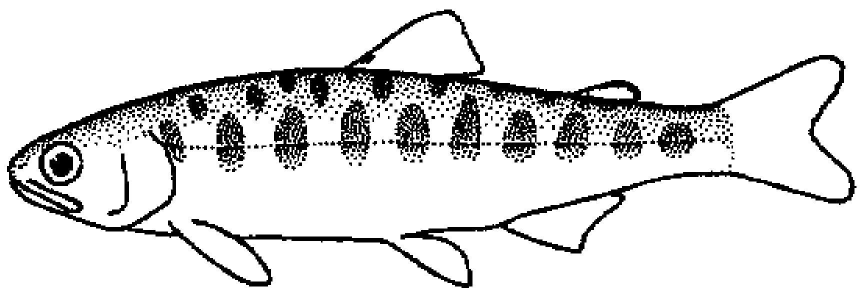
FLOW-HABITAT RELATIONSHIPS FOR JUVENILE SPRING-RUN AND FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT REARING IN CLEAR CREEK BETWEEN CLEAR CREEK ROAD AND THE SACRAMENTO RIVER



U. S. Fish and Wildlife Service
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, CA 95825

Prepared by staff of
The Restoration and Monitoring Program

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

PREFACE

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

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

Mark Gard, Senior Biologist
Restoration and Monitoring Program
U.S. Fish and Wildlife Service
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, CA 95825

Mark_Gard@fws.gov

ACKNOWLEDGMENTS

The field work for this study was conducted by Mark Gard, Ed Ballard, Bill Pelle, Rick Williams, Kevin Aceituno, and Dan Cox. Criteria sets for other rivers were provided by Mark Allen of Thomas R. Payne and Associates. Data analysis and report preparation were performed by Ed Ballard and Mark Gard. Funding was provided by the Central Valley Project Improvement Act.

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

ABSTRACT

Flow-habitat relationships were derived for spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing in Clear Creek between Clear Creek Road Bridge and the Sacramento River. A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this study to model available habitat. Habitat was modeled for ten sites in the Lower Alluvial segment, which were representative of the mesohabitat types available in that segment for spring-run and fall-run Chinook salmon and steelhead/rainbow trout. Bed topography was collected for these sites using a total station and a survey-grade Real-Time Kinematic Global Positioning System (RTK GPS). Additional data were collected to develop stage-discharge relationships at the upstream and downstream end of the sites as an input to RIVER2D. Velocities measured in the site were used to validate the velocity predictions of RIVER2D. The raw topography data were refined by defining breaklines going up the channel along features such as thalwegs, tops of bars and bottoms of banks. A finite element computational mesh was then developed to be used by RIVER2D for hydraulic calculations. RIVER2D hydraulic data were calibrated by adjusting bed roughness heights until simulated water surface elevations matched measured water surface elevations. The calibrated files for each site were used in RIVER2D to simulate hydraulic characteristics for 23 simulation flows. Fall-run Chinook salmon habitat suitability criteria (HSC) were developed from depth, velocity, adjacent velocity, and cover measurements collected at the locations of 326 fall-run Chinook salmon fry and 184 fall-run Chinook salmon juvenile. Logistic regression was used to develop the HSC. The horizontal locations of a separate set of fall-run Chinook salmon observations, located in nine of the ten study sites, were measured with a total station to use in biological validation of the habitat models. The spring-run Chinook salmon and steelhead/rainbow trout HSC used in this study were those developed in a previous study of the Upper Alluvial and Canyon segments. No biological validation was performed for spring-run Chinook salmon and steelhead/rainbow trout in the Lower Alluvial segment. The biological validation showed a significant difference between the suitability of occupied and unoccupied locations for both fry and juvenile fall-run Chinook salmon. The 2-D model predicts the highest total weighted usable area values (WUA) for: 1) spring-run Chinook salmon fry rearing at 900 cfs; 2) spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing at 850 cfs; 3) fall-run Chinook salmon and steelhead/rainbow trout fry rearing at 50 cfs; and 4) fall-run Chinook salmon juvenile rearing at 350 cfs. The results of this study suggest that the flow recommendations in the CVPIA Anadromous Fish Restoration Program during the spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing period of October-September (150-200 cfs) may be close to achieving maximum habitat availability and productivity for rearing fall-run Chinook salmon fry and juveniles and steelhead/rainbow trout fry in the Lower Alluvial Segment of Clear Creek (79 to 94 % of maximum WUA), but is substantially lower than the maximum habitat availability for rearing spring-run Chinook salmon fry and juveniles and steelhead/rainbow trout juveniles (51 to 61 % of maximum WUA). Given the much large population size of fall-run Chinook salmon, versus spring-run Chinook salmon and steelhead, habitat is much more likely to be limiting for this race/species.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act provided for enactment of all reasonable efforts to double sustainable natural production of anadromous fish stocks including the four races of Chinook salmon (fall, late-fall, winter, and spring runs), steelhead, white and green sturgeon, American shad and striped bass. For Clear Creek, the Central Valley Project Improvement Act Anadromous Fish Restoration Plan (AFRP) calls for a release from Whiskeytown Dam of 200 cfs from October through June and a release of 150 cfs or less from July through September (U. S. Fish and Wildlife Service 2001). The Clear Creek study was planned to be a 5-year effort, the goals of which are to determine the relationship between stream flow and physical habitat availability for all life stages of Chinook salmon (fall- and spring-run) and steelhead/rainbow trout. There were four phases to this study based on the life stages to be studied and the number of segments delineated for Clear Creek from downstream of Whiskeytown Reservoir to the confluence with the Sacramento River[2]. The rearing habitat study sites for the fourth phase of the study were selected that encompassed the Lower Alluvial segment of the creek, including the restored portion of a two-mile restoration reach (U.S. Fish and Wildlife Service 2005a). The goal of this report was to produce models predicting the availability of physical habitat in Clear Creek between Clear Creek Road and the Sacramento River, including the restored portion of the two-mile restoration reach, for spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing over a range of stream flows that meet, to the extent feasible, the levels of accuracy specified in the methods section. The tasks and their associated objectives are given in Table 1.

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

---

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

Table 1. Study tasks and associated objectives.

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

which define the actual living space of the organisms. The total habitat available to a species/life stage at any streamflow is the area of overlap between available microhabitat and suitable macrohabitat conditions.

Conceptual models are essential for establishing theoretical or commonly-accepted frameworks, upon which data collection and scientific testing can be interpreted meaningfully. A conceptual model of the link between rearing habitat and population change may be described as follows (Bartholow 1996, Bartholow et al. 1993, Williamson et al. 1993). Changes in flows result in changes in depths and velocities. These changes, in turn, along with the distribution of cover, alter the amount of habitat area for fry and juvenile rearing for anadromous salmonids. Changes in the amount of habitat for fry and juvenile rearing could affect rearing success through alterations in the conditions that favor fry and juvenile growth and promote survival. These alterations in rearing success could ultimately result in changes in salmonid populations.

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

The results of this study are intended to support or revise the flow recommendations above. The range of Clear Creek flows to be evaluated for management generally falls within the range of 50 cfs (the minimum required release from Whiskeytown Dam) to 900 cfs (75% of the outlet capacity of the controlled flow release from Whiskeytown Dam). Accordingly, the range of study flows encompasses the range of flows to be evaluated for management. The assumptions of this study are: 1) that physical habitat is the limiting factor for salmonid populations in Clear Creek; 2) that rearing habitat quality can be characterized by depth, velocity, adjacent velocity and cover; 3) that the ten study sites are representative of anadromous salmonid rearing habitat in Clear Creek between Clear Creek Road and the Sacramento River, including the restored portion of the two-mile restoration reach; 4) theoretical equations of physical processes along with a description of stream bathymetry and roughness height and a stage-discharge relationship provide sufficient input to simulate velocity distributions through a study site; and 5) that Clear Creek is in a state of dynamic equilibrium.

METHODS

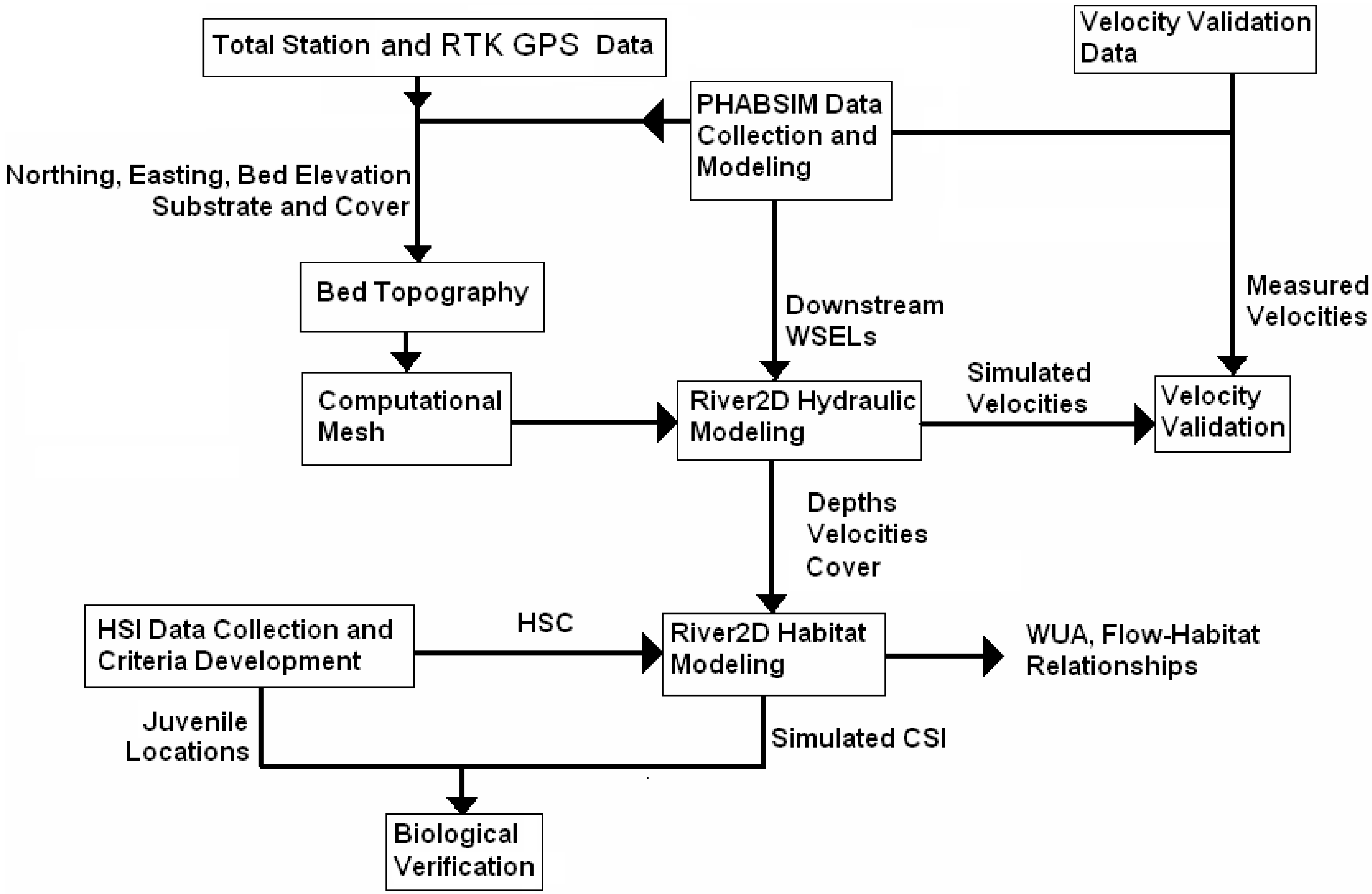
Approach

A two-dimensional model, River2D Version 0.93 November 11, 2006 by P. Steffler, A. Ghanem, J. Blackburn and Z. Yang (Steffler and Blackburn 2002) was used for predicting Weighted Useable Area (WUA), instead of the Physical Habitat Simulation (PHABSIM[3]) component of IFIM. River2D inputs include the bed topography and bed roughness height, and the water surface elevation at the downstream end of the site. The amount of habitat present in the site is computed using the depths and velocities predicted by River2D, and the substrate and cover present in the site. River2D avoids problems of transect placement, since data are collected uniformly across the entire site (Gard 2009b). River2D also has the potential to model depths and velocities over a range of flows more accurately than would PHABSIM because River2D takes into account upstream and downstream bed topography and bed roughness height, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's Equation (Leclerc et al. 1995) and a velocity adjustment factor. Other advantages of River2D are that it can explicitly handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions (Ghanem et al. 1996, Crowder and Diplas 2000, Pasternack et al. 2004). With appropriate bathymetry data, the model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. River2D, with compact cells, should be more accurate than PHABSIM, with long rectangular cells, in capturing longitudinal variation in depth, velocity and substrate. River2D should do a better job of representing patchy microhabitat features, such as gravel patches. The data for two-dimensional modeling can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate and cover. Bed topography and substrate/cover mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the up- and downstream ends of the site and flow, and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

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

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

Figure 1. Flow diagram of data collection and modeling.



