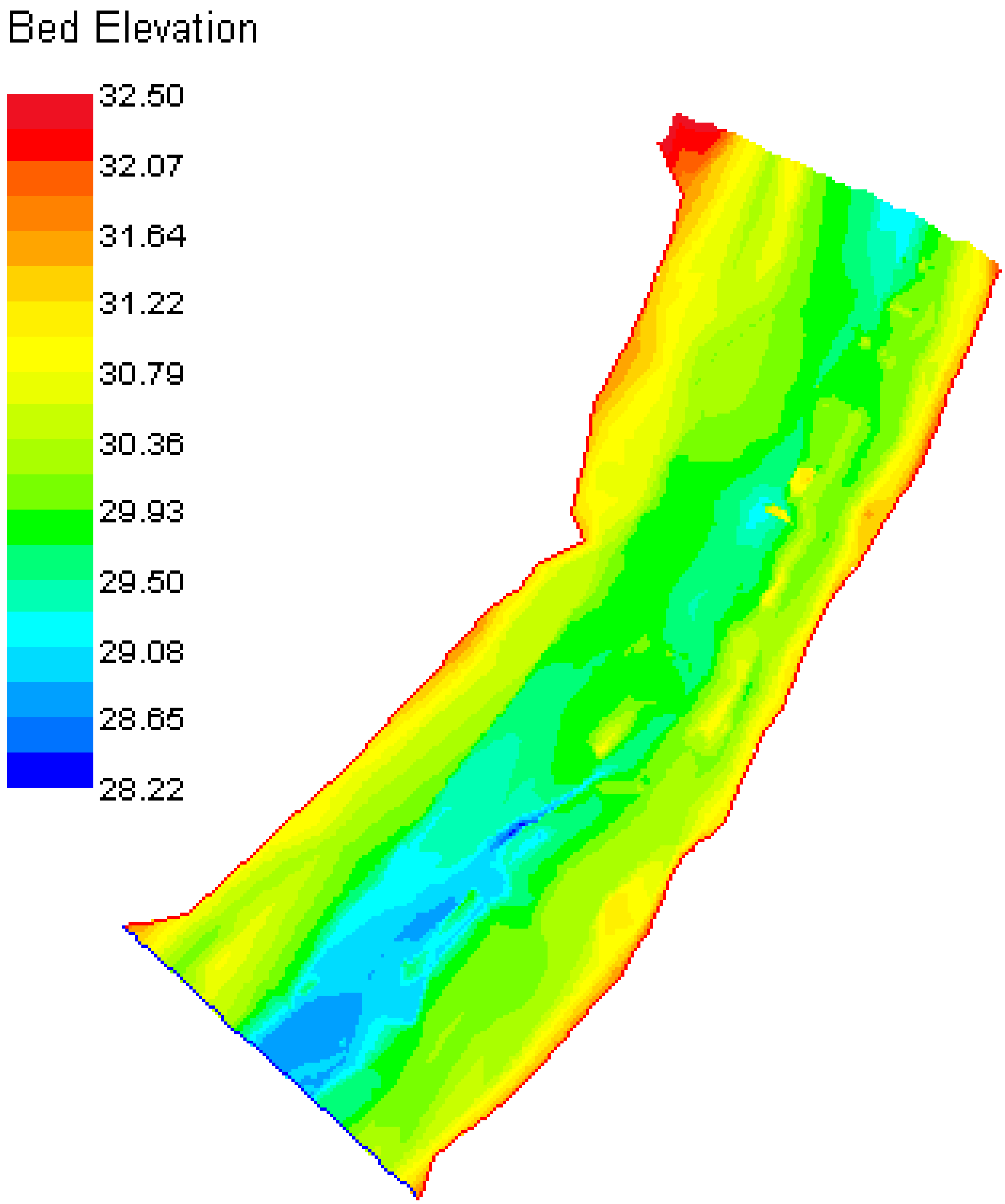
Lower Placer

	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



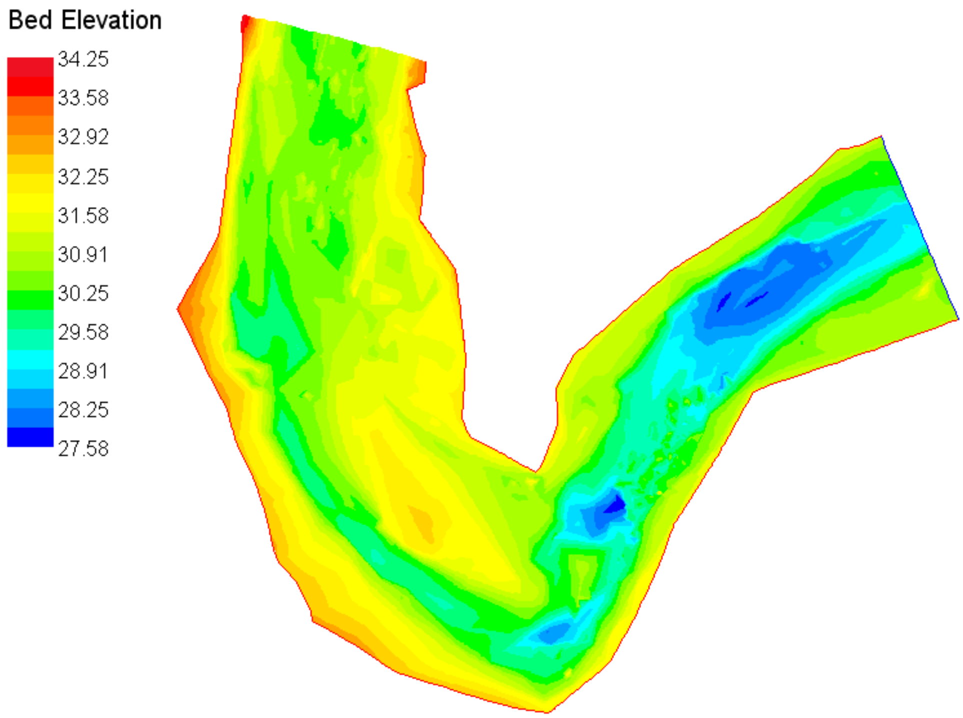
APPENDIX C
BED TOPOGRAPHY OF STUDY SITES

Spawn Area 4 Study Site



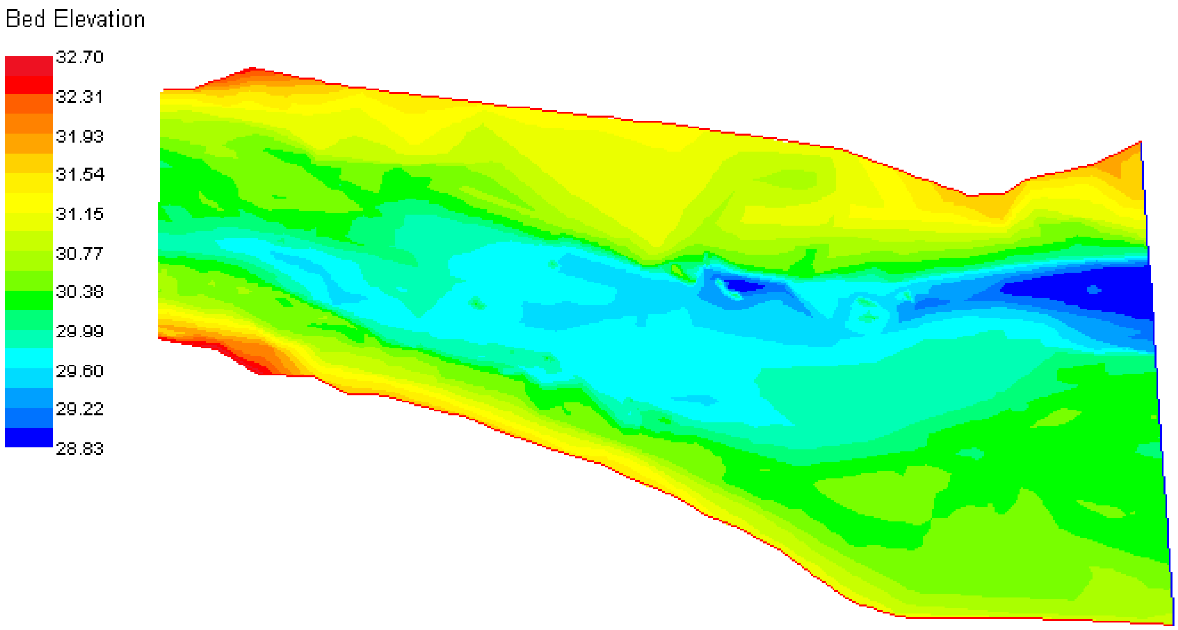
Units of Bed Elevation are meters.

Peltier Study Site



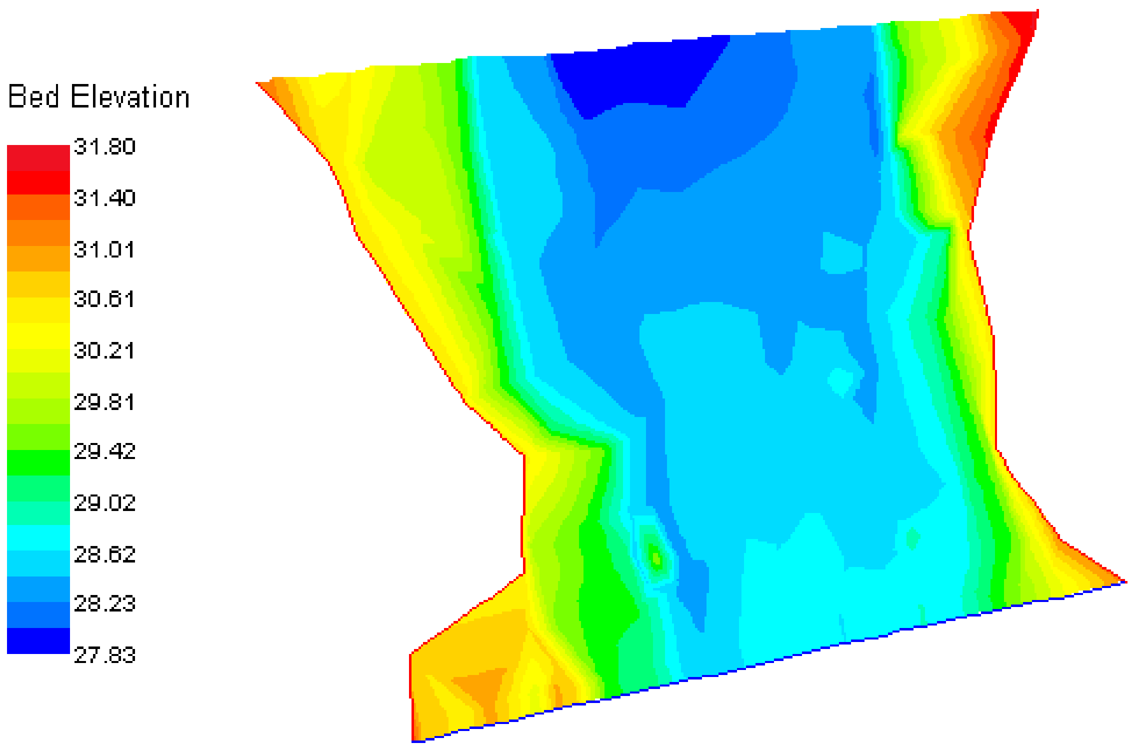
Units of Bed Elevation are meters.