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

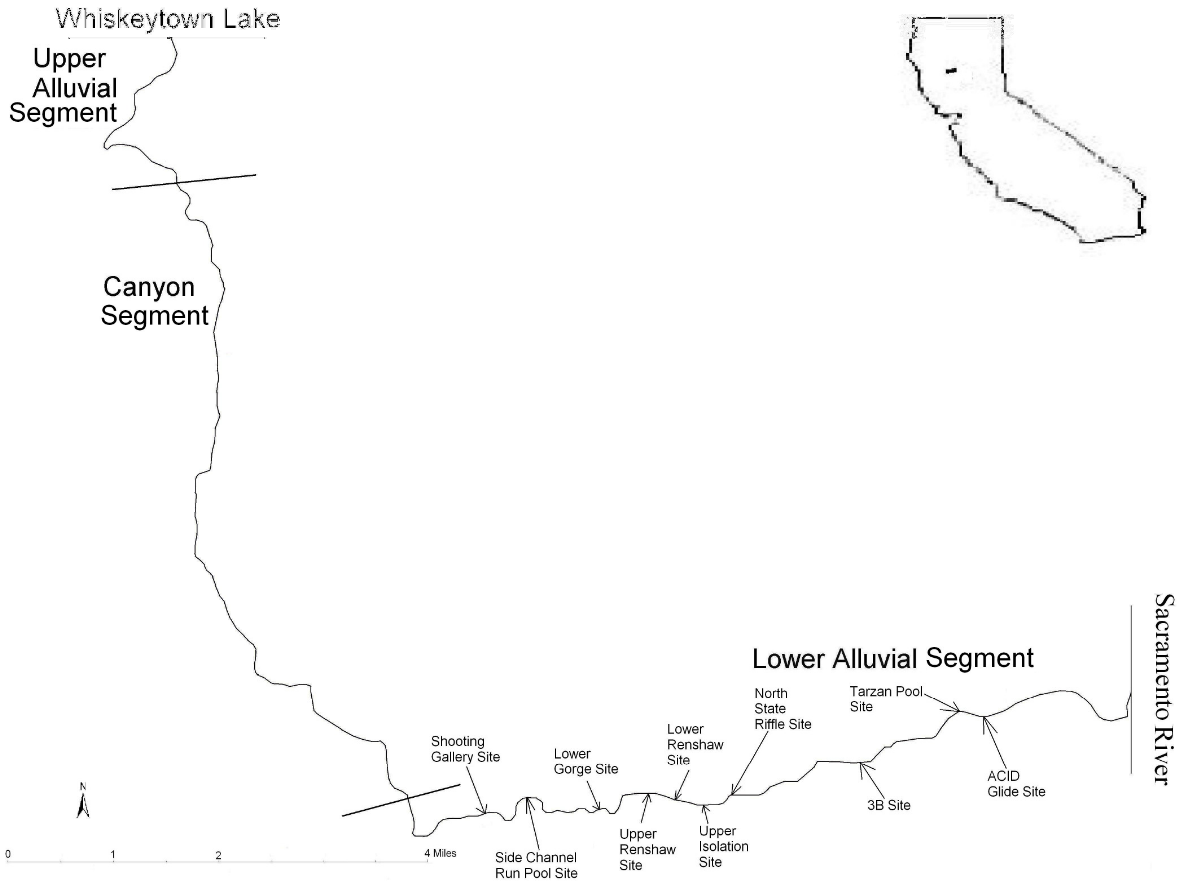
Study Segment Selection

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

Habitat Mapping

Mesohabitat mapping of the lower alluvial segment, excluding the two-mile restoration reach, was performed February 4-7, 2008. This work consisted of hiking and wading downstream from Clear Creek Road bridge to the confluence with the Sacramento River, delineating the mesohabitat units using an adaptation of habitat-typing protocols developed by the California Department of Fish and Game (CDFG). The CDFG habitat typing protocols designates 12 mesohabitat types: bar complex glides, bar complex pools, bar complex riffles, bar complex runs, flatwater glides, flatwater pools, flatwater riffles, flatwater runs, side channel glides, side channel pools, side channel riffles, and side channel runs (Snider et al. 1992). However, we decided to combine the “bar complex” and “flatwater” primary habitat types into “main channel”, as this simplification of the classification system seemed appropriate for a stream the size of Clear Creek. Definitions of the habitat types are given in Table 2. Aerial photos from June 2007 flown at 1:4200 were used in conjunction with direct observations to determine the aerial extent of each habitat unit. The location of the upstream and downstream boundaries of habitat units was recorded with a Global Positioning System (GPS) unit. The habitat units were also delineated on the aerial photos. Following the completion of the mesohabitat mapping on February 7, 2008, the mesohabitat types and number of habitat units of each habitat type were enumerated, and shapefiles of the mesohabitat units were created in a Geographic Information System (GIS) using the GPS data and the aerial photos. The area of each mesohabitat unit was computed in GIS from the above shapefiles.

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



Field Reconnaissance and Study Site Selection

Based on the results of habitat mapping, we used a stratified random sampling design to select five juvenile habitat study sites that, together with five previously selected spawning sites (U.S. Fish and Wildlife Service 2011a), adequately represent the mesohabitat types present in each segment. The five new study sites were randomly selected out of all of the mesohabitat units of the mesohabitat types that were not adequately represented in the five previously selected study sites. Mesohabitat types were considered adequately represented by at least one mesohabitat unit of less common mesohabitat types and multiple mesohabitat units of more common mesohabitat types. As a result, the mesohabitat composition of the study sites, taken together, were roughly proportional to the mesohabitat composition of the entire segment. The five new study sites were randomly selected, stratified by mesohabitat type, to ensure unbiased selection of the study sites. For the sites selected for modeling, the landowners along both riverbanks were identified and temporary entry permits were sent, accompanied by a cover letter, to acquire permission for entry onto their property during the course of the study.

Table 2. Mesohabitat type definitions.

Habitat Type	Definition
Main Channel	More than 20 percent of total flow.
Side Channel	Less than 20 percent of total flow.
Pool	Primary determinant is downstream control - thalweg gets deeper as go upstream from bottom of pool. Fine and uniform substrate, below average water velocity, above average depth, tranquil water surface.
Glide	Primary determinants are no turbulence (surface smooth, slow and laminar) and no downstream control. Low gradient, substrate uniform across channel width and composed of small gravel and/or sand/silt, depth below average and similar across channel width, below average water velocities, generally associated with tails of pools or heads of riffles, width of channel tends to spread out, thalweg has relatively uniform slope going downstream.
Run	Primary determinants are moderately turbulent and average depth. Moderate gradient, substrate a mix of particle sizes and composed of small cobble and gravel, with some large cobble and boulders, above average water velocities, usually slight gradient change from top to bottom, generally associated with downstream extent of riffles, thalweg has relatively uniform slope going downstream.
Riffle	Primary determinants are high gradient and turbulence. Below average depth, above average velocity, thalweg has relatively uniform slope going downstream, substrate of uniform size and composed of large gravel and/or cobble, change in gradient noticeable.

Transect Placement (study site setup)

The study sites were established between February and July 2008. Whenever possible, the study site boundaries (up- and downstream transects) were selected to coincide with the upstream and downstream ends of the mesohabitat unit. The location of these boundaries was established during site setup by going to the locations marked on aerial photos during the mesohabitat mapping. In some cases, the upstream or downstream boundary had to be moved upstream or downstream to a location where the hydraulic conditions were more favorable (e.g., more linear direction of flow, more consistent water surface elevations from bank to bank).

For each study site, a transect was placed at the upstream and downstream end of the site. The downstream transect was modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. The upstream transect was used in calibrating the 2-D model - bed roughness heights are adjusted until the WSEL at the top of the site matches the WSEL predicted by PHABSIM. Transect pins (headpins and tailpins) were installed on each river bank above the 900 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Data Collection

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

Hydraulic and structural data collection began in February 2008 and was completed in March 2009. The precision and accuracy of the field equipment used for the hydraulic and structural data collection is given in Table 3. The data collected at the inflow and outflow transects included: 1) WSELs measured to the nearest 0.01 foot (0.0031 m) at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bank-full discharge surveyed to the nearest 0.1 foot (0.031 m); 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate[4] and cover classification at these same locations (Tables 4 and 5) and also where dry ground elevations were surveyed. When conditions allowed, WSELs were measured along both banks and in the middle of each transect. Otherwise, the WSELs were measured along both banks. If the WSELs measured for a transect were within 0.1 foot (0.031 m) of each other, the WSELs at each transect were then derived by averaging the two to three values. If the WSEL differed by greater than 0.1 foot (0.031 m), the WSEL for the transect was selected based on which side of the transect was considered most representative of the flow conditions. For sites where there was a gradual gradient change in the vicinity of the downstream transect, there could be a point in the thalweg a short way downstream of the site that was higher than that measured at the downstream transect thalweg simply due to natural variation in topography (Figure 3). This stage of zero flow downstream of the site acts as a control on the water surface elevations at the downstream transect, and could cause errors in the WSELs. Because the true stage of zero flow is needed to

---

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

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

Equipment	Parameter	Precision	Accuracy
Marsh-McBirney	Velocity		± 2% + 1.5 cm/s
Total Station	Slope Distance	± (5ppm + 5) mm	
Total Station	Angle		4 sec
Survey-Grade RTK GPS	Northing, Easting, Bed Elevation		0.3 cm
Electronic Distance Meter	Slope Distance		1.5 cm
Autolevel	Elevation		0.3 cm

Table 4. Substrate codes, descriptors and particle sizes.

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

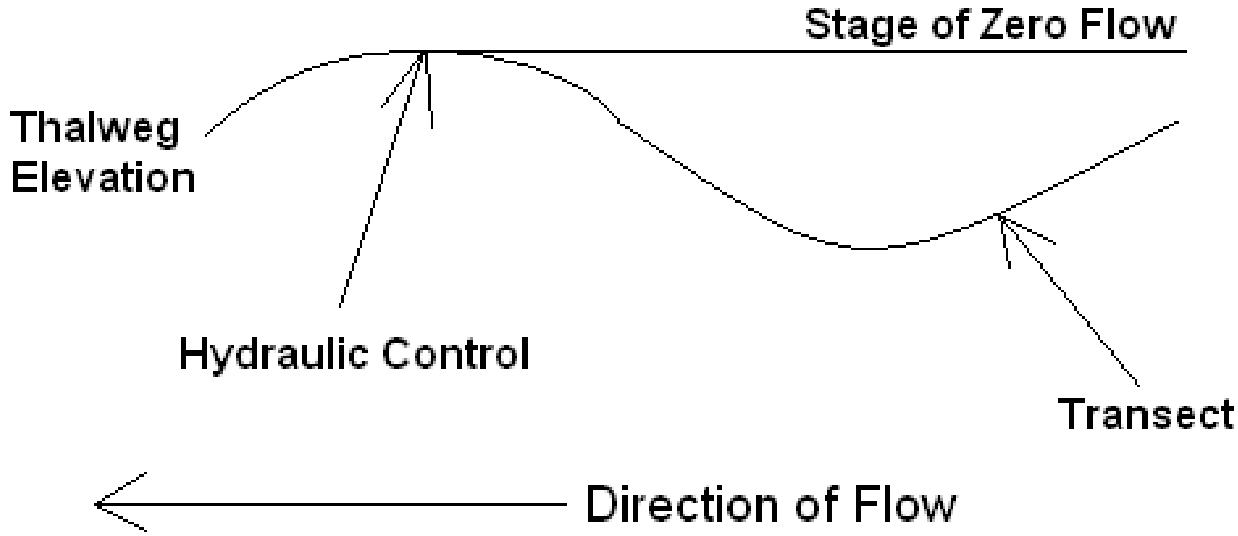
Table 5. Cover coding system.

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

accurately calibrate the water surface elevations on the downstream transect, this stage of zero flow in the thalweg downstream of the downstream transect was surveyed in using differential leveling. If the true stage of zero flow was not measured as described above, the default stage of zero flow would be the thalweg elevation at the transect. Depth and velocity measurements were made using a wading rod equipped with a Marsh-McBirney^{R} model 2000 velocity meter. The distance intervals of each depth and velocity measurement from the headpin or tailpin were measured using a tape or hand held laser range finder[5]. For sites that did not include the total

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

Figure 3. Stage of zero flow diagram.



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

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

To validate the velocities predicted by the 2-D model, depth, velocity, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter. These validation velocities and the velocities measured on the transects described previously were collected at 0.6 of the depth for 20 seconds. The horizontal locations and bed elevations were recorded by sighting from the total station to a stadia rod and prism held at each point where depth and velocity were measured. A minimum of 50 representative points were measured per site.