NEED Camp Study Site



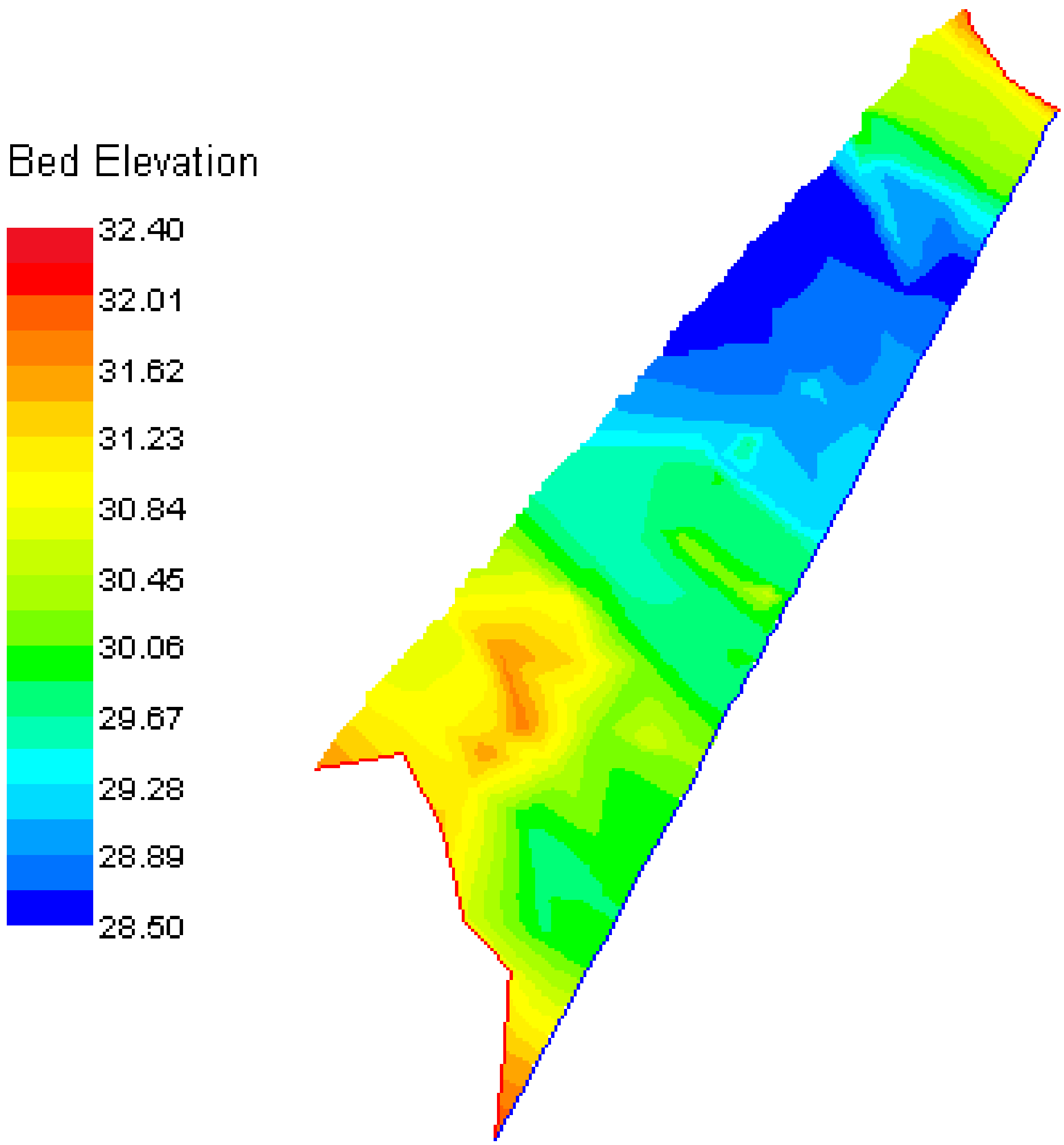
Units of Bed Elevation are meters.

Indian Rhubarb Study Site



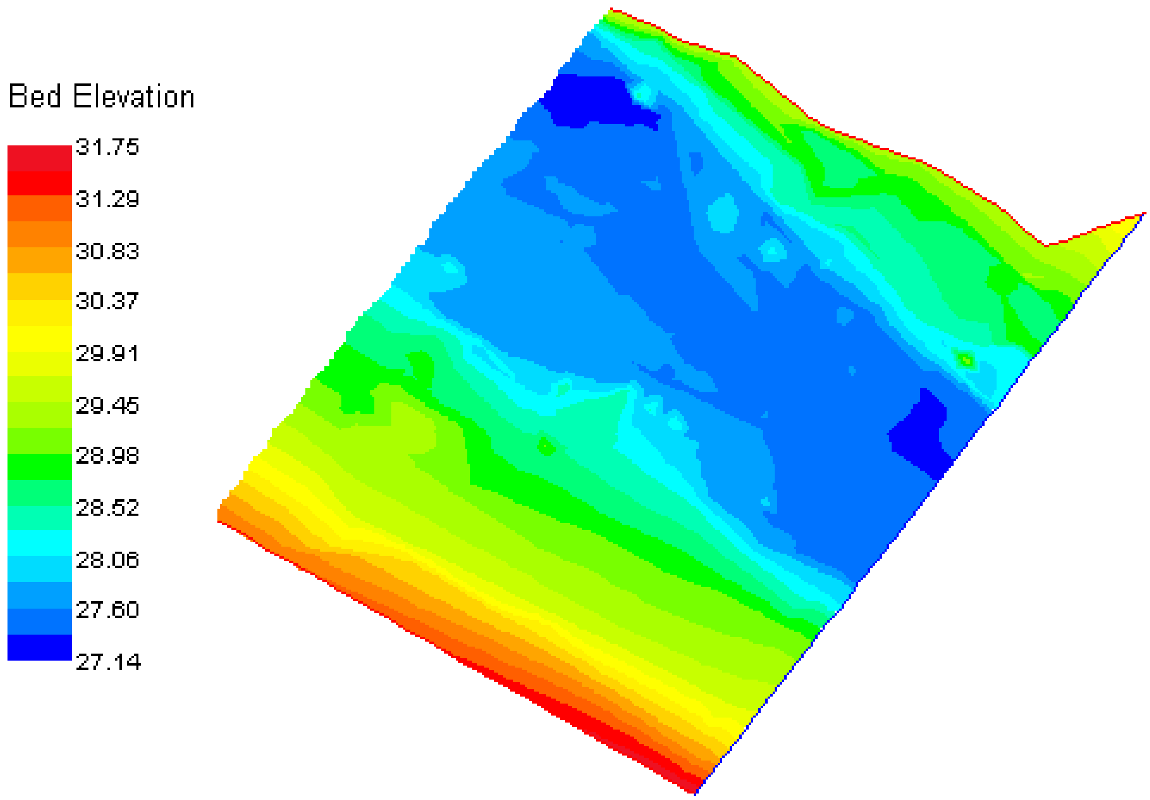
Units of Bed Elevation are meters.

Upper Placer Study Site



Units of Bed Elevation are meters.

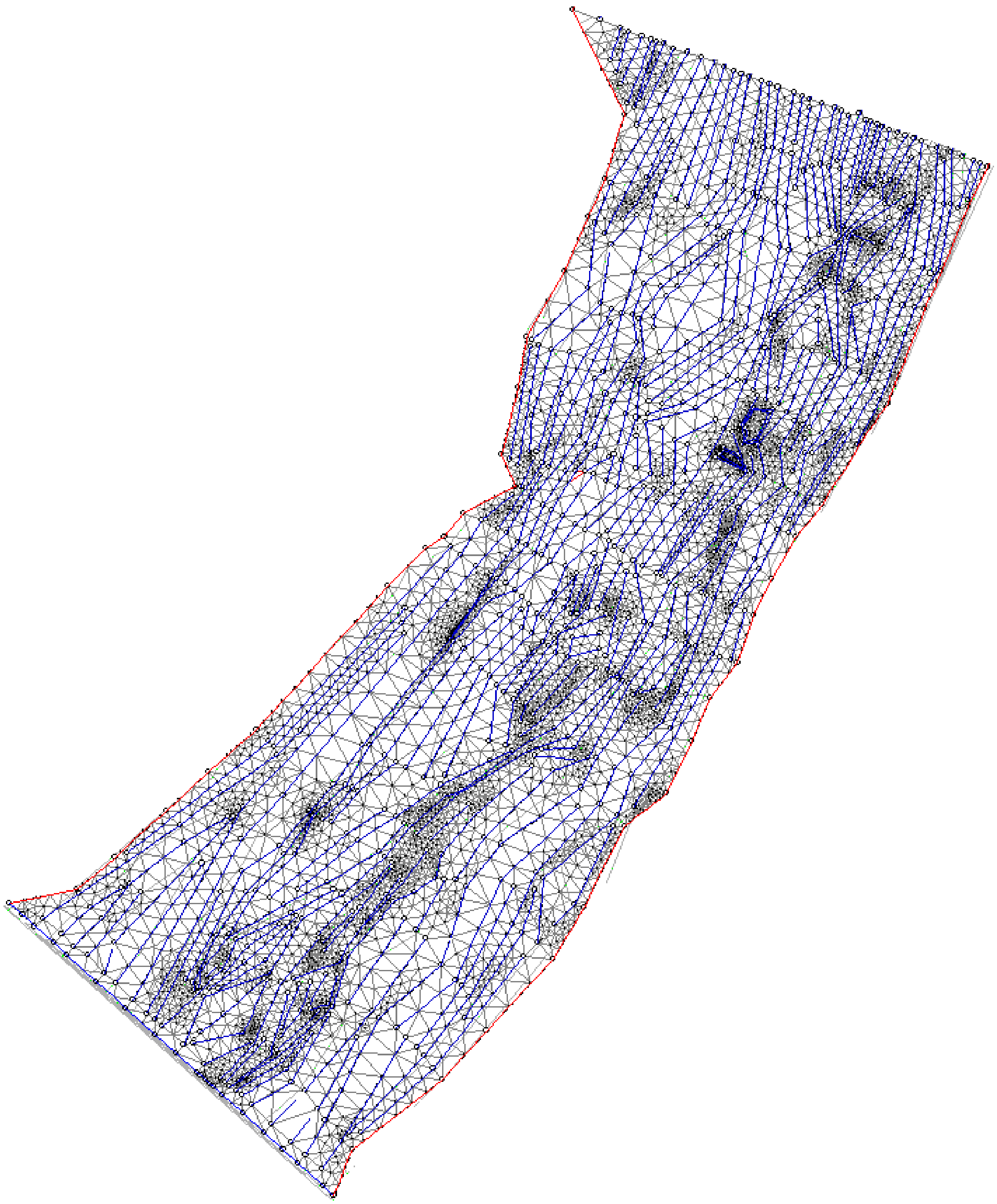
Lower Placer Study Site



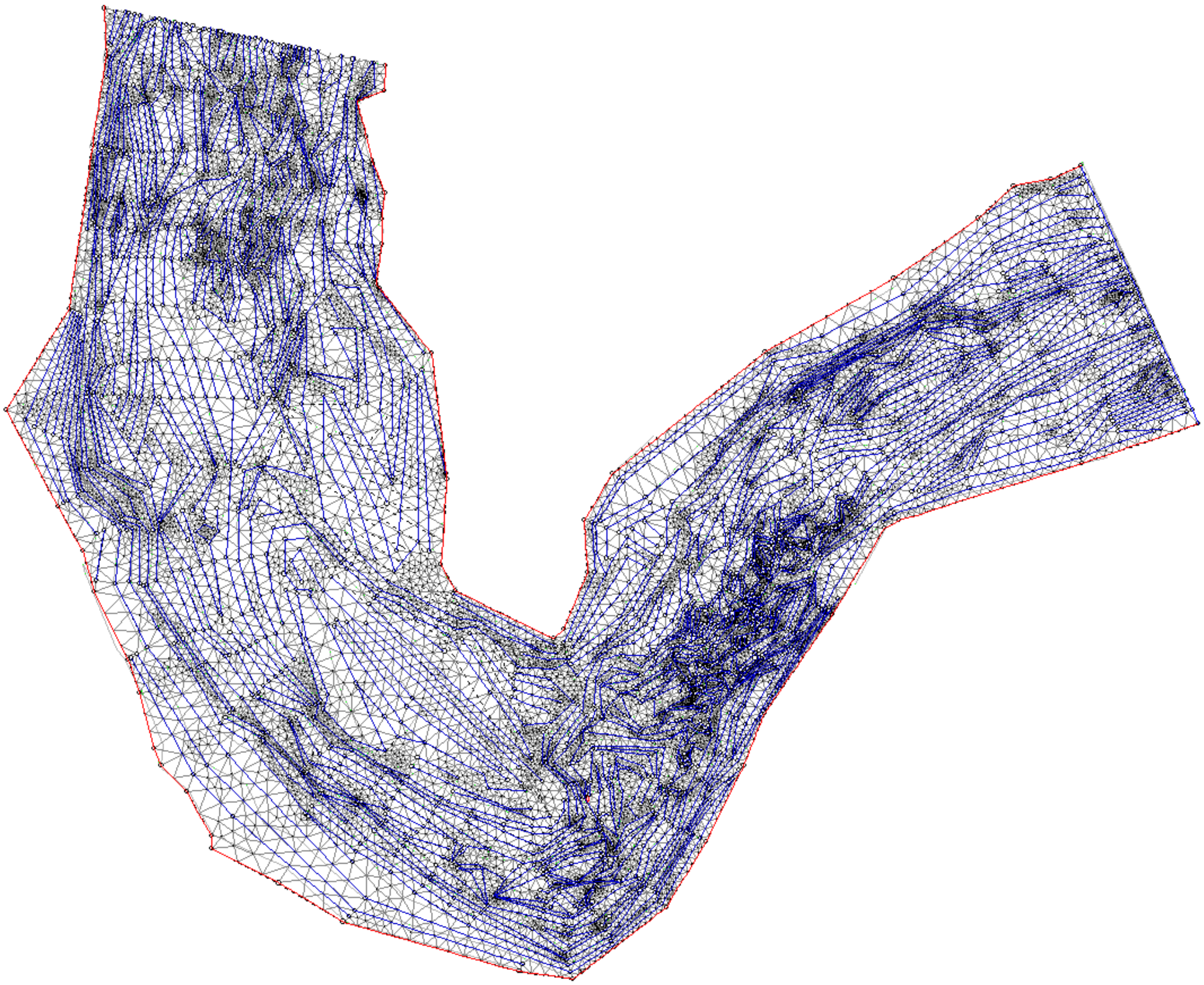
Units of Bed Elevation are meters.