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

All velocity, depth, and station data collected were compiled in an Excel spreadsheet for each site and checked before entry into PHABSIM files for the upstream and downstream transects. A table of substrate and cover ranges/values was created to determine the substrate and cover for each vertical/cell (e.g., if the substrate size class was 2-4 inches (5-10 cm) on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the WSEL of the highest flow to be modeled. An American Standard Code for Information Interchange (ASCII) file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton, U.S. Fish and Wildlife Service, 1998) to get the PHABSIM input file and then translated into RHABSIM Version 2.0[6] files. A separate PHABSIM file was constructed for each study site. A total of four or five WSEL sets at low, medium, and high flows were used. If WSELs were available for several closely spaced flows, the WSEL that corresponded with the velocity set or the WSEL collected at the lowest flow was used in the PHABSIM data files. Flow/flow regressions were performed for sites which did not include the entire Clear Creek flow, using the flows measured with a wading rod and Marsh-McBirney flow meter in the side channel adjacent to the site and the corresponding gage total flows for the dates that the side channel flows were measured. The regressions were developed from four sets of flows. Calibration flows in the PHABSIM files were the flows calculated from gage readings[7] or from the above flow/flow regressions. The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. In habitat types without backwater effects (e.g., riffles and runs), this value generally represents the lowest point in the streambed across a transect. However, if a transect directly upstream contains a lower bed elevation than the adjacent downstream transect, the SZF for the downstream transect applies to both. In some cases, data collected in between the transects showed a higher thalweg elevation than either transect; in these cases the higher thalweg elevation was used as the SZF for the upstream transect.

---

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

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

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous et al. 1989) was run on each dataset to compare predicted and measured WSELs. This model produces a stage-discharge relationship using a log-log linear rating curve calculated from at least three sets of measurements taken at different flows. Besides *IFG4*, two other hydraulic models are available in PHABSIM to predict stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the condition of the channel and the nature of the streambed controls WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects. *IFG4,* the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs[8]. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier[9] and flow; and 3) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

Velocity Adjustment Factors (VAFs)[10] were examined for all of the simulated flows as a potential indicator of problems with the stage-discharge relationship. The acceptable range of VAF values is 0.2 to 5.0 and the expected pattern for VAFs is a monotonic increase with an increase in flows (U.S. Fish and Wildlife Service 1994).

RIVER2D Model Construction

After completing the PHABSIM calibration process to arrive at the simulation WSELs that were used as inputs to the RIVER2D model, the next step was to construct the RIVER2D model using the collected bed topography data. The total station data and the PHABSIM transect data were combined in a spreadsheet to create the input files (bed and cover) for the 2-D modeling

---

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

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

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

program. An artificial extension one channel-width-long was added upstream of the topography data collected upstream of the study site, to enable the flow to be distributed by the model when it reached the study area, thus minimizing boundary conditions influencing the flow distribution at the upsteam transect and within the study site.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness height value for each point, while the cover files contain the horizontal location, bed elevation and cover code for each point. The initial bed roughness height value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness height values in Table 6, with the bed roughness height value for each point computed as the sum of the substrate bed roughness height value and the cover bed roughness height value for the point. The resulting initial bed roughness height value for each point was therefore a combined matrix of the substrate and cover roughness height values. The bed roughness height values for substrate in Table 6 were computed as five times the average particle size[11]. The bed roughness height values for cover in Table 6 were computed as five times the average cover size, where the cover size was measured on the Sacramento River on a representative sample of cover elements of each cover type. The bed and cover files were exported from the spreadsheet as ASCII files.

A utility program, R2D_BED (Steffler 2002), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines[12] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. The first step in refining the TIN was to conduct a quality assurance/quality control process, consisting of a point-by-point inspection to eliminate quantitatively wrong points, and a qualitative process where we checked the features constructed in the TIN against aerial photographs to make sure we had represented landforms correctly. Breaklines were also added along lines of constant elevation.

An additional utility program, R2D_MESH (Waddle and Steffler 2002), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final bed file as an input. The first stage in creating the

---

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

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

Table 6. Initial bed roughness height values.

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05, 0.76, 2[13]	9	0.29
10	1.4	9.7	0.57
		10	3.05

[13] For substrate code 9, we used bed roughnesses of 0.76 and 2, respectively, for cover codes 1 and 2, and a bed roughness of 0.05 for all other cover codes. The bed roughness value for cover code 1 (cobble) was estimated as five times the assumed average size of cobble (6 inches [0.15 m]). The bed roughness values for cover code 2 (boulder) was estimated as five times the assumed median size of boulders (1.3 feet [0.4 m]). Bed roughnesses of zero were used for cover codes 0.1, 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

computational mesh was to define mesh breaklines[14] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and then additional nodes were added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Waddle and Steffler 2002). The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. The final step with the R2D_MESH software was to generate the computational (cdg) file.

RIVER2D Model Calibration

Once a River2D model has been constructed, calibration is then required to determine that the model is reliably simulating the flow-WSEL relationship that was determined through the PHABSIM calibration process using the measured WSELs. The cdg files were opened in the River2D software, where the computational bed topography mesh was used together with the WSEL at the bottom of the site, the flow entering the site, and the bed roughness heights of the computational mesh elements to compute the depths, velocities and WSELs throughout the site. The basis for the current form of River2D is given in Ghanem et al. (1995). The computational mesh was run to steady state at the highest flow to be simulated, and the WSELs predicted by River2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the upstream transect. Calibration was considered to have been achieved when the WSELs predicted by River2D at the upstream transect were within 0.1 foot (0.031 m) of the WSEL predicted by PHABSIM. In cases where the simulated WSELs at the highest simulation flow varied across the channel by more than 0.1 foot (0.031 m), we used the highest measured flow within the range of simulated flows for River2D calibration. The bed roughness heights of the computational mesh elements were then modified by multiplying them by a constant bed roughness height multiplier (BR Mult) until the WSELs predicted by River2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect. The minimum groundwater depth was adjusted to a value of 0.05 to increase the stability of the model. The values of all other River2D hydraulic parameters were left at their default values (upwinding coefficient = 0.5, groundwater transmissivity = 0.1, groundwater storativity = 1, and eddy viscosity parameters ε_1 = 0.01, ε_2 = 0.5 and ε_3 = 0.1).

---

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

We then calibrated the upstream transect using the methods described above, varying the BR Mult until the simulated WSEL at the upstream transect matched the measured WSEL at the upstream transect. A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than 1% (Steffler and Blackburn 2002). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than 1.0[15]. Finally, the WSEL predicted by the 2-D model should be within 0.1 foot (0.031 m) of the WSEL measured at the upstream transects[16].

RIVER2D Model Velocity Validation

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

RIVER2D Model Simulation Flow Runs

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

Habitat Suitability Criteria (HSC) Data Collection

Habitat suitability criteria (HSC) are used within 2-D habitat modeling to translate hydraulic and structural elements of rivers into indices (HSIs) of habitat quality (Bovee 1986). HSC refer to the overall functional relationships that are used to convert depth, velocity and cover values into

---

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

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

habitat quality (HSI). HSI refers to the dependent variable in the HSC relationships. The primary habitat variables which were used to assess physical habitat suitability for Chinook salmon and steelhead/rainbow trout fry and juvenile rearing were depth, velocity, cover and adjacent velocity[17].

Traditionally, criteria are created from observations of fish use by fitting a nonlinear function to the frequency of habitat use for each variable (depth, velocity, and cover). One concern with this technique is the effect of availability of habitat on the observed frequency of habitat use. For example, if a cover type is relatively rare in a stream, fish will be found primarily not using that cover type simply because of the rarity of that cover type, rather than because they are selecting areas without that cover type. Guay et al. (2000) proposed a modification of this technique where depth, velocity, and cover data are collected both in locations where juveniles are present and in locations where juveniles are absent, and a logistic regression is used to develop the criteria. This approach is employed in this study.

HSC data collection for fall-run Chinook salmon YOY (fry and juvenile) rearing was conducted January 2007 - September 2007. Data were collected by snorkeling upstream through the habitat units. We also collected depth, velocity, adjacent velocity and cover data on locations which were not occupied by YOY Chinook salmon (unoccupied locations). This was done so that we could apply the method presented in Guay et al. (2000) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability). Before going out into the field, a data book was prepared with one line for each unoccupied location where depth, velocity, cover and adjacent velocity would be measured. Each line had a distance from the bank, with a range of 0.5 to 10 feet (0.15 to 3.05 m) by 0.5 foot (0.15 m) increments, with the values produced by a random number generator.

---

[17] Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed (Fausch and White 1981). Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth. The adjacent velocity was measured within 2 feet (0.61 m) on either side of the location where the velocity was the highest. Two feet (0.61 m) was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon and steelhead/rainbow trout reside, taking into account that the median size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, USGS, personal communication), and assuming that the mean depth of Clear Creek is around 4 feet (1.22 m) (i.e., 4 feet [1.22 m] x ½ = 2 feet [0.61 m]).

When conducting snorkel surveys adjacent to the bank, one person snorkeled upstream along each bank and placed a weighted, numbered tag at each location where YOY Chinook salmon were observed. The snorkeler recorded the tag number, the cover code[18] and the number of individuals observed in each 10-20 mm size class on a Poly Vinyl Chloride (PVC) wrist cuff. The average and maximum distance from the water's edge that was sampled, cover availability in the area sampled (percentage of the area with different cover types) and the length of bank sampled (measured with a 300-foot-long [91m] tape) were also recorded. The cover coding system used is shown in Table 5. A 300-foot-long (91 m) tape was put out with one end at the location where the snorkeler finished and the other end where the snorkeler began. Three people went up the tape, one with a stadia rod and data book and the other two with wading rods and velocity meters. At every 20-foot (6 m) interval along the tape, the person with the stadia rod measured out the distance from the bank given in the data book. If there was a tag within 3 feet (1 m) of the location, "tag within 3" was recorded on that line in the data book and the people proceeded to the next 20-foot (6 m) mark on the tape, using the distance from the bank on the next line. If there was no tag within 3 feet (1 m) of that location, one of the people with the wading rod measured the depth, velocity, adjacent velocity and cover at that location. Depth was recorded to the nearest 0.1 ft (0.03 m) and average water column velocity and adjacent velocity were recorded to the nearest 0.01 ft/s (0.003 m/s). Another individual retrieved the tags, measured the depth and mean water column velocity at the tag location, measured the adjacent velocity for the location, and recorded the data for each tag number. Data taken by the snorkeler and the measurer were correlated at each tag location. The same procedures were used for sampling mid-channel, except that distance was measured from the edge of the width of channel sampled rather than from water's edge.

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

Biological Validation Data Collection

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

---

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

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

Habitat Suitability Criteria (HSC) Development

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

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

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

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

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

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

where Exp is the exponential function; I, J, K, L and M are coefficients calculated by the logistic regression; and V is velocity or depth. The logistic regressions were conducted in a sequential fashion, where the first regression tried was a fourth order regression. If any of the coefficients or the constant were not statistically significant at $p = 0.05$, the associated terms were dropped from the regression equation, and the regression was repeated. The results of the regression equations were rescaled so that the highest value of suitability was 1.0. The resulting HSC were modified by truncating at the slowest/shallowest and deepest/fastest ends, so that the next shallower depth or slower velocity value below the shallowest observed depth or the slowest observed velocity had a SI value of zero, and so that the next larger depth or faster velocity value above the deepest observed depth or the fastest observed velocity had an SI value of zero; and eliminating points not needed to capture the basic shape of the curves.

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

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

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

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

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

To evaluate whether we spent equal effort sampling areas with and without woody cover, we have developed two different groups of cover codes based on snorkel surveys we conducted on the Sacramento River: Cover Group 1 (cover codes 3.7, 4, 4.7, 5.7, 7 and 9.7), and Cover Group 0 (all other cover codes). In U.S. Fish and Wildlife Service (2005b), which describes the derivation of these two cover groups, we had addressed the availability of cover in developing the Sacramento River criteria using the following process: 1) ranking the sites sampled in descending order by the percentage of cover group 1; 2) calculating the cumulative feet sampled of cover groups 0 and 1 going down through the sites until we reached an equal number of cumulative feet of cover groups 0 and 1 sampled; and 3) continuing the development of cover criteria using only the above subset of sites. This process allowed us to maximize the amount of area sampled to include in development of the cover criteria while equalizing the amount of area sampled in cover groups 0 and 1. We were unable to use this process for the Lower Alluvial segment of Clear Creek because of the low amount of cover group 1 present in the Lower Alluvial segment of Clear Creek. Instead, we developed the Clear Creek fall-run Chinook salmon cover criteria using a logistic regression analysis. For a categorical independent variable, the result of a logistic regression is the percentage of occupied locations (number of occupied locations / (number of occupied locations + number of unoccupied locations)) for each category of the independent variable.