APPENDIX D
COMPUTATIONAL MESHES OF STUDY SITES

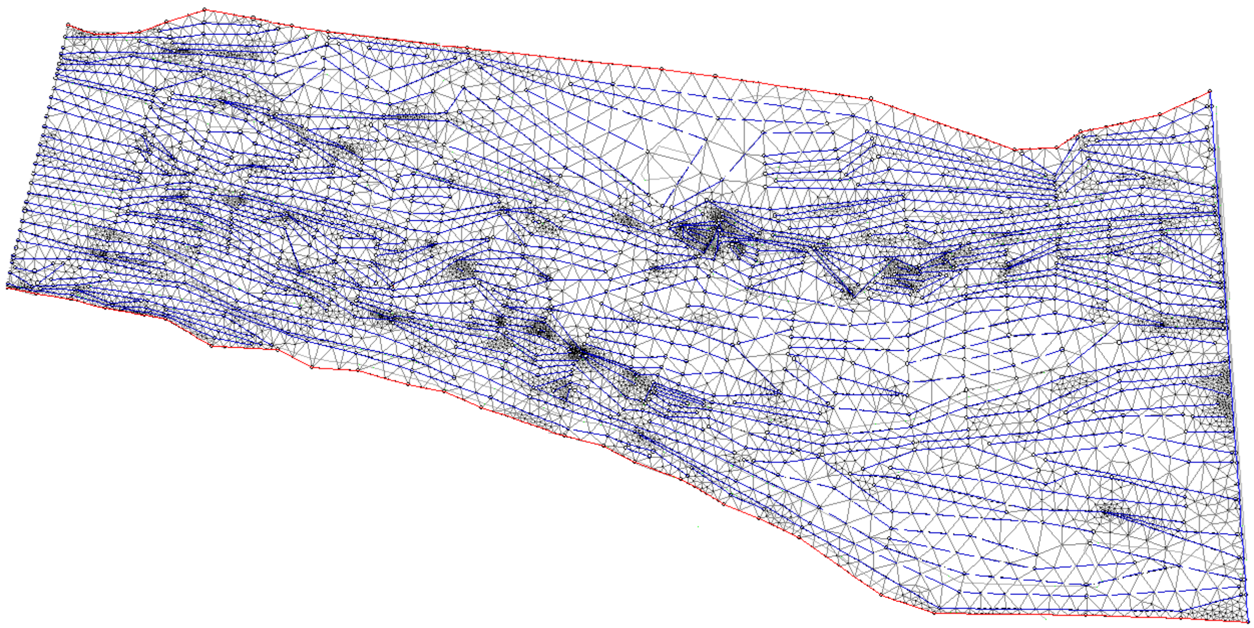
Spawn Area 4 Study Site



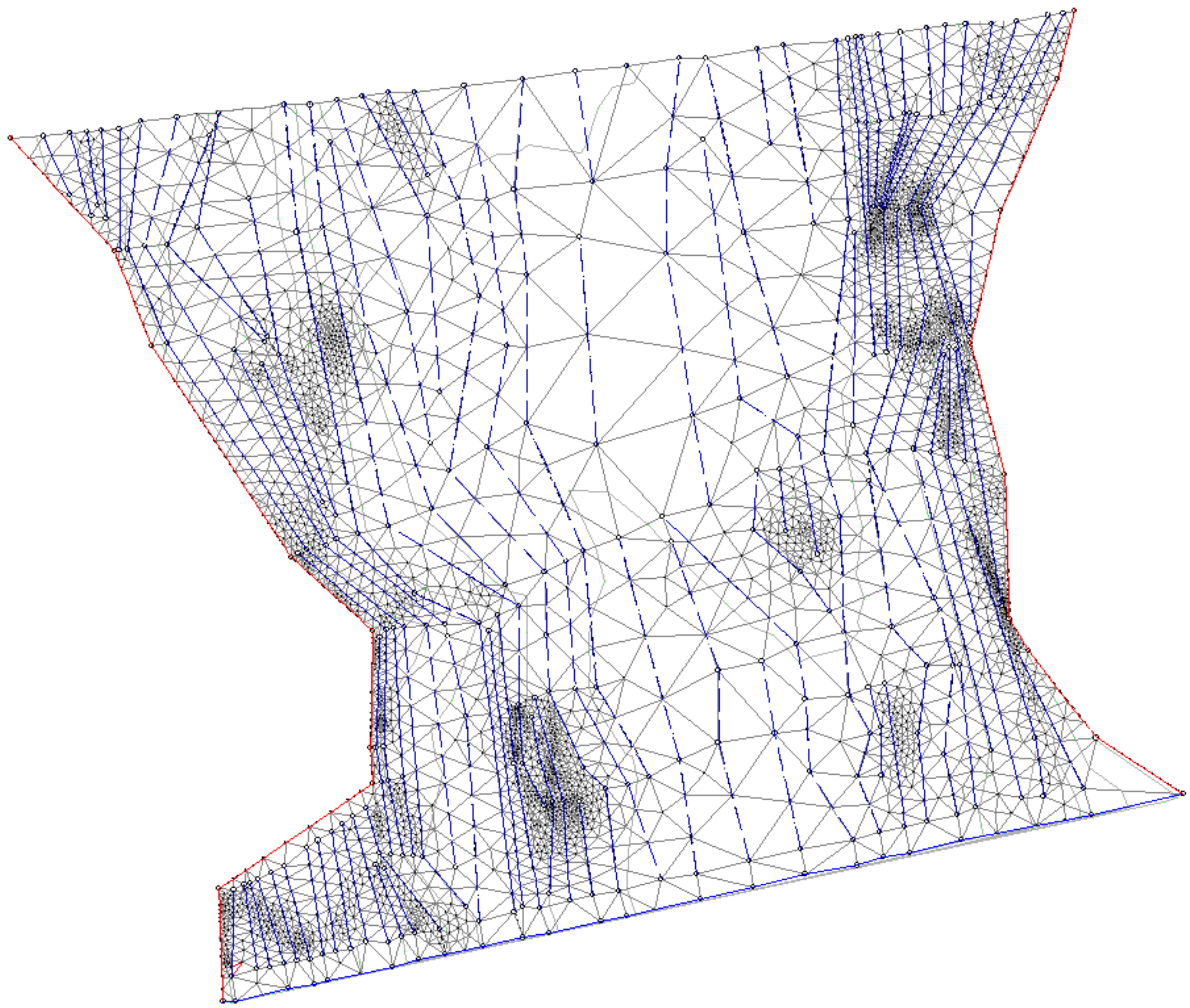
Peltier Study Site



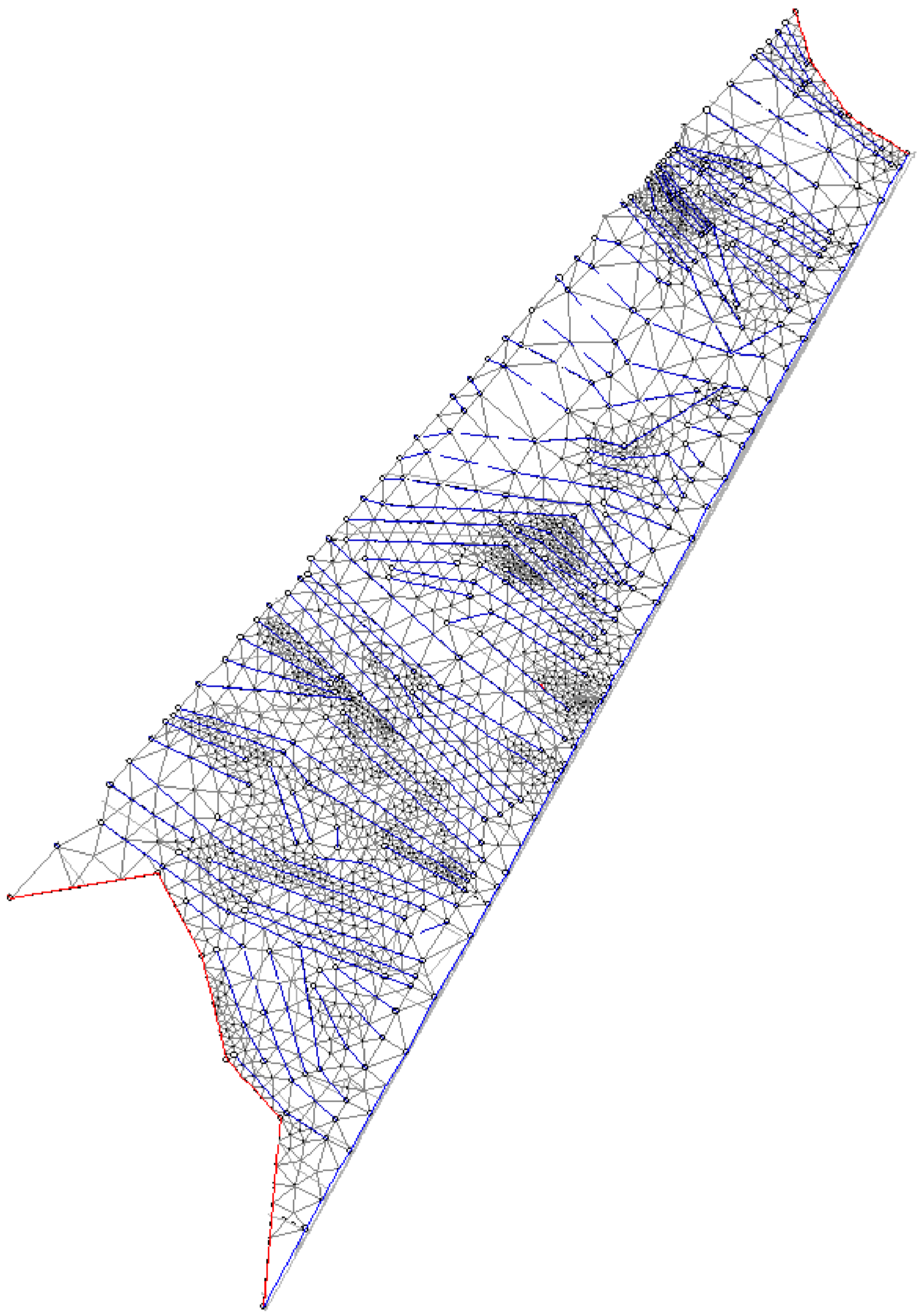
NEED Camp Study Site



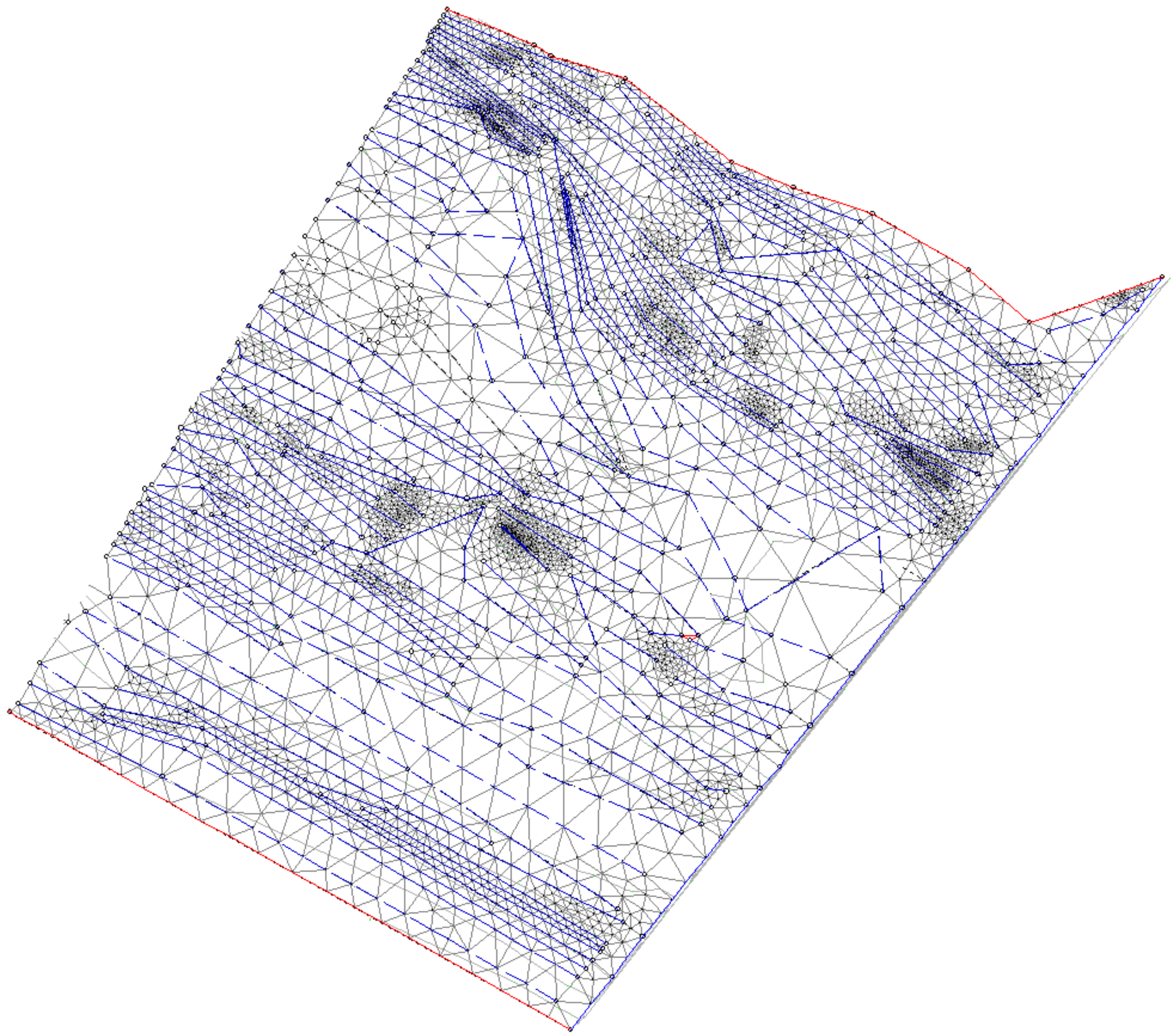
Indian Rhubarb Study Site



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

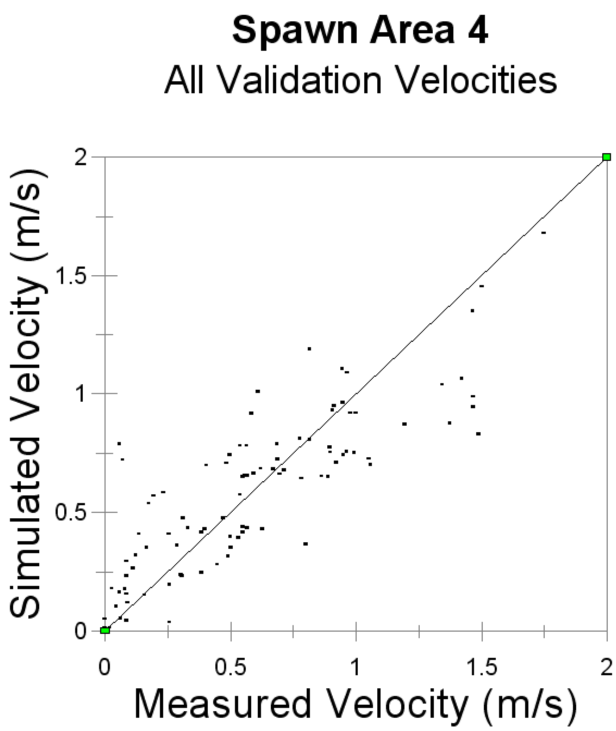
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

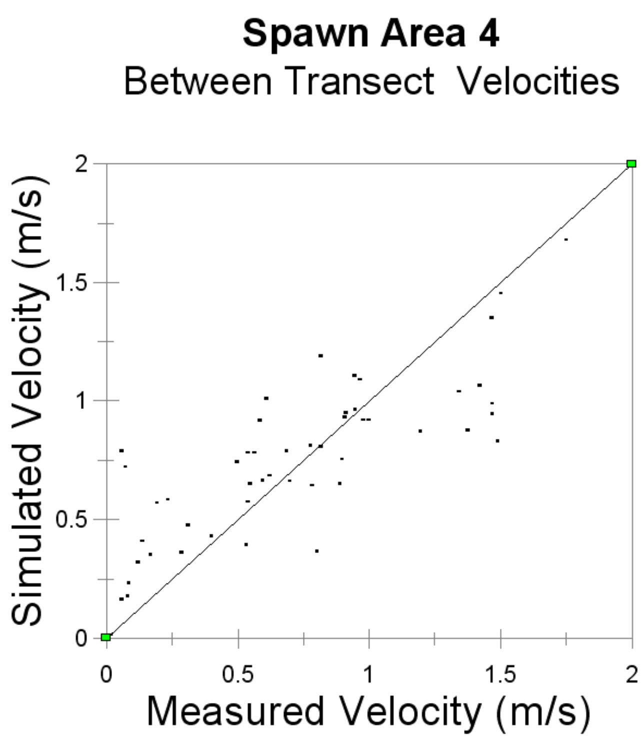