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

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

Biological Validation

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

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

Habitat Simulation

The final step was to simulate available habitat for each site. Preference curve files were created containing the digitized fry and juvenile rearing HSC developed for the spring-run and fall-run Chinook salmon and steelhead/rainbow trout. The final cdg files, the cover file and the preference curve file were used in River2D to calculate the combined suitability of depth, velocity and cover for each site. The resulting data were exported into a comma-delimited file for each flow, species, life stage, and each mesohabitat type present in each site. These files were then run through a GIS post-processing software[19] to incorporate the adjacent velocity criteria into the habitat suitability, and to calculate the WUA values for each mesohabitat type in each site over the desired range of flows for all ten sites. The total WUA for the Lower Alluvial segment was calculated using the following equation:

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

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

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

RESULTS

Study Segment Selection

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

Habitat Mapping

A total of 166 mesohabitat units were mapped for the Lower Alluvial Segment. Table 7 summarizes the habitat types, area and numbers of each type recorded during the habitat mapping process, while Appendix A gives a complete list of the habitat units.

Study Site Selection

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

Hydraulic and Structural Habitat Data Collection

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

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

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

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

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

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

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

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

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

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

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

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

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

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

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

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

RIVER2D Model Construction

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

RIVER2D Model Calibration

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

---

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

RIVER2D Model Velocity Validation

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

RIVER2D Model Simulation Flow Runs

The simulation flows were 50 cfs to 300 cfs by 25 cfs increments and 300 cfs to 900 cfs by 50 cfs increments. The production cdg files all had a solution change of less than 0.00001. The net Q was less than 1% for all of the simulation flows for two of the five sites. The Side Channel Run Pool site had two flows that had net Qs exceeding 1%, North State Riffle had three flows with net Qs that exceeded 1%, and Restoration Site 3B had 17 flows with net Qs that exceeded 1%, (Appendix H). The maximum Froude Number was greater than one for all of the simulated flows for Restoration Site 3B, 18 of the 23 simulated flows for Side Channel Run Pool, 20 of the 23 simulated flows for North State Riffle, 15 of the 23 simulated flows for Tarzan Pool, and 8 of the 23 simulated flows for ACID Glide (Appendix H).

Habitat Suitability Criteria (HSC) Data Collection

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

---

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

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

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

A total of 58 mesohabitat units were surveyed. A total of 2.4 miles (3.9 km) were sampled. Table 12 summarizes the number of feet of different mesohabitat types sampled and Table 13 summarizes the number of feet of different cover types sampled. To evaluate whether we have spent equal effort sampling areas with and without woody cover, we have developed two different groups of cover codes based on snorkel surveys we conducted on the Sacramento River: Cover Group 1 (cover codes 4 and 7 and composite [3.7, 4.7, 5.7 & 9.7, i.e. instream+overhead] cover), and Cover Group 0 (all other cover codes). A total of 10,536 feet (3,211 m) of Cover Group 0 and 2,263 feet (690 m) of Cover Group 1 were sampled. The spring-run Chinook salmon and steelhead/rainbow trout HSC utilized in this study were those developed for the rearing study of the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2011b).

Biological Validation Data Collection

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

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

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

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

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

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

Habitat Suitability Criteria (HSC) Development

The results of the Mann-Whitney U tests and Pearson's test for association to test for differences between fry and juvenile salmonids, as shown in Table 14, showed significant differences (at $p = 0.05$) between fry and juvenile habitat use for depth and velocity for all three criteria to separate fry from juveniles, but no significant difference for adjacent velocity and cover for the, respectively, < 40 mm versus > 40 mm and <80 mm versus > 80 mm, criteria to separate fry from juveniles. In addition, there was the greatest difference between fry and juvenile habitat use for three of the four parameters for the < 60 mm versus > 60 mm criteria to separate fry from juveniles (see Z and C values in Table 14). Therefore, we selected 60 mm as the criteria to separate fry from juveniles. Hereafter, fry refers to YOY less than 60 mm, while juvenile refers to YOY greater than 60 mm.

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

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

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

Table 14. Differences in YOY fall-run Chinook salmon habitat use as a function of size.

Variable	<40 mm Versus > 40 mm	<60 mm Versus > 60 mm	< 80 mm Versus > 80 mm
Depth	χ^2 = 17.2, p = 0.00003, n = 18, 481	χ^2 = 50.7, p < 0.000001, n = 326, 174	χ^2 = 12.9, p = 0.0003, n = 479, 47
Velocity	χ^2 = 5.8, p = 0.016, n = 18, 481	χ^2 = 30.4, p < 0.000001, n = 326, 174	χ^2 = 13, p = 0.0003, n = 479, 47
Adjacent Velocity	χ^2 =0.6, p = 0.43, n = 18, 481	χ^2 = 5.8, p = 0.02, n = 326, 174	χ^2 = 6.6, p = 0.01, n = 479, 47
Cover	C = 28, p = 0.0058, n = 18, 468	C = 79, p < 0.000001, n = 316, 170	C = 17, p = 0.14, n = 466, 47

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

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

The initial analysis of cover used the occupied and unoccupied observations in Table 15. For fall-run Chinook salmon fry, there was a total of two or less observations for cover codes 5 (log), 8 (undercut bank) and 9.7 (aquatic vegetation plus overhead). For fall-run Chinook salmon juveniles, there was a total of two or less observations for cover codes 5 and 8. The statistical tests for cover are presented in Tables 18 and 19. For Table 18, an asterisk indicates that presence/absence of fish for those cover codes were significantly different at p = 0.05. For Table 19, an asterisk indicates that fish presence/absence was significantly different between groups at p = 0.05. Our analysis indicated that there were two distinct groups of cover types for both fall-run Chinook salmon fry and juveniles. This was the minimum number of groups for which there were significant differences between groups but no significant differences among the cover codes in each group. For both sets of criteria there were no occupied or unoccupied observations of cover code 10; we assigned cover code 10 the same HSI as cover code 2, since most rip-rap consists of boulder-sized rock. For fall-run Chinook salmon fry, we assigned cover codes 5, 8 and 9.7 the same suitability as cover codes 4.7 (branches plus overhead), 3.7 (fine woody plus overhead), 5.7 (log plus overhead) and 4 (branches), since there were no unoccupied observations for cover codes 5, 8 and 9.7, indicating that these cover codes should have a high suitability. For fall-run Chinook juvenile, we assigned cover codes 5 and 8 the same suitability as cover codes 3.7 and 4.7, since the Sacramento River cover criteria had the same suitability for cover codes

Table 16. Logistic regression coefficients. A blank for a coefficient or constant value indicates that term or the constant was not used in the logistic regression, because the p-value for that coefficient or for the constant was greater than 0.05. The coefficients in this table were determined from Equation 2. The logistic regression and all associated parameters were statistically significant.

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

Table 17. Adjacent velocity logistic regression coefficients and R^2 values. The R^2 values are McFadden's Rho-squared values. The coefficients in this table were determined from Equation 3.

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

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

Biological Validation

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

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

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

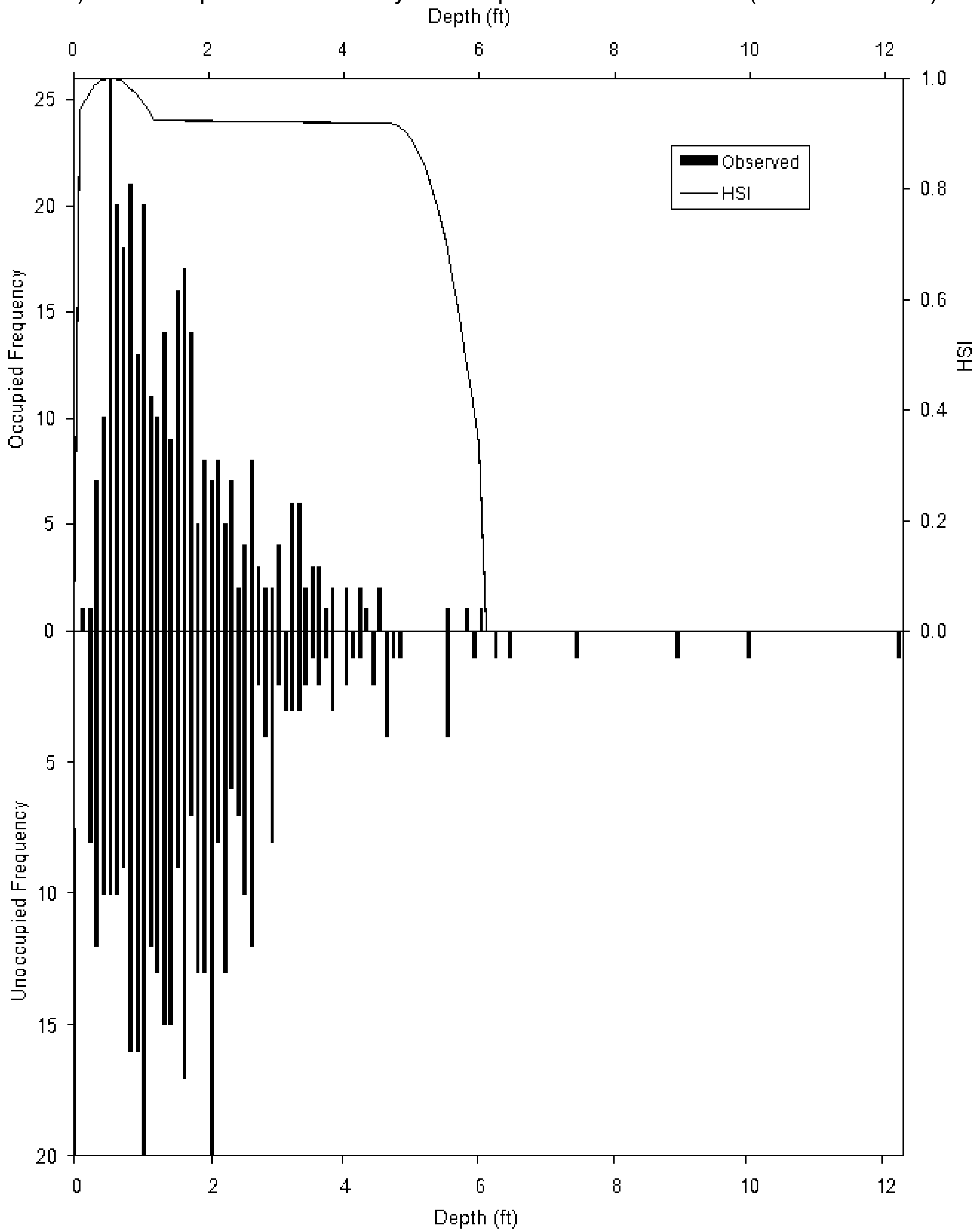


Figure 5. Fall-run Chinook salmon fry rearing velocity HSC. The HSC show that fall-run Chinook salmon fry rearing has a non-zero suitability for velocities of 0 to 3.11 feet/sec (0 to 0.948 m/s) and an optimum suitability at a velocity of zero.

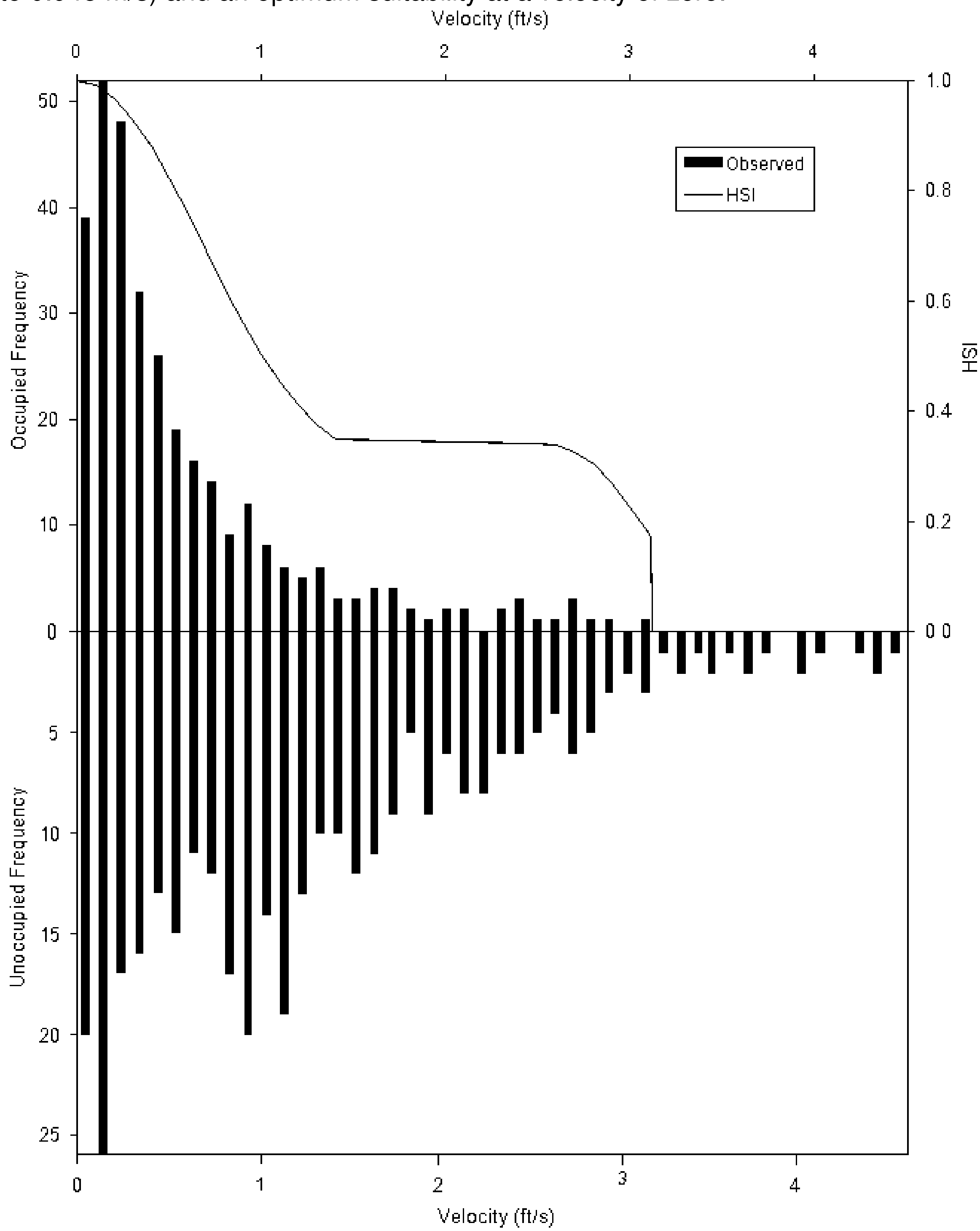


Figure 6. Fall-run Chinook salmon juvenile rearing depth HSC. The HSC show that fall-run Chinook salmon juvenile rearing has a non-zero suitability for depths of 0.5 to 5.3 feet (0.15 to 1.62 m) and an optimum suitability at a depth of 2.9 to 3.2 feet (0.88 to 0.98 m).