Measured Velocities greater than 3 ft/s

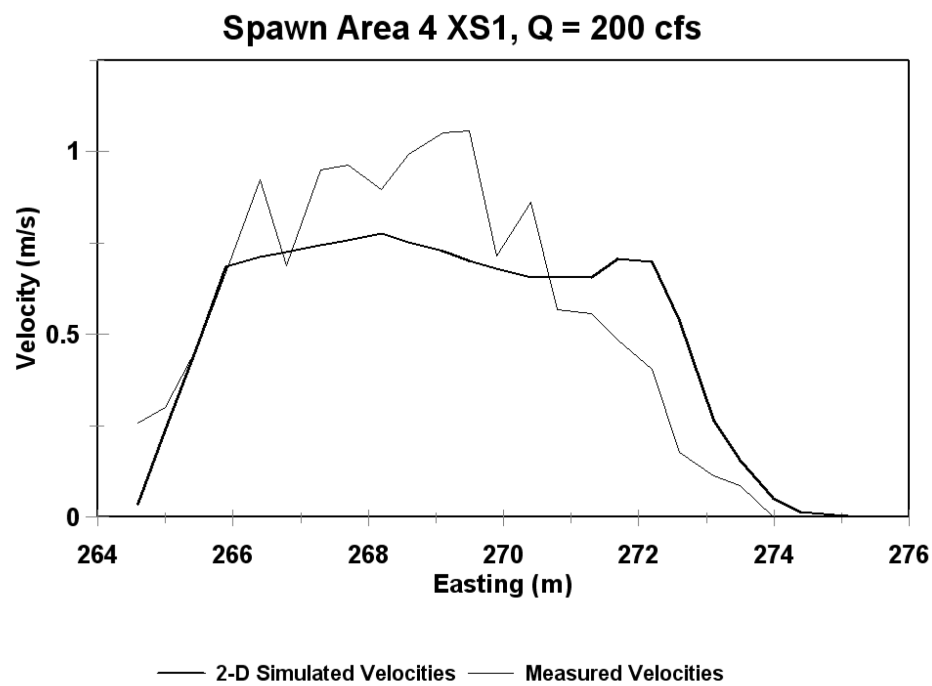
Percent Difference (measured vs. pred. velocities)

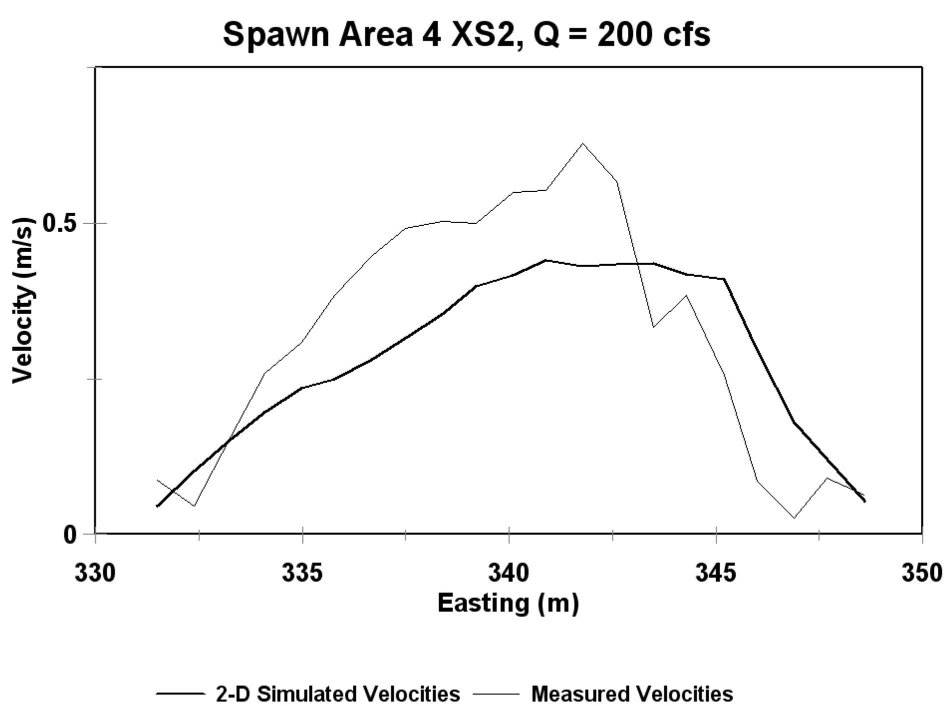
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Spawn Area 4	21	21%	12%	44%
Peltier	14	43%	26%	92%
NEED Camp	15	22%	12%	42%
Indian Rhubarb	12	20%	9%	35%
Upper Placer	20	36%	28%	100%
Lower Placer	47	19%	16%	67%

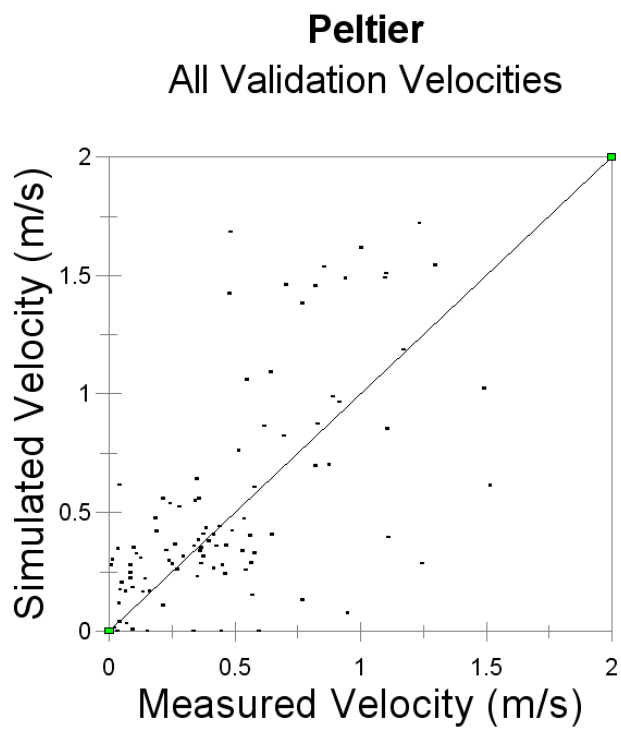
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

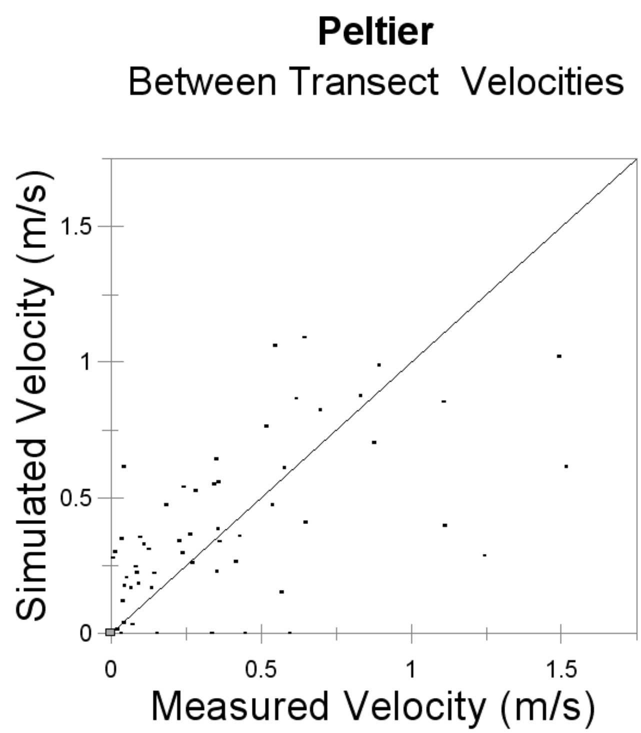

Spawn Area 4
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0
0.5
1
1.5
2

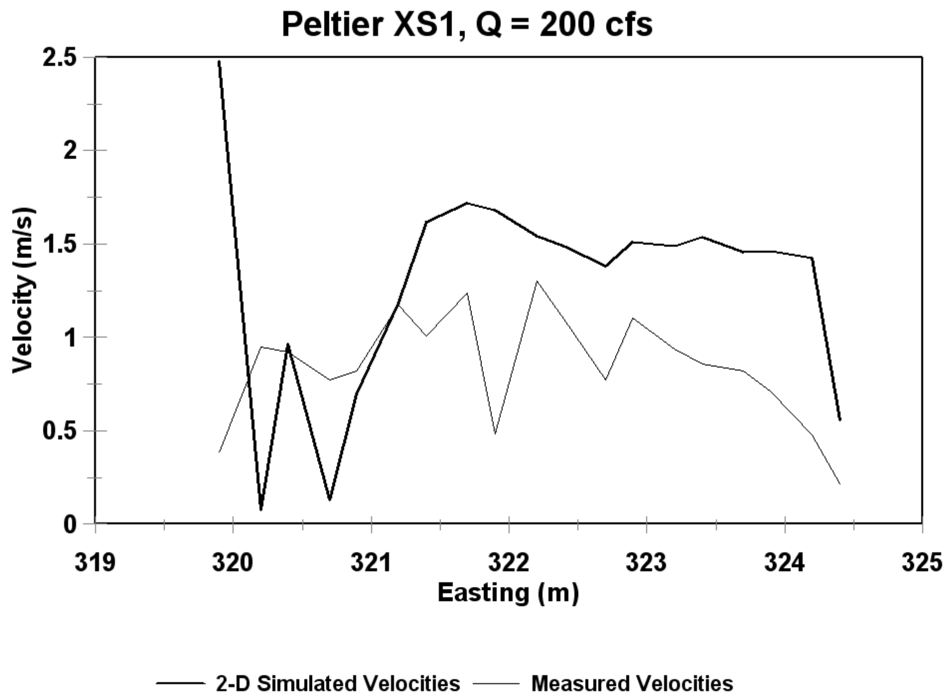

Spawn Area 4
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0
0.5
1
1.5
2

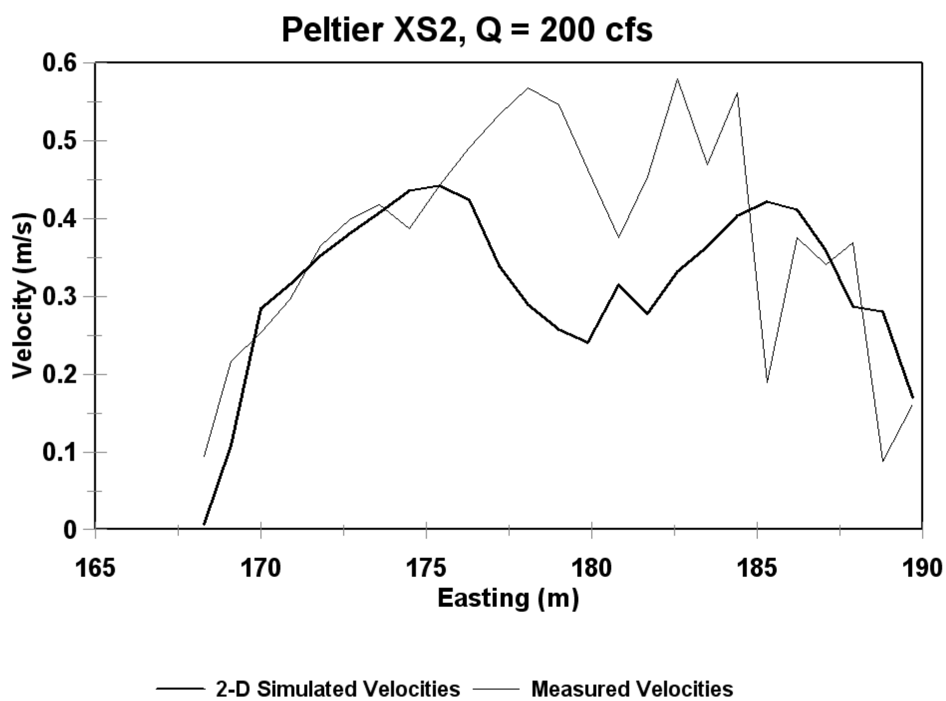

Spawn Area 4 XS1, Q = 200 cfs
Velocity (m/s)
1
0.5
0
264
266
268
270
272
274
276
Easting (m)
2-D Simulated Velocities
Measured Velocities


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

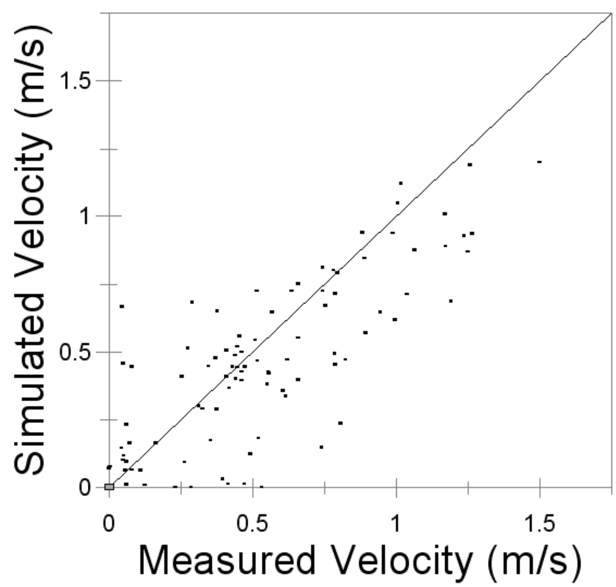

Peltier
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0
0.5
1
1.5
2


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

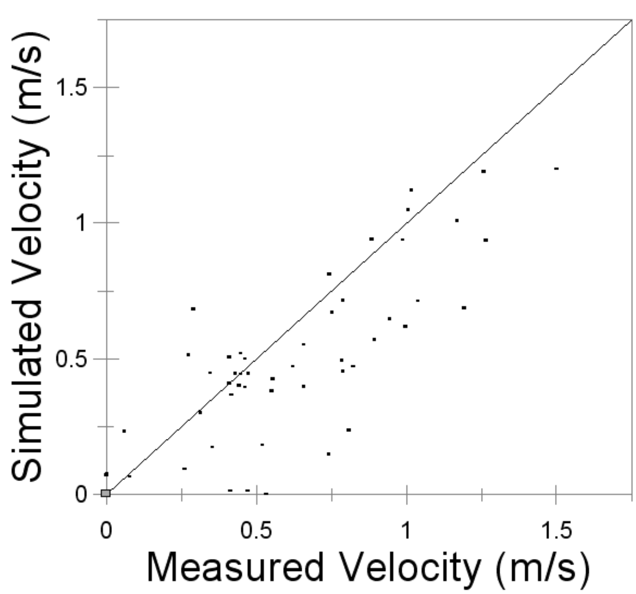

Peltier XS1, Q = 200 cfs
Velocity (m/s)
2.5
2
1.5
1
0.5
0
319
320
321
322
323
324
325
Easting (m)
2-D Simulated Velocities
Measured Velocities

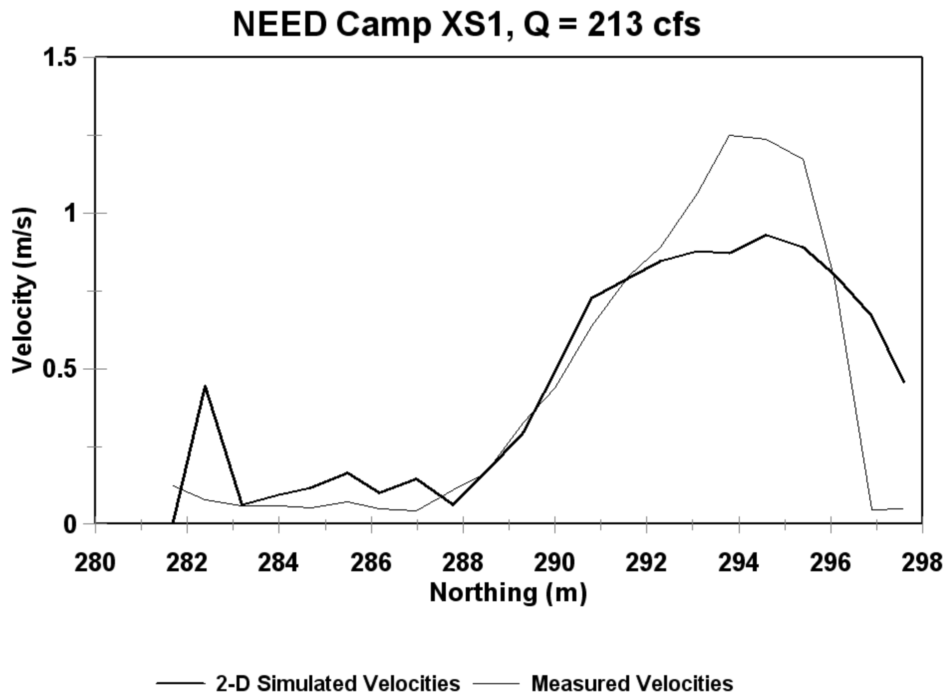

Peltier XS2, Q = 200 cfs
Velocity (m/s)
0.6
0.5
0.4
0.3
0.2
0.1
0
165
170
175
180
185
190
Easting (m)
2-D Simulated Velocities
Measured Velocities