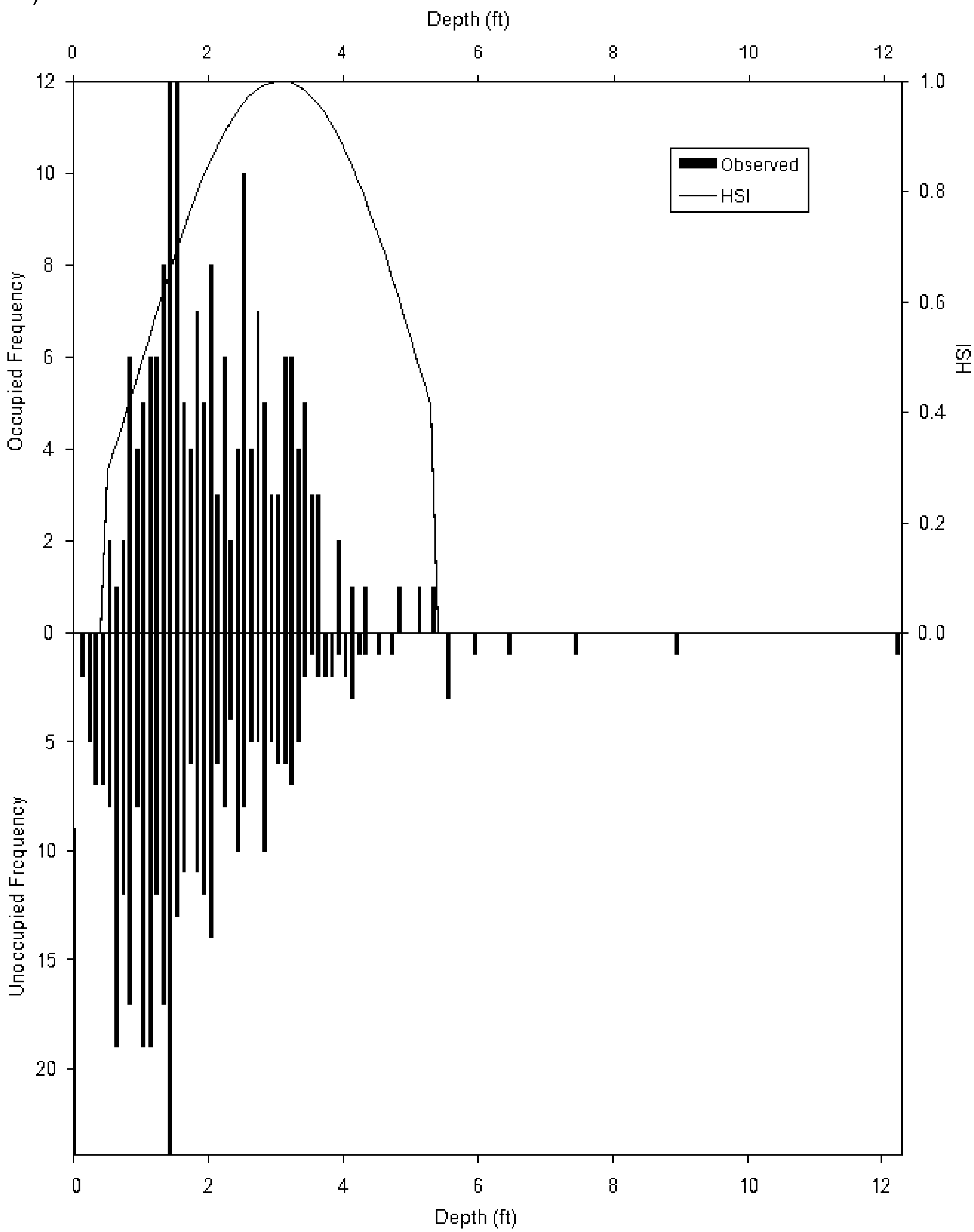


Figure 7. Fall-run Chinook salmon juvenile rearing velocity HSC. The HSC show that fall-run Chinook salmon juvenile rearing has a non-zero suitability for velocities of 0 to 3.06 feet/sec (0 to 0.933 m/s) and an optimum suitability at a velocity of zero.

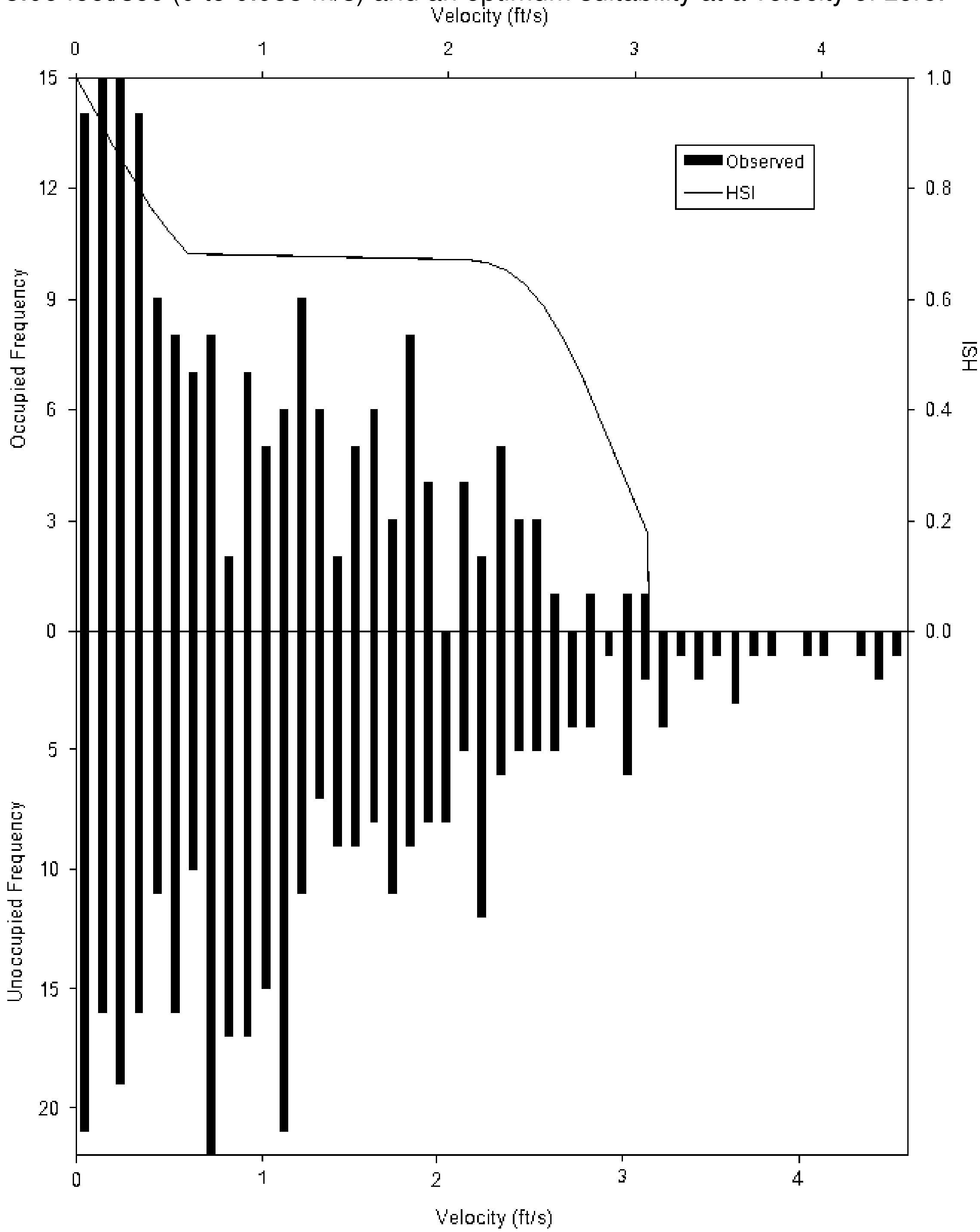


Figure 8. Fall-run Chinook salmon fry rearing adjacent velocity HSC.

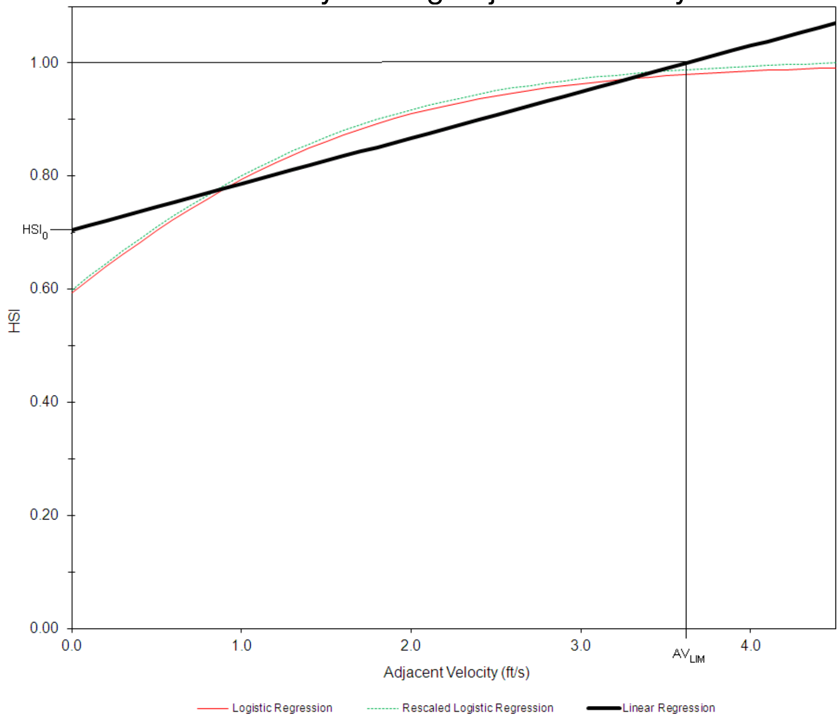


Figure 9. Fall-run Chinook salmon juvenile rearing adjacent velocity HSC.

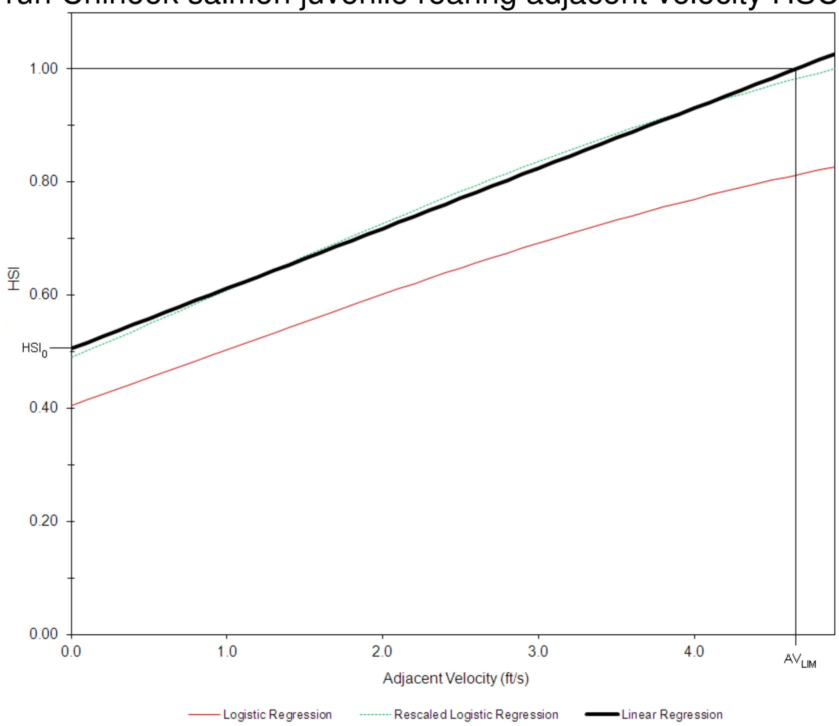


Table 18. Statistical tests of difference between cover codes, using the number of observations where fish were present and absent. An asterisk indicates that presence/absence of fish for those cover codes were significantly different at p = 0.05.