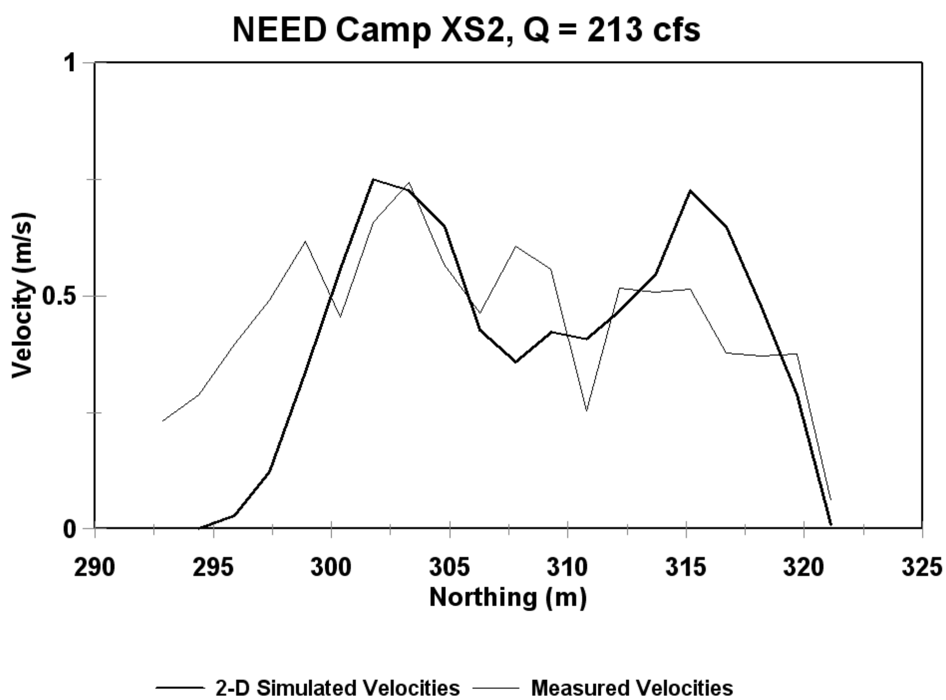
NEED Camp
All Validation Velocities

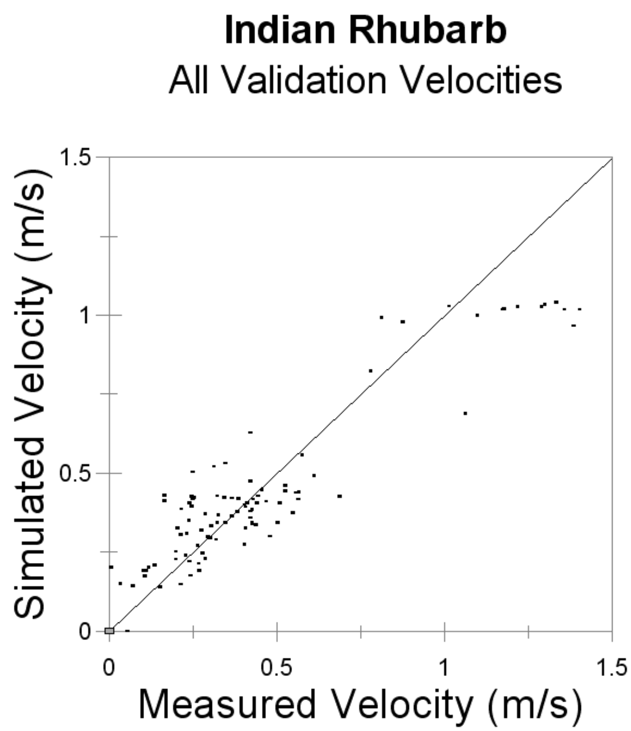


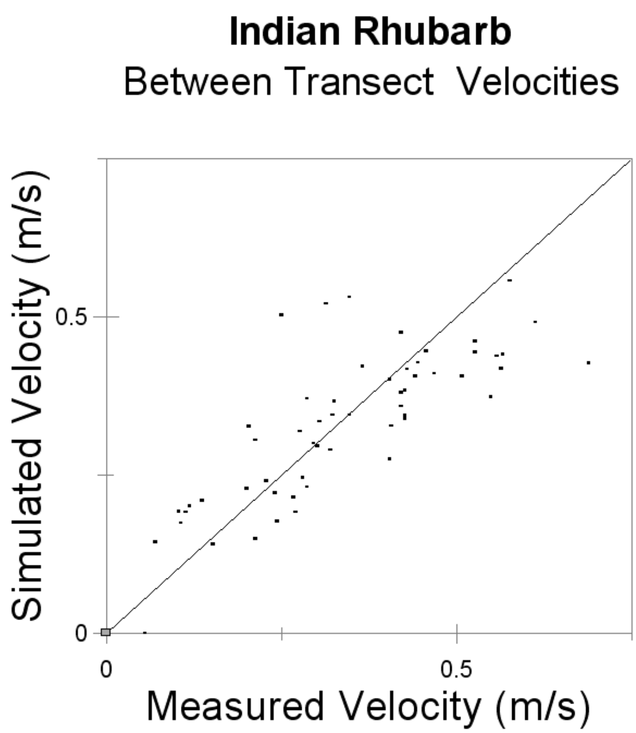
NEED Camp
Between Transect Velocities

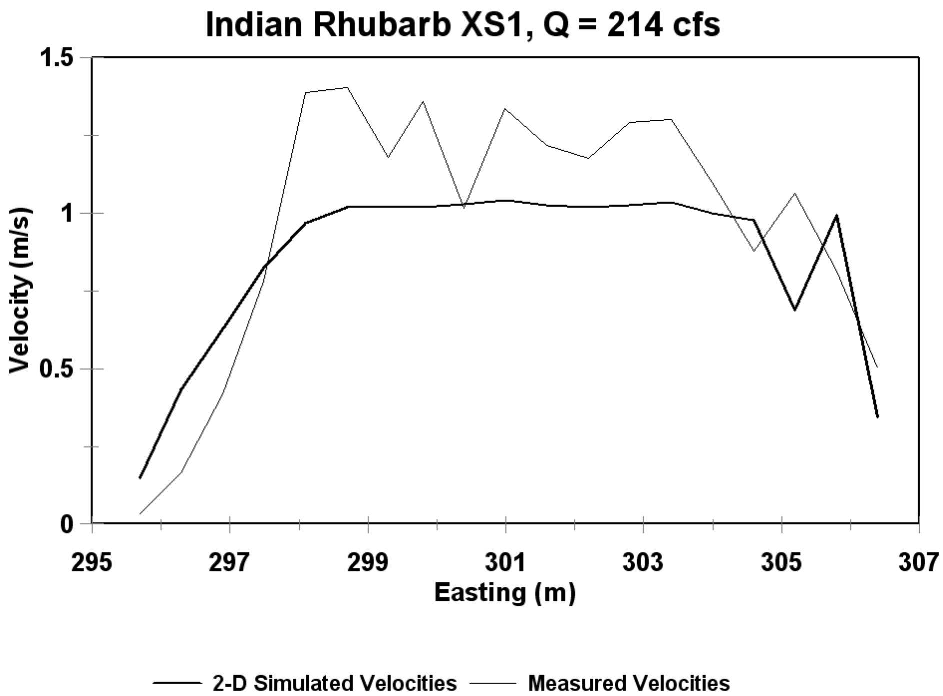


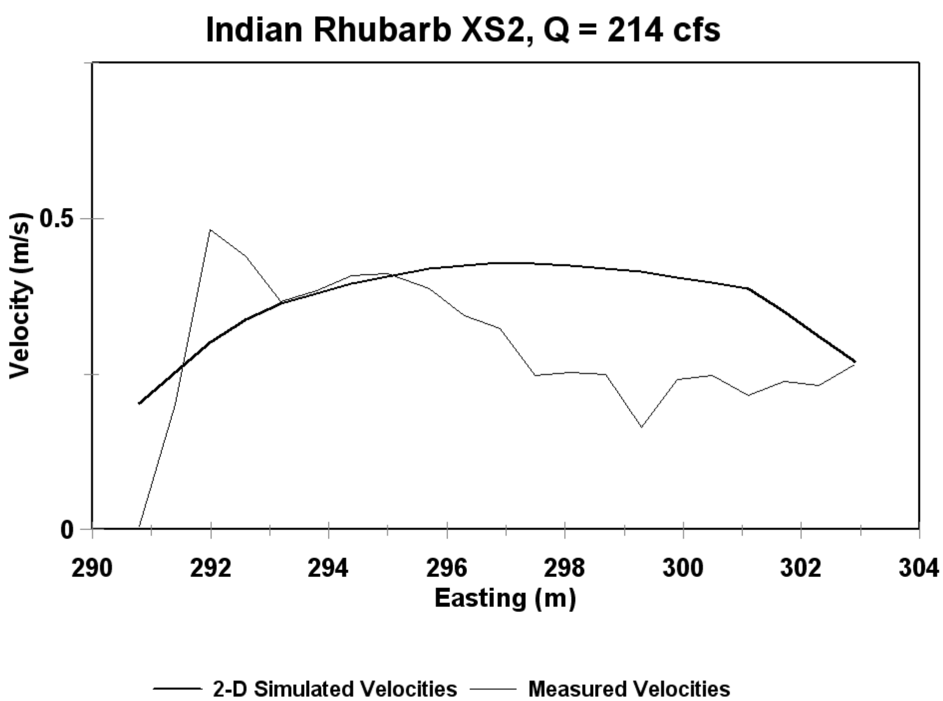

NEED Camp XS1, Q = 213 cfs
1.5
1
0.5
0
Velocity (m/s)
280
282
284
286
288
290
292
294
296
298
Northing (m)
2-D Simulated Velocities
Measured Velocities


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

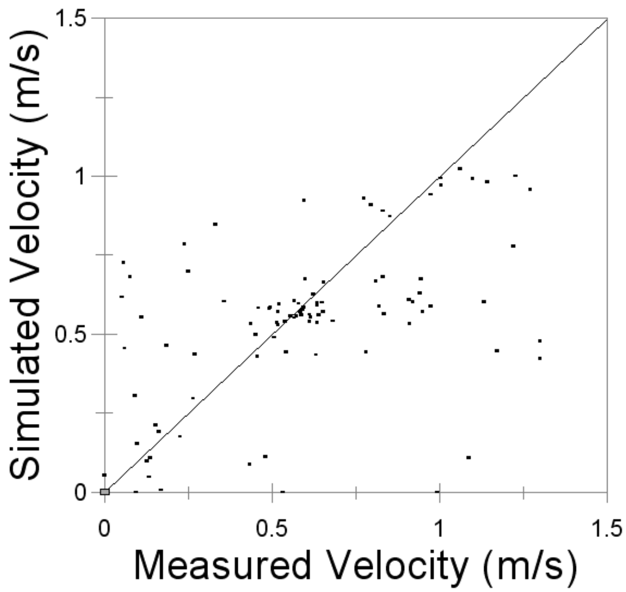

Indian Rhubarb
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
1.5
1
0.5
0
0
0.5
1
1.5


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

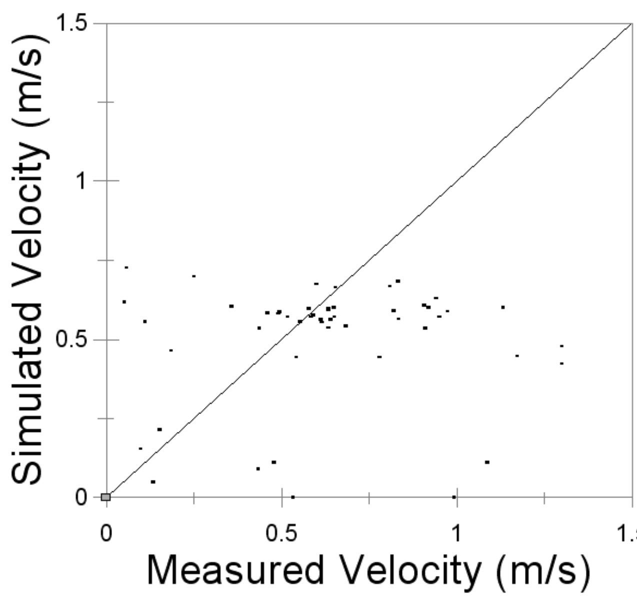

Indian Rhubarb XS1, Q = 214 cfs
Velocity (m/s)
1.5
1
0.5
0
295
297
299
301
303
305
307
Easting (m)
2-D Simulated Velocities
Measured Velocities

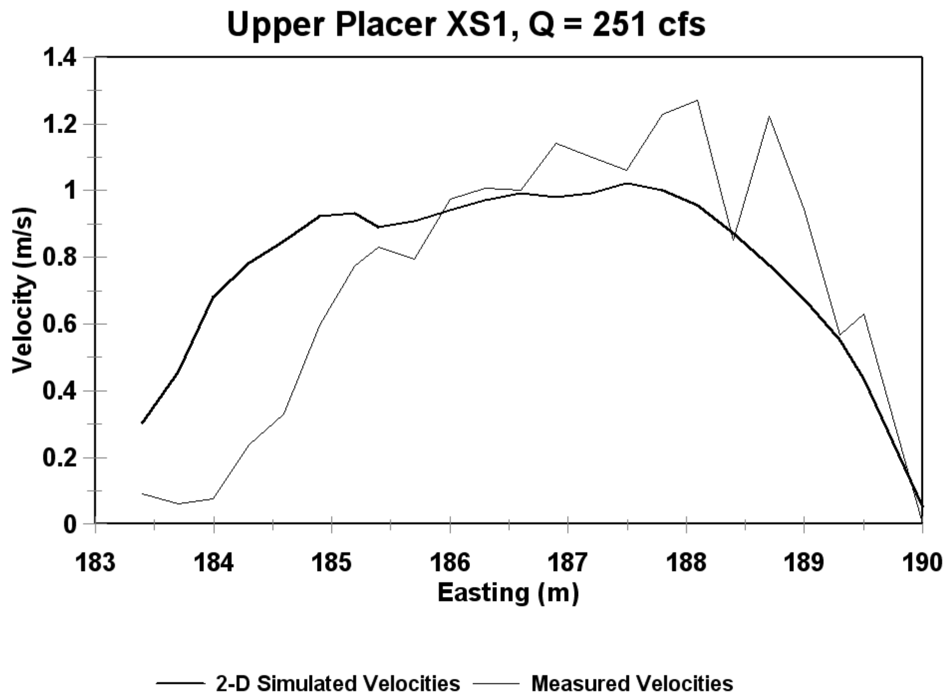

Indian Rhubarb XS2, Q = 214 cfs
Velocity (m/s)
0.5
0
290
292
294
296
298
300
302
304
Easting (m)
2-D Simulated Velocities
Measured Velocities

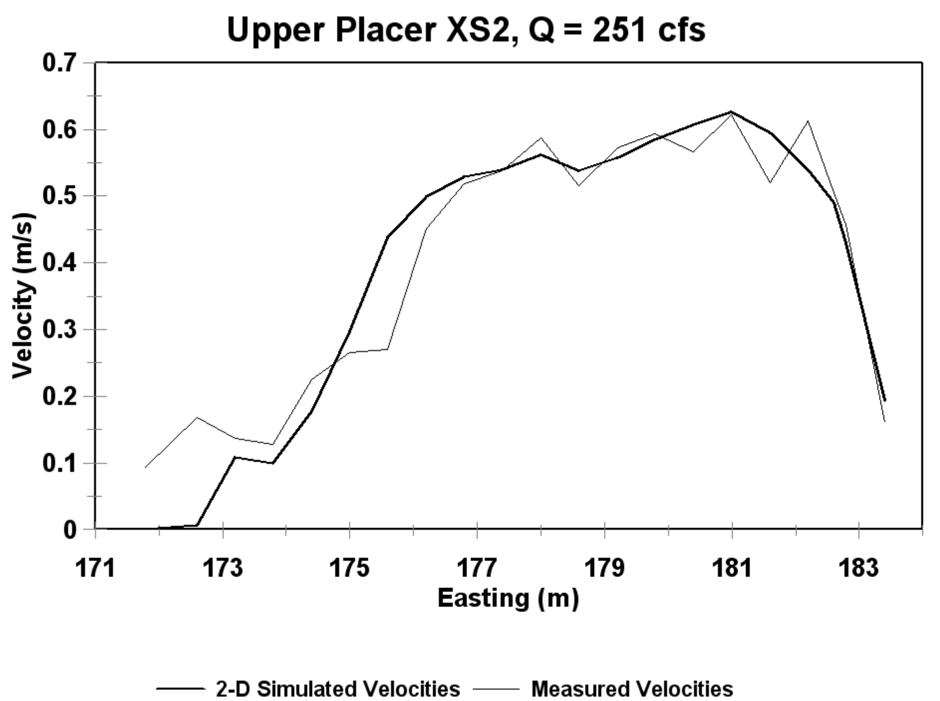
Upper Placer
All Validation Velocities

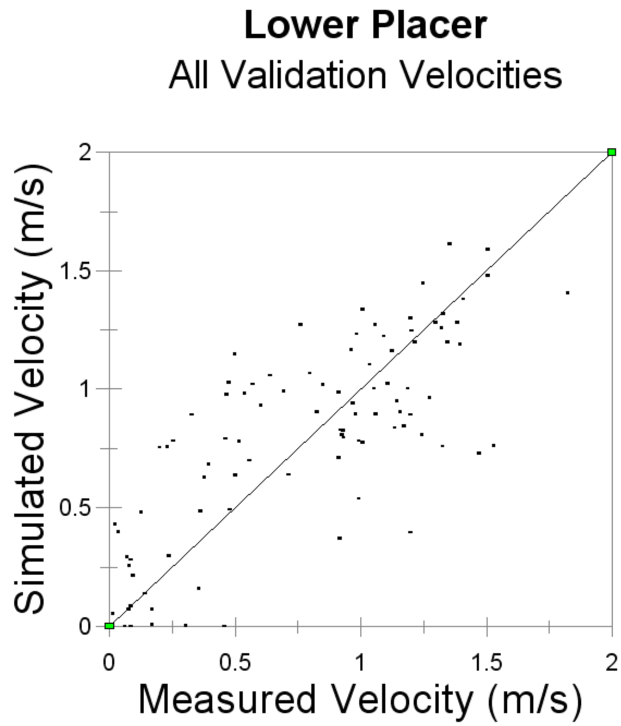


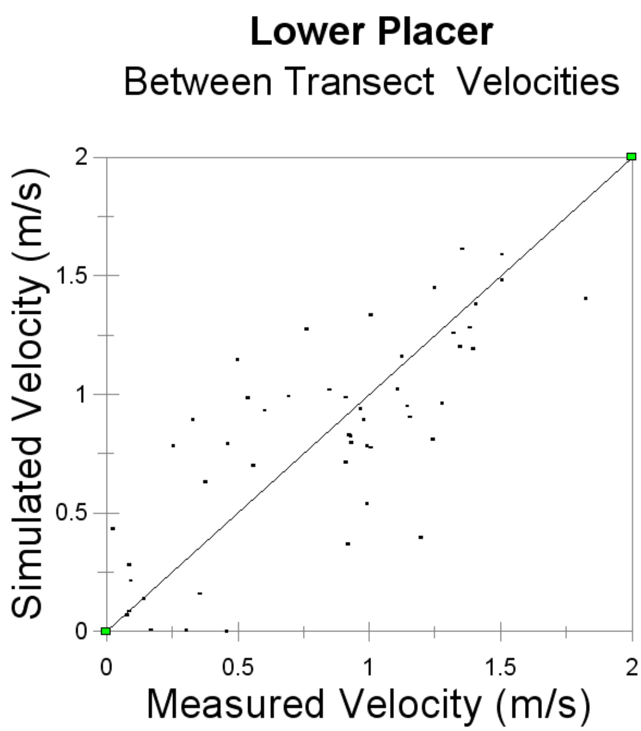
Upper Placer
Between Transect Velocities

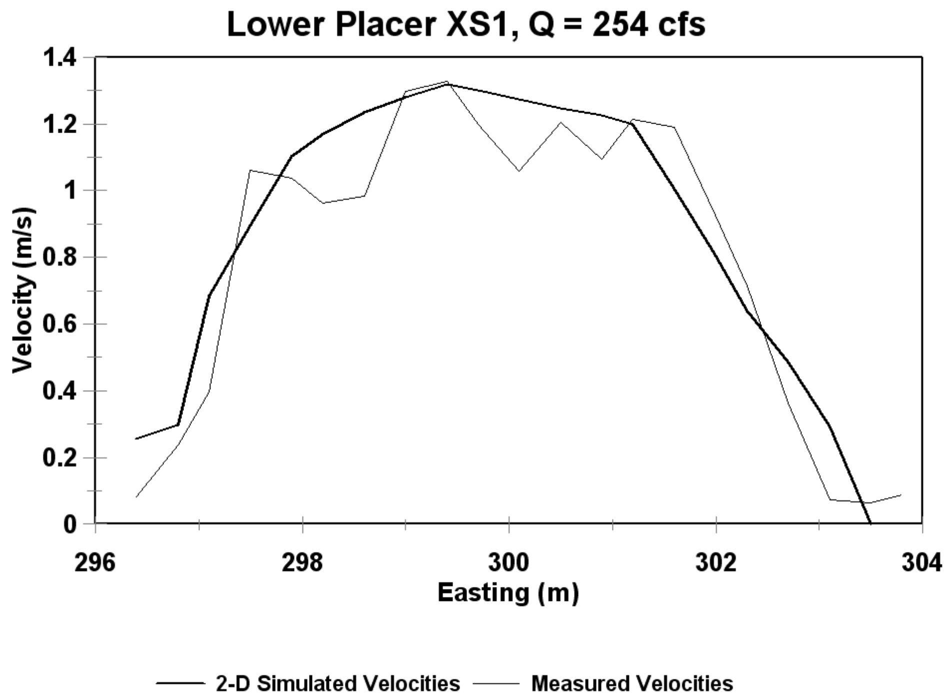


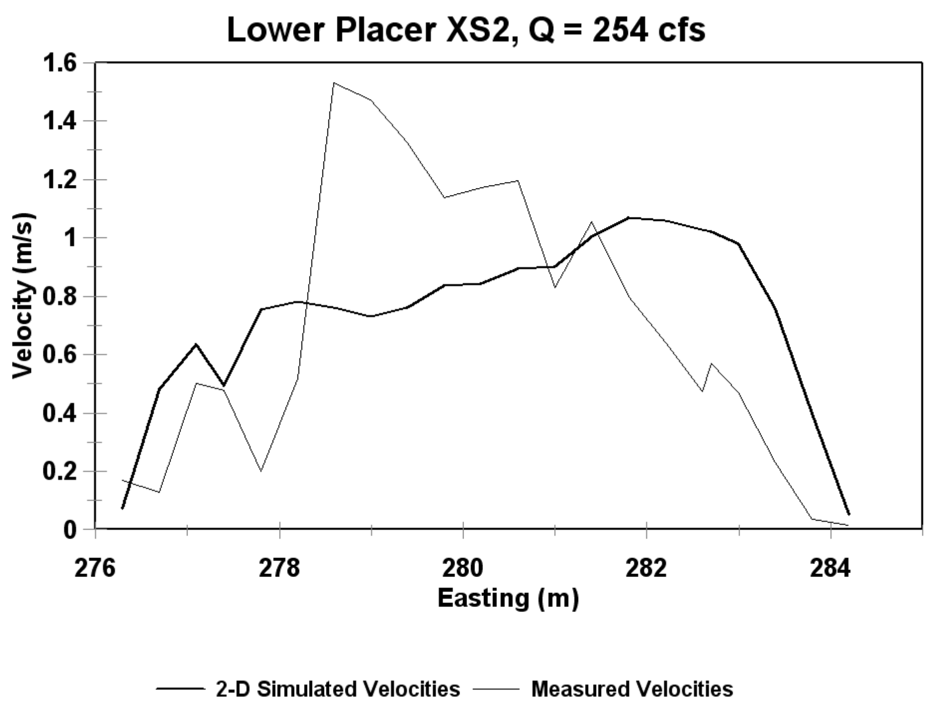

Upper Placer XS1, Q = 251 cfs
Velocity (m/s)
Easting (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
183
184
185
186
187
188
189
190
2-D Simulated Velocities
Measured Velocities


Upper Placer XS2, Q = 251 cfs
Velocity (m/s)
Easting (m)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
171
173
175
177
179
181
183
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)
Easting (m)
2-D Simulated Velocities
Measured Velocities


Lower Placer XS2, Q = 254 cfs
Velocity (m/s)
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	Water Velocity (ft/s)	SI Value	Substrate Composition	SI Value
0.0	0	0.00	0	0	0
0.7	0	0.69	0	0.1	0
0.8	0.08	0.70	0.06	1	0
0.9	0.11	0.80	0.08	1.2	0.19
1.0	0.15	0.90	0.10	1.3	0.64
1.1	0.18	1.00	0.13	2.3	0.82
1.2	0.22	1.10	0.17	2.4	1
1.4	0.28	1.20	0.21	3.4	0.56
1.7	0.34	1.30	0.25	3.5	0.12
1.8	0.35	1.40	0.30	4.6	0.01
1.9	0.36	1.50	0.36	6.8	0
2.2	0.36	1.60	0.41	10	0
2.3	0.35	1.70	0.48	100	0
2.4	0.35	1.80	0.54		
2.5	0.34	1.90	0.60		
2.6	0.33	2.00	0.66		
2.7	0.33	2.10	0.72		
2.8	0.32	2.20	0.77		
2.9	0.32	2.30	0.82		
3.0	0.31	2.40	0.87		
3.4	0.31	2.50	0.91		
3.5	0.32	2.60	0.94		
3.6	0.32	2.70	0.97		
3.8	0.34	2.80	0.98		
4.2	0.42	2.90	1		
4.5	0.51	3.00	1		
4.6	0.55	3.10	1		
4.7	0.58	3.20	0.99		
4.8	0.62	3.30	0.97		
4.9	0.67	3.40	0.95		
5.4	0.87	3.50	0.92		
5.6	0.93	3.60	0.88		
5.9	0.99	3.70	0.83		
6.0	1	3.80	0.79		
6.2	1	3.90	0.73		
6.3	0.99	4.00	0.67		
6.4	0.97	4.10	0.61		
6.5	0.94	4.20	0.55		
6.6	0.90	4.30	0.49		
6.7	0.84	4.40	0.43		
6.8	0.76	4.41	0		
6.9	0.67	100	0		
7.0	0.56				
7.1	0				
100	0				

STEELHEAD/RAINBOW TROUT SPAWNING HSC

Water Depth (ft)	SI Value	Water Velocity (ft/s)	SI Value	Substrate Composition	SI Value
0.00	0	0.00	0	0	0
0.3	0	0.60	0	0.1	0
0.4	0.16	0.61	0.08	1	0.38
0.5	0.26	0.70	0.14	1.2	1.00
0.6	0.38	0.80	0.25	1.3	0.44
0.7	0.51	0.90	0.38	2.3	0.26
0.8	0.64	1.00	0.53	2.4	0.07
0.9	0.75	1.10	0.66	3.4	0.06
1.0	0.85	1.20	0.78	3.5	0.04
1.1	0.92	1.30	0.87	4.6	0.01
1.2	0.96	1.40	0.94	6.8	0
1.3	0.99	1.50	0.98	10	0
1.4	1	1.60	1.00	100	0
1.5	1	1.70	1.00		
28.6	0	1.80	0.99		
100	0	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		