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

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

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

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

Habitat Simulation

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

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

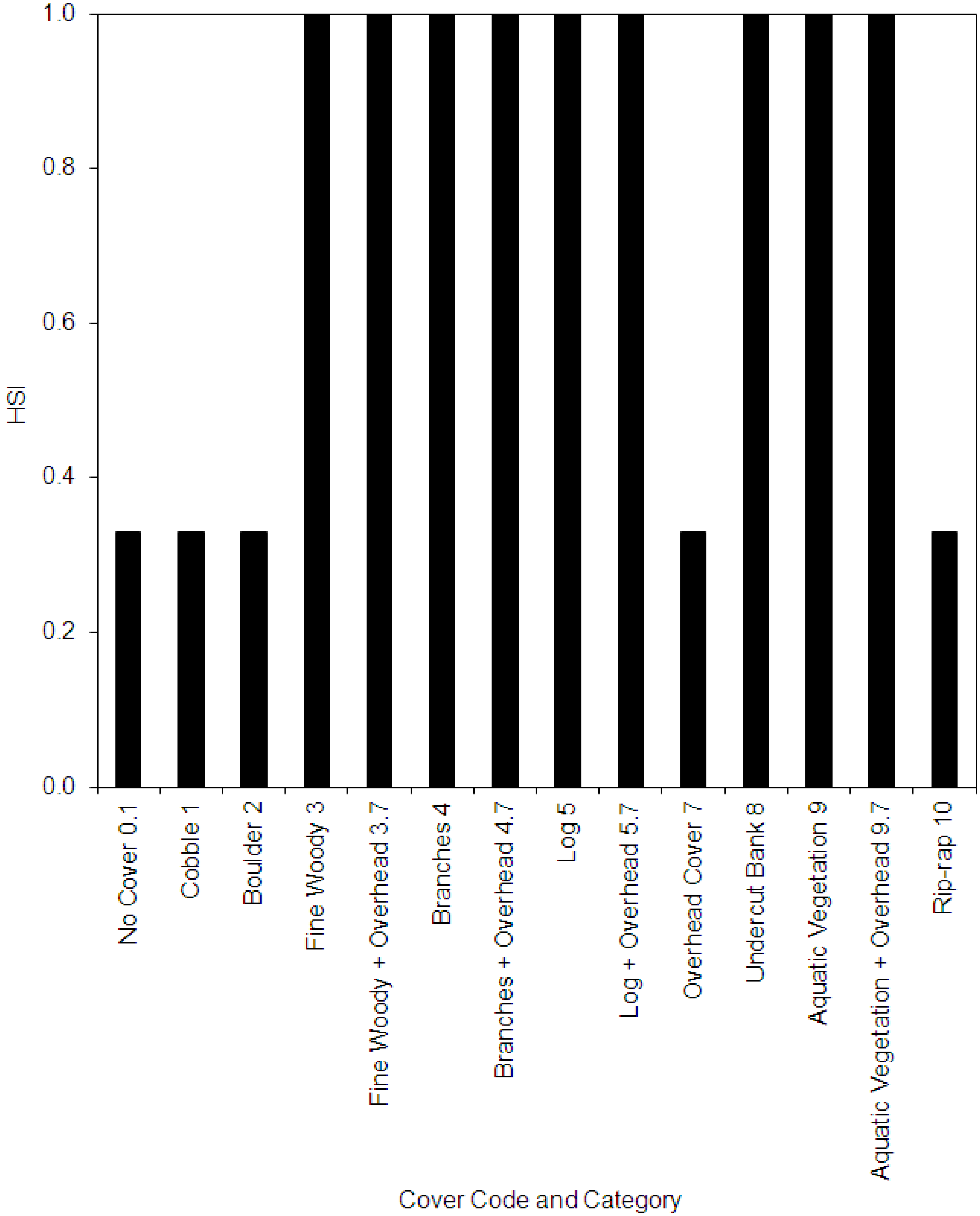


Figure 11. Fall-run Chinook salmon juvenile rearing cover HSC.

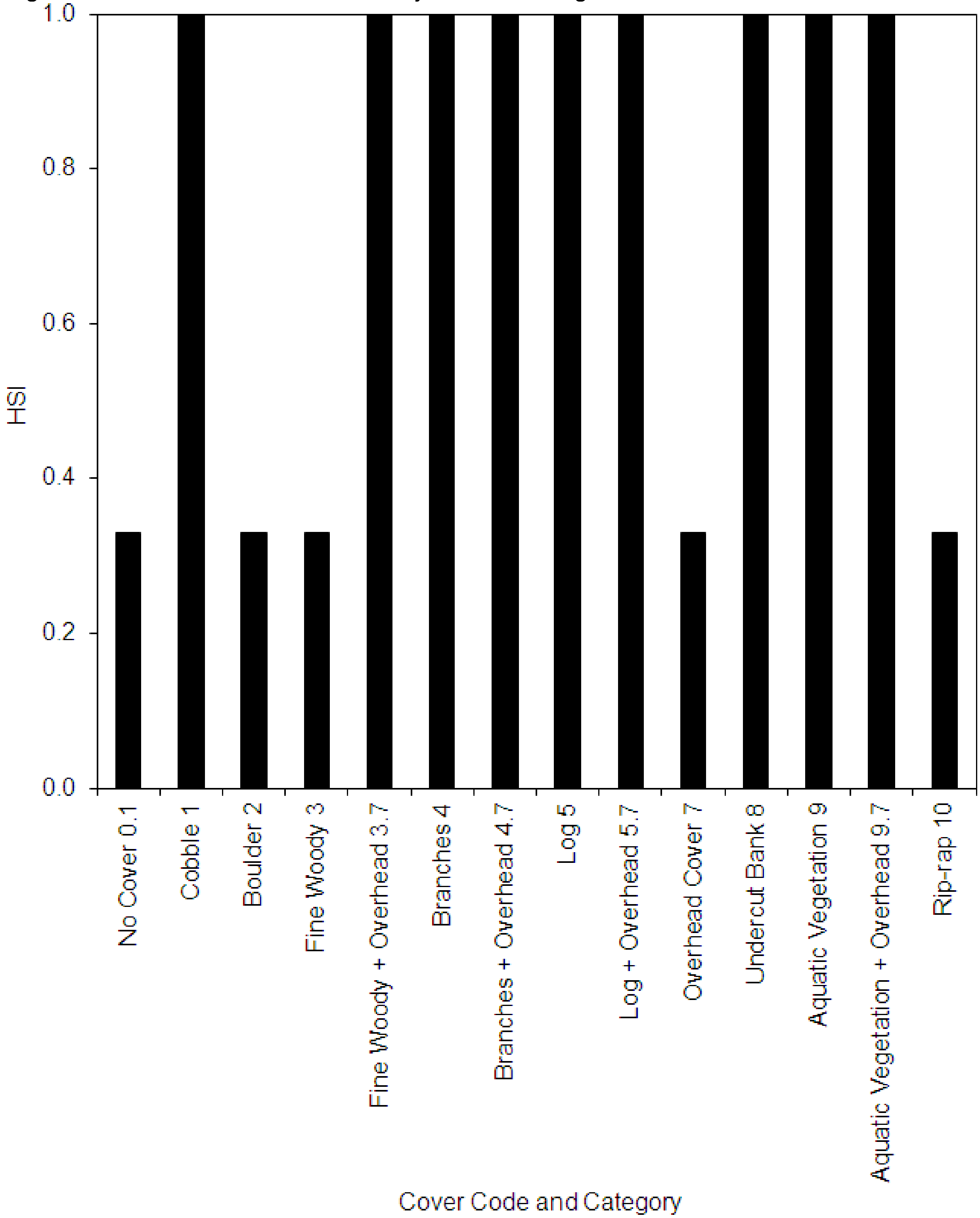


Figure 12. Combined suitability for 2-D model locations with (occupied) and without (unoccupied) fall-run Chinook salmon fry. The median combined suitability for occupied and unoccupied locations was, respectively, 0.33 and 0.16.

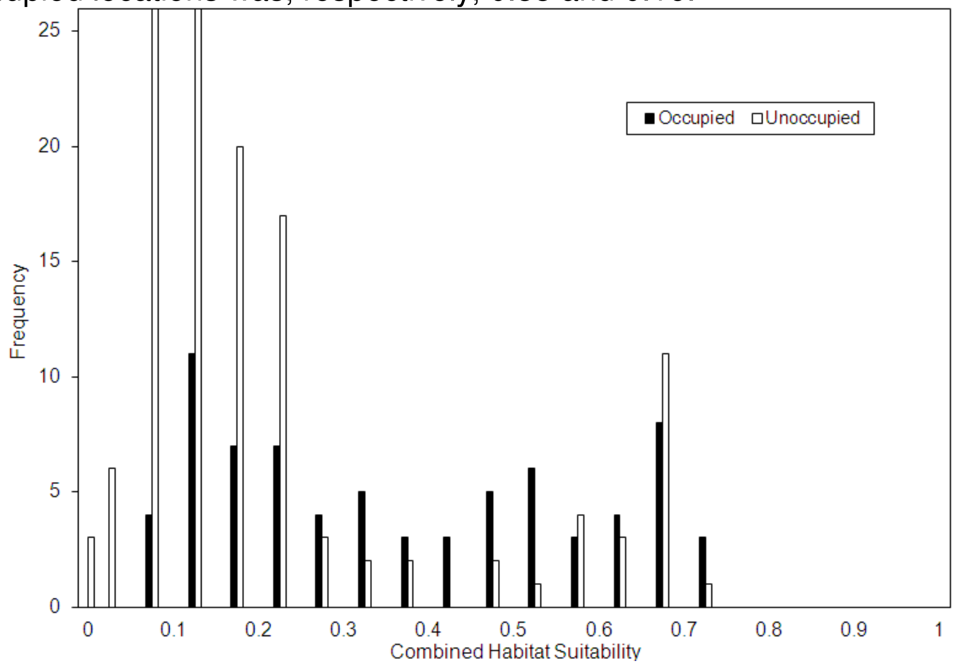


Figure 13. Combined suitability for 2-D model locations with (occupied) and without (unoccupied) fall-run Chinook salmon juveniles. The median combined suitability for occupied and unoccupied locations was, respectively, 0.13 and 0.10.

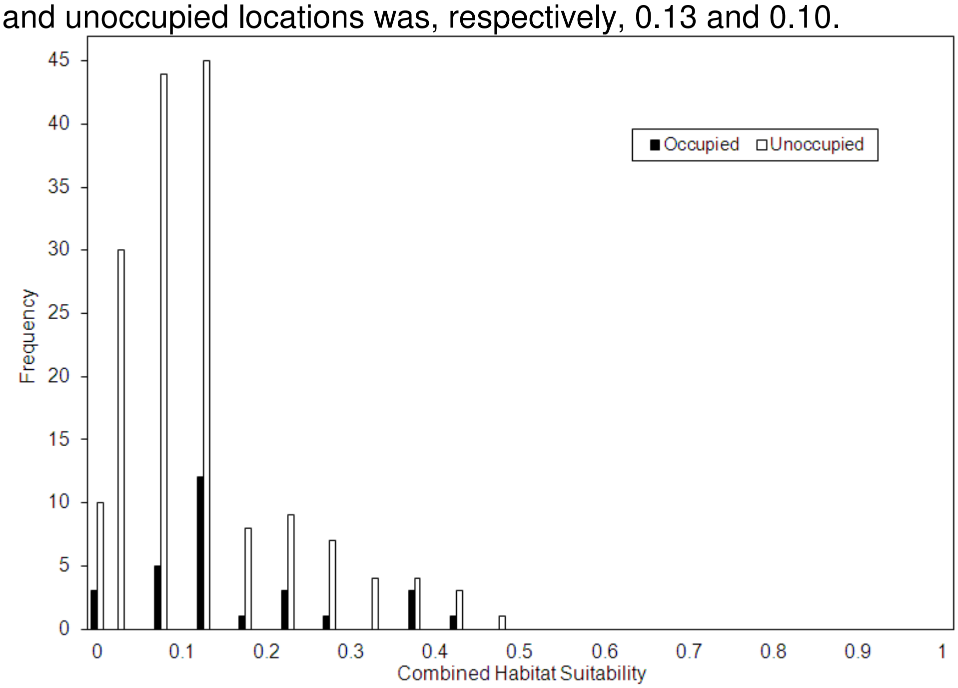


Table 21. Ratio of habitat areas in segment to habitat areas in modeled sites. Entries with an asterisk indicate that the habitat type was not modeled in that segment. Entries with two asterisks indicate that the habitat type was not present in that segment. The ratios were adjusted to account for study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

Habitat Type	Lower Alluvial Segment
Main Channel Glide	3.42
Main Channel Pool	11.42
Main Channel Riffle	3.28
Main Channel Run	4.93
Side Channel Glide	*
Side Channel Pool	42.25
Side Channel Riffle	*
Side Channel Run	43.80
Restored Channel	1.41

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

DISCUSSION

Habitat Mapping

Traditionally habitat mapping is done in a linear fashion going downstream. The two-dimensional habitat mapping used in this study is more consistent with a two-dimensional-based hydraulic and habitat modeling of habitat availability. In addition, as shown in Figure 19, two-dimensional habitat mapping better captures the complexity of mesohabitat units in Clear Creek.