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

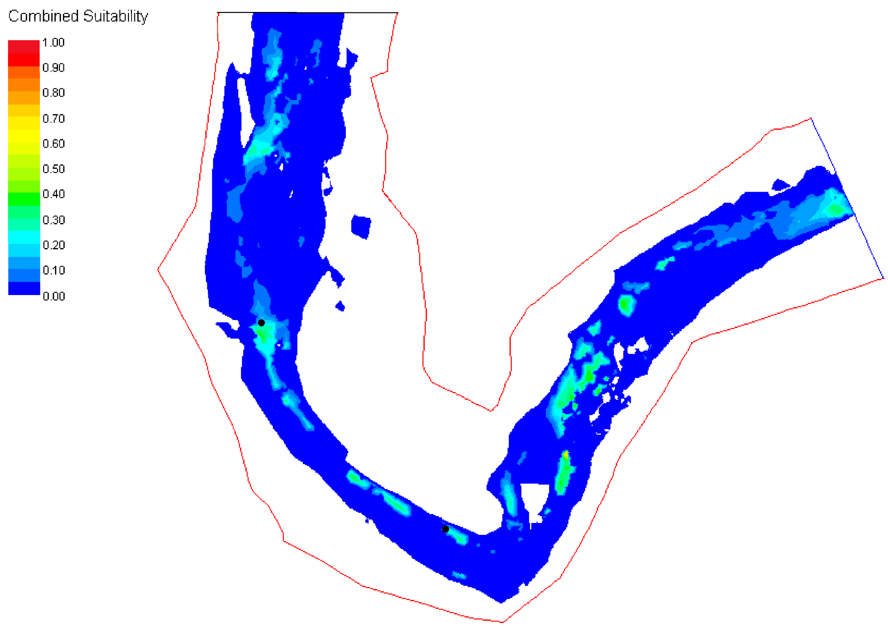
Flow	Spawn Area 4	Peltier	NEED Camp	Total
50	218	742	1310	12276
75	313	1320	1870	18951
100	392	1850	2395	25084
125	491	2241	2845	30175
150	640	2601	3151	34579
175	771	2955	3412	38615
200	849	3178	3548	40980
225	903	3376	3602	42634
250	941	3530	3635	43851
275	955	3655	3657	44725
300	971	3781	3639	45390
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

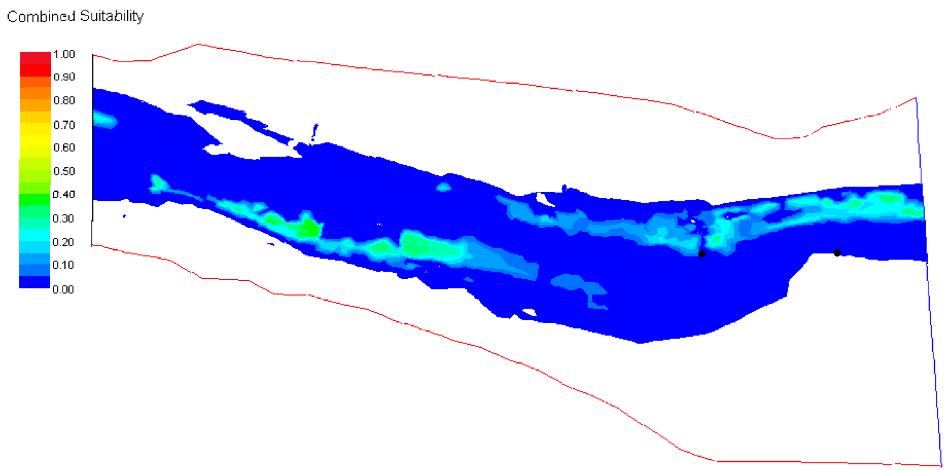
APPENDIX J
RIVER2D COMBINED SUITABILITY OF REDD LOCATIONS

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



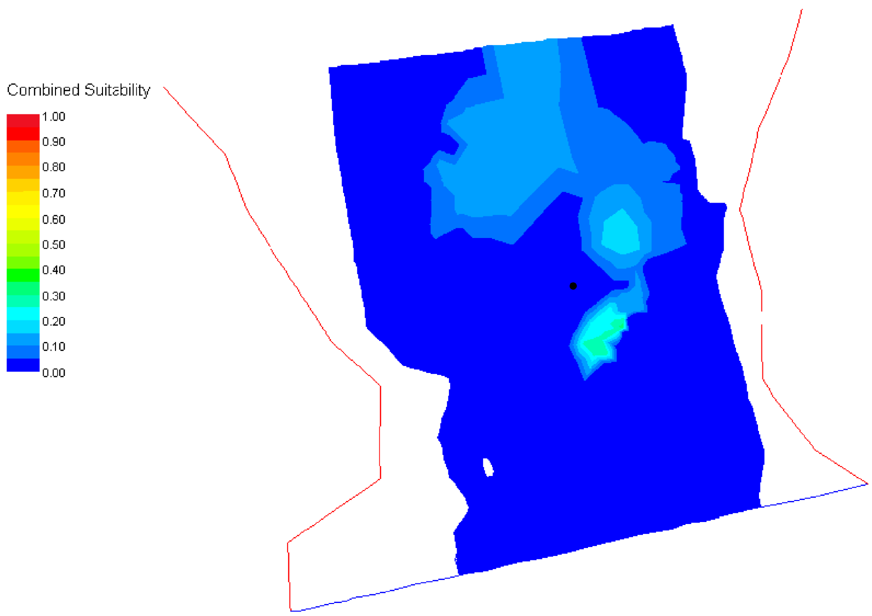
Redd locations: ●

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



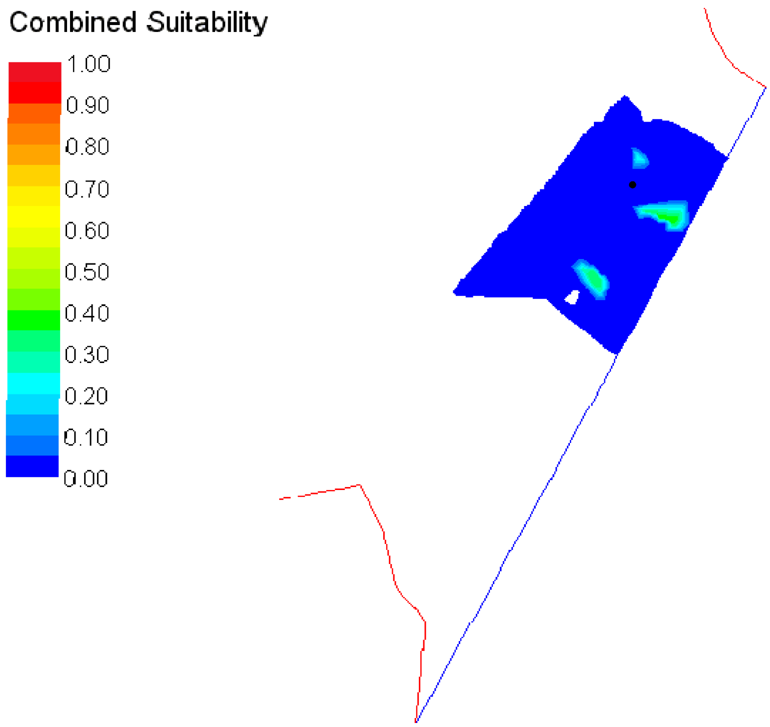
Redd locations: ●

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



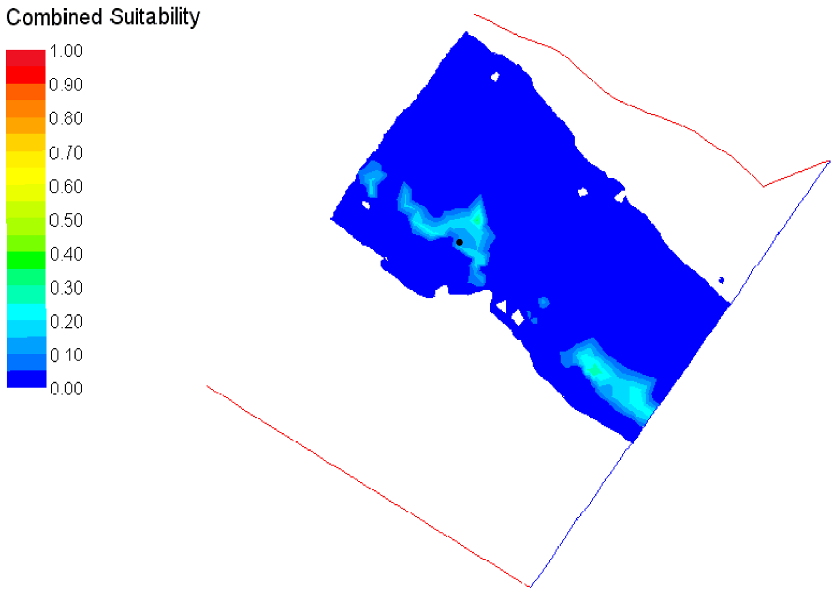
Redd locations: ●

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



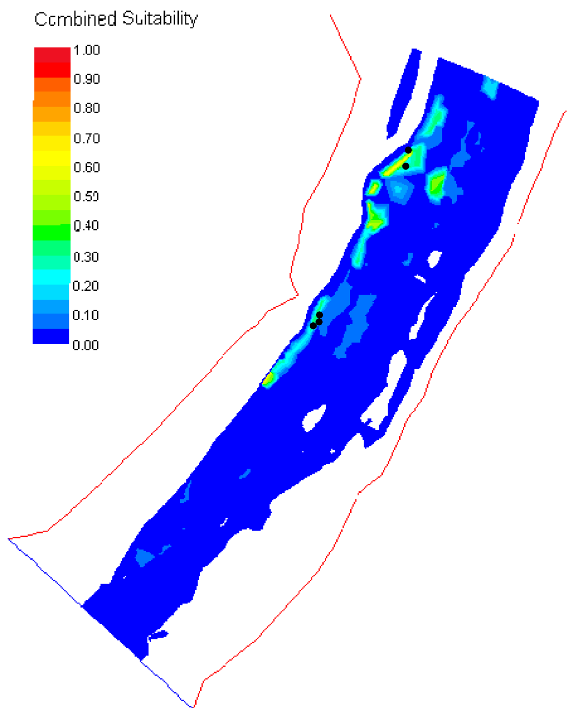
Redd locations: ●

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



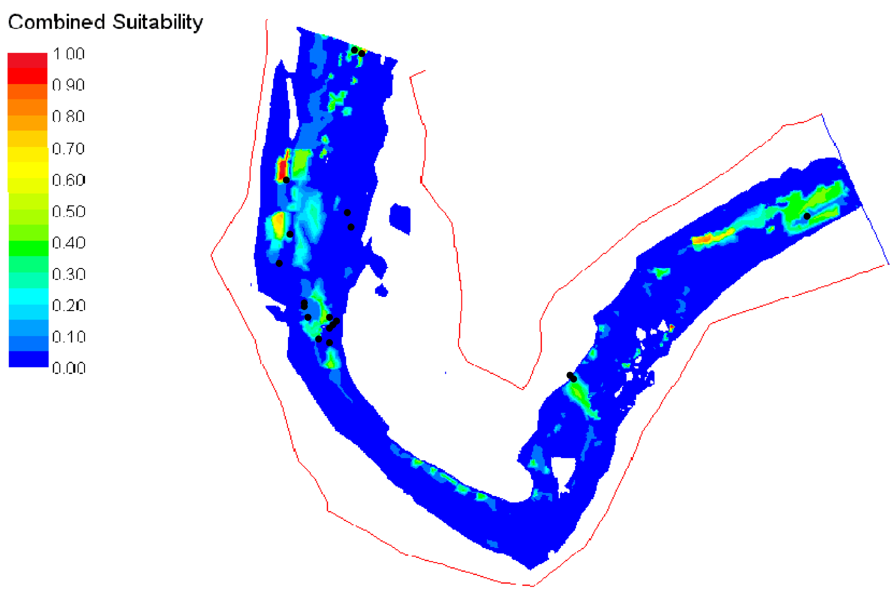
Redd locations: ●

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



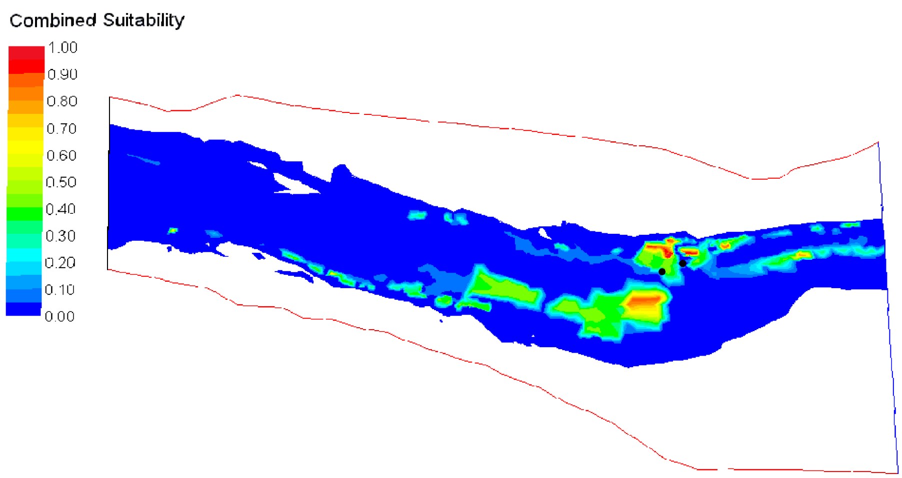
Redd locations: ●

PELTIER STUDY SITE
STEELHEAD SPAWNING, FLOW = 200 CFS



Redd locations: ●

NEED CAMP STUDY SITE
STEELHEAD SPAWNING, FLOW = 262 CFS



Redd locations: ●