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

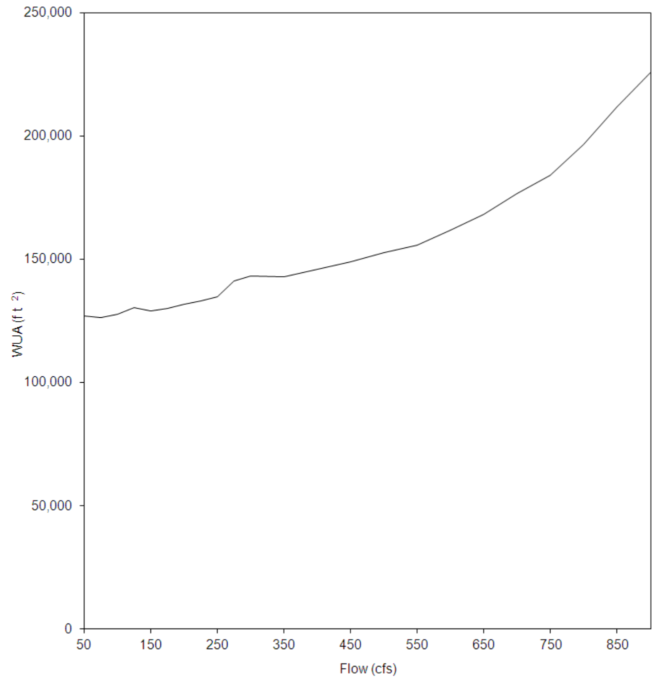


Figure 15. Fall-run Chinook salmon fry rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum fall-run Chinook salmon fry rearing habitat was 50 cfs.

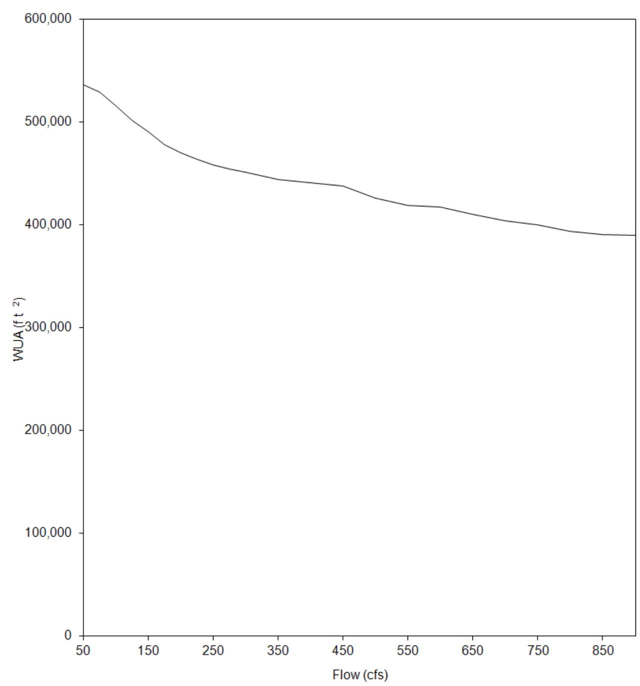


Figure 16. Steelhead/rainbow trout fry rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum steelhead/rainbow trout fry rearing habitat was 50 cfs.

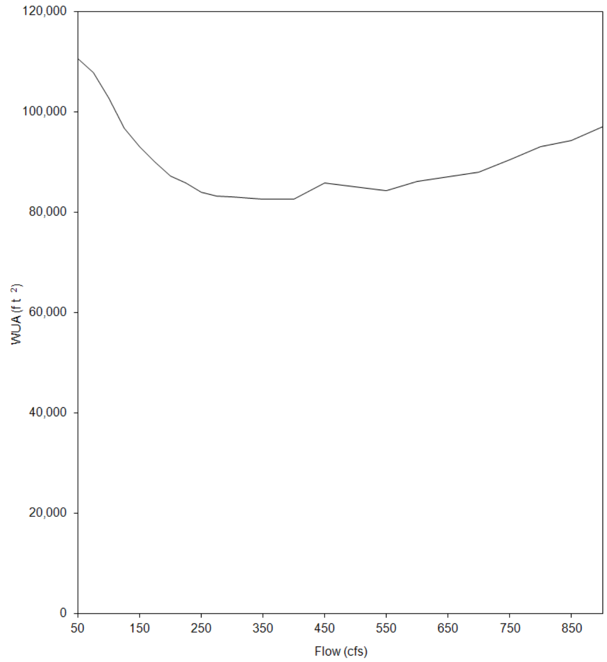


Figure 17. Spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum spring-run Chinook salmon and steelhead/rainbow trout juvenile rearing habitat was 850 cfs.

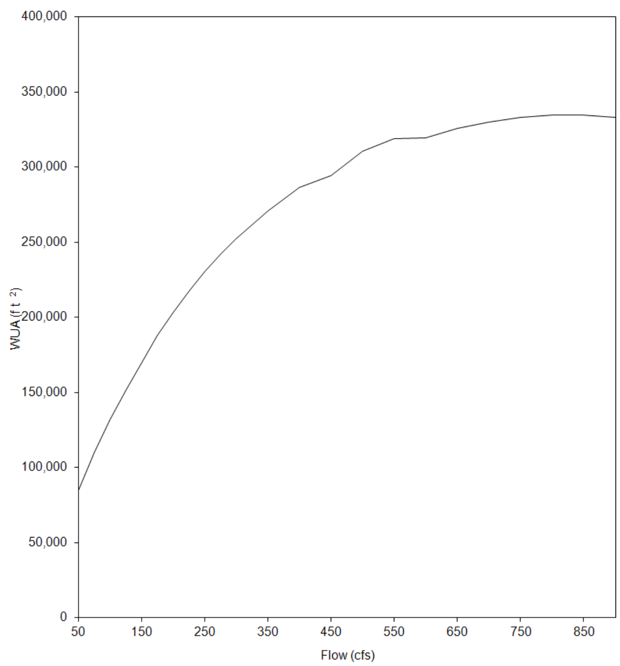


Figure 18. Fall-run Chinook salmon juvenile rearing flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum fall-run Chinook salmon juvenile rearing habitat was 350 cfs.

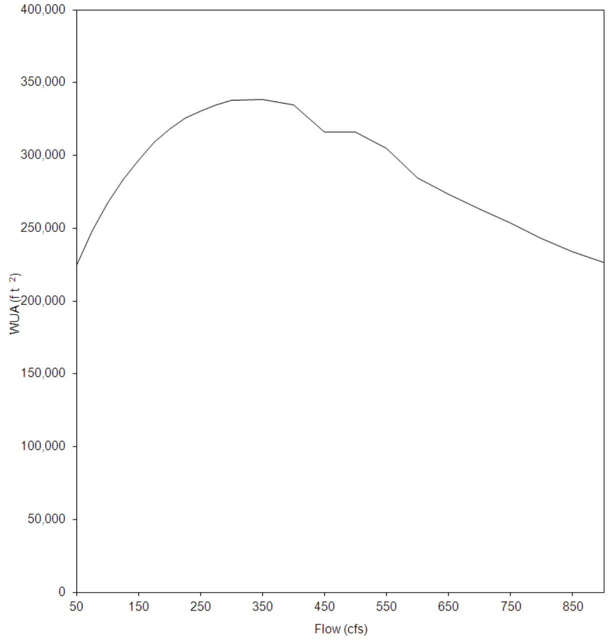


Figure 19. Detail of habitat mapping of the Side Channel Run Pool study site.

PHABSIM WSEL Calibration

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

For the 3B upstream transect, the model, in mass balancing, was decreasing water velocities at high flows so that the known discharge would pass through the increased cross-sectional area. We concluded that this phenomena was caused by channel characteristics which form hydraulic controls at some flows but not others (compound controls), thus affecting upstream water elevations. Accordingly, the performance of IFG4 for this transect was considered adequate despite unusual VAF pattern. We did not regard the deviation in the VAF values for this transect as problematic since RHABSIM was only used to simulate WSELs and not velocities.

RIVER2D Model Construction

In most cases, the portions of the mesh where there was greater than a 0.1 foot (0.03 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.03 m) vertically of the bed file within 1.0 foot (0.3 m) horizontally of the bed file location. Given that we had a 1-foot (0.3 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file.

RIVER2D Model Calibration

In general, the Side Channel Run Pool, 3B and ACID Glide sites at the highest simulated flow had WSELs on the two banks that differed by more than 0.1 foot. In all three cases, we were uncertain which model was responsible for the discrepancies between the WSELs predicted by RIVER2D and PHABSIM. As a result, we felt that it would be more accurate to calibrate these sites using the measured WSELs for the highest flow within the range of simulated flows. Our general rule is that it is more accurate to calibrate sites using the WSELs simulated by PHABSIM at the highest simulated flow because the RIVER2D model is more sensitive to the bed roughness height multiplier at higher flows, versus lower flows. However, when we have concluded, as for these sites, that the simulation of the WSEL at the upstream transect at the highest simulation flow by PHABSIM is potentially inaccurate, it no longer makes sense to calibrate RIVER2D using the WSELs simulated by PHABSIM at the highest simulation flow. In these cases, we use the fall-back option of calibrating RIVER2D using the WSELs measured at the highest flow within the range of simulation flows.

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

RIVER2D Model Velocity Validation

Differences in magnitude in most cases are likely due to (1) aspects of the bed topography of the site that were not captured in our data collection; (2) operator error during data collection, i.e., the probe was not facing precisely into the direction of current; (3) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations; and (4) the measured velocities on the transects being the component of the velocity in the downstream direction, while the velocities predicted by the 2-D model were the absolute magnitude of velocity[24]. We attribute most of the differences between measured and predicted velocities to noise in the measured velocity measurements. The 2-D model integrates effects from the surrounding elements at each point. Thus, point measurements of velocity can differ from simulated values simply due to the local area integration that takes place. As a result, the area integration effect noted above will produce somewhat smoother lateral velocity profiles than the observations. For the Side Channel Run Pool and Tarzan Pool downstream transects and ACID Glide upstream transect, where RIVER2D over or under-predicted the velocities on both sides of the channel, we attribute this to errors in the bed topography that did not properly characterize features that resulted in faster/slower velocities. For the ACID Glide downstream transect, the over-predicted velocities on the north and south sides of the channel can be attributed to errors in the velocity measurement on the transect (being too low), since the discharge calculated from the measured velocities was 22 percent lower than the gage flow.

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

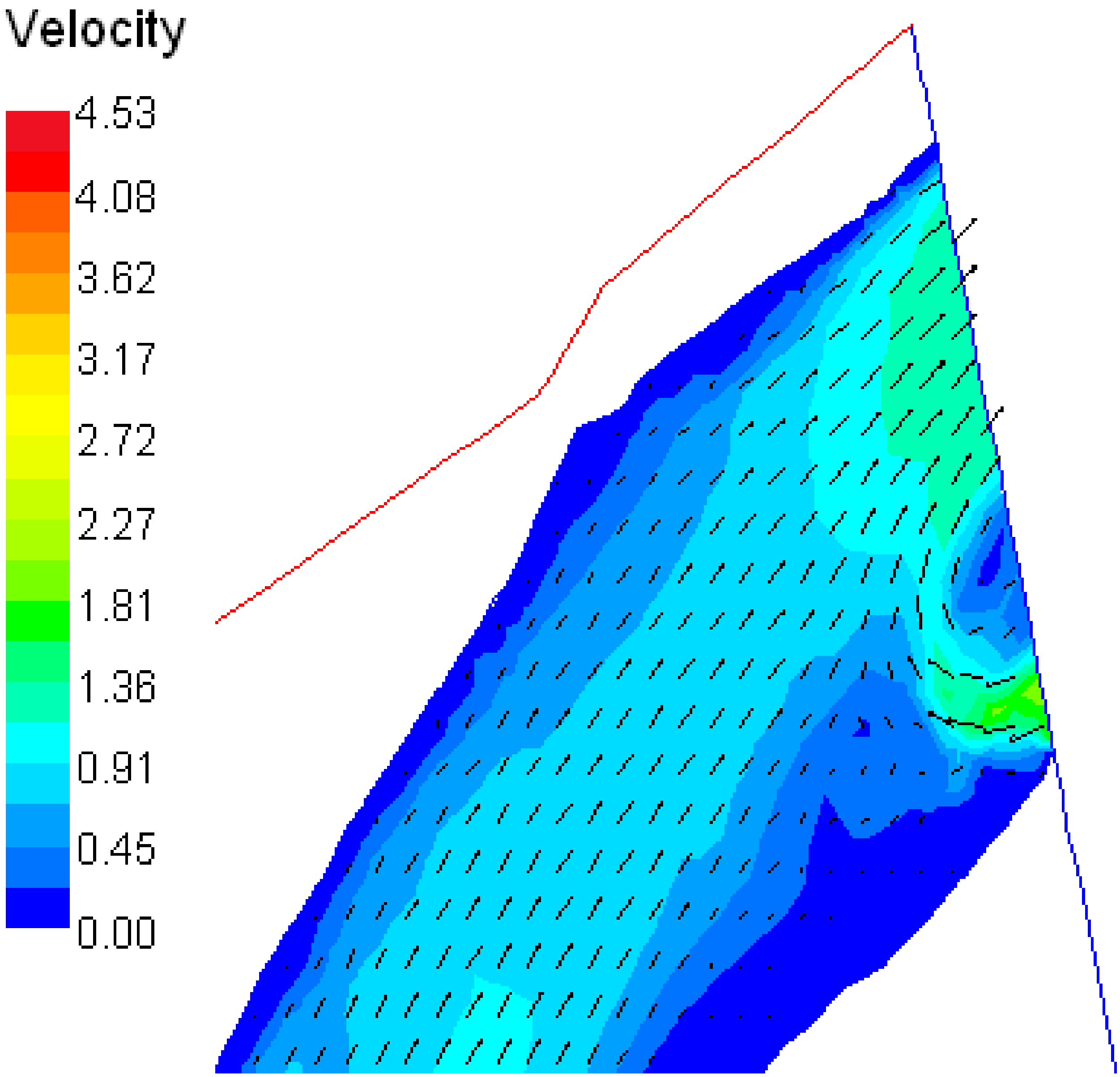
RIVER2D Model Simulation Flow Runs

The three lowest simulation flow run cdg files for North State Riffle, as well as one flow for Side Channel Run Pool and 11 flows for 3B, where the net Q was greater than 1%, were still considered to have a stable solution since the net Q was not changing and the net Q in all cases was less than 5%. In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is within the same range as the accuracy for USGS gages, and is considered acceptable. In the case of the Side Channel Run Pool lowest flow simulation run and 6 of the 3B simulation flows, where the net Q significantly exceeded the 5% level, we consider that a level of uncertainty applies to results for those production files. We attribute the high net Q in the 3B simulation

---

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

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



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

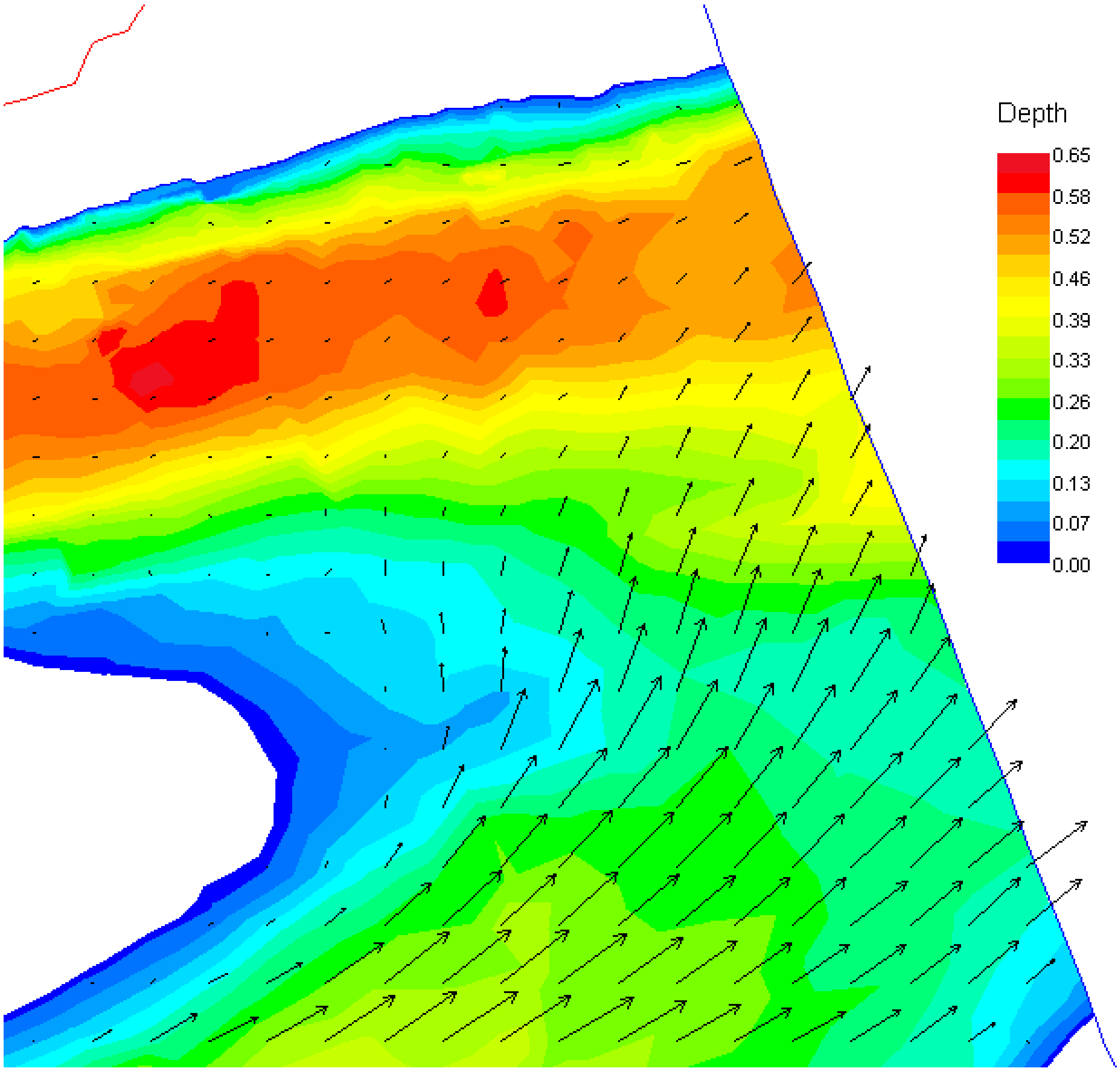
Although a majority of the simulation flow files had Max Froude values that exceeded 1, we considered these production runs to be acceptable since the Froude Number was only greater than 1 at a few nodes, with the vast majority of the area within the site having Froude Numbers less than 1. Again, as described in RIVER2D Model Calibration discussion, these nodes were located either at the water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results.

Habitat Suitability Criteria (HSC) Development

The R^2 values in Tables 16 and 17 in general reflect the large degree of overlap in occupied and unoccupied depths and velocities, as shown in Figures 4 to 7. Low R^2 values are the norm in logistic regression, particularly in comparison with linear regression models (Hosmer and Lemeshow 2000). The R^2 values in this study were significantly lower than those in Knapp and Preisler (1999), Geist et al. (2000) and Guay et al. (2000), which had R^2 values ranging from 0.49 to 0.86. We attribute this difference to the fact that the above studies used a multivariate logistic regression which included all of the independent variables. It would be expected that the proportion of variance (R^2 value) explained by the habitat suitability variables would be apportioned among depth, velocity, adjacent velocity and cover. For example, McHugh and Budy (2004) had much lower R^2 values, in the range of 0.13 to 0.31, for logistic regressions with only one independent variable. It should be noted that the regressions were fit to the raw occupied and unoccupied data, rather than to the frequency histograms shown in Figures 4 through 7. In general, the criteria track the occupied data, but drop off slower than the occupied data due to the frequency of the unoccupied data also dropping over the same range of depths and velocities.

Rubin et al. (1991) present a similar method to logistic regression using fish density instead of presence-absence, and using an exponential polynomial regression, rather than a logistic regression. Rubin et al. (1991) selected an exponential polynomial regression because the distribution of counts of fish resembles a Poisson distribution. We did not select this method for

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



the following reasons: 1) we had low confidence in the accuracy of our estimates of the number of fish in each observation; and 2) while it is reasonable to assume that a school of fish represents higher quality habitat than 1 fish, it is probably unreasonable to assume that, for example, 100 fish represents 100 times better habitat than 1 fish. A more appropriate measure of the effects of the number of fish on habitat quality would probably be to select some measure like log (number of fish + 1), so that 1-2 fish would represent a value of one, 3-30 fish would represent a value of two, 31-315 fish would represent a value of three, and 316-3161 fish would represent a value of four[25]. We are not aware of any such measure in the literature, nor are we aware of how we could determine what an appropriate measure would be.

Figures 22 to 25 compare the four to five sets of HSC from this study. Consistent with the scientific literature (Gido and Propst 1999, Sechnick et al. 1986, Baltz and Moyle 1984 and Moyle and Vondracek 1985), our data showed that larger fish select deeper and faster conditions than smaller fish. The criteria also show a consistent selection for composite cover (instream woody plus overhead – cover codes 3.7 and 4.7). Composite cover likely is an important aspect of juvenile salmonid habitat because it reduces the risk of both piscivorous and avian predation. The cover criteria also suggest that cobble cover is more important for Chinook salmon and steelhead/rainbow trout juveniles than for steelhead/rainbow trout fry or Chinook salmon fry.

Figures 26 to 33 compare the fall-run Chinook salmon criteria from this study with the criteria from other studies. See U.S. Fish and Wildlife Service (2011b) for a comparison of the spring-run Chinook salmon and steelhead/rainbow trout criteria from this study with criteria from other studies. We compared the fall-run Chinook salmon juvenile depth and velocity criteria with those from criteria with those from Bovee (1978), since these criteria are commonly used in instream flow studies as reference criteria. A previous instream flow study on Clear Creek (California Department of Water Resources 1985) used the Bovee (1978) criteria to simulate juvenile rearing habitat for fall-run Chinook salmon. Since Bovee (1978) does not have criteria for Chinook salmon fry, we used another commonly cited reference criteria (Raleigh et al. 1986). We also used criteria from Battle Creek (TRPA 1988) and the Feather River (California Department of Water Resources 2005), since these streams are also located in the Sacramento River basin. For cover, we were limited to comparing the criteria from this study to criteria we had developed on other studies which used the same, unique cover coding system. We compared the fall-run Chinook salmon fry and juvenile criteria from this study to those we had developed for fall-run Chinook salmon on the Sacramento River (Gard 2006) and the Yuba River (U.S. Fish and Wildlife Service 2010). For adjacent velocity, the only other HSC we were able to identify for Chinook salmon fry or juvenile rearing were the criteria we developed on the Sacramento River (Gard 2006) and the Yuba River (U.S. Fish and Wildlife Service 2010).

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

---

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

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

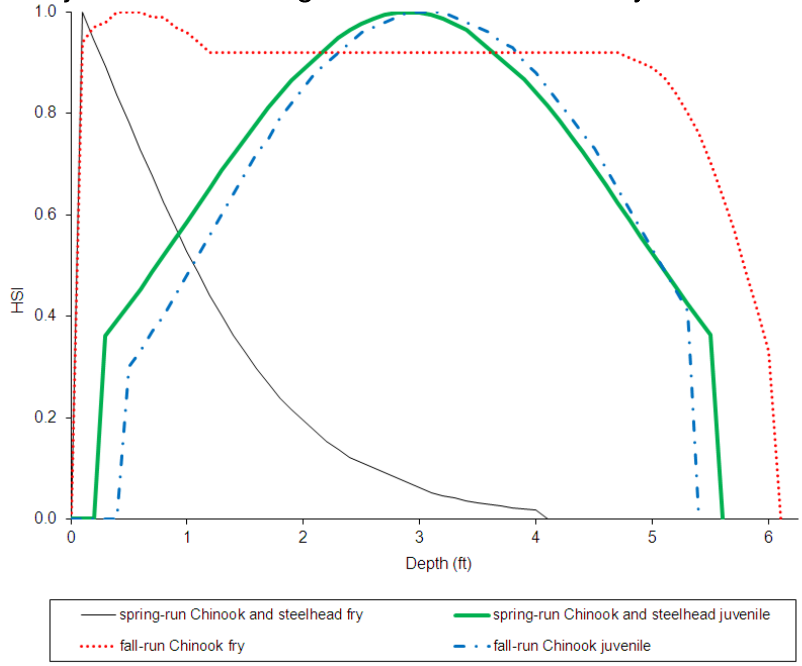


Figure 23. Comparison of velocity HSC from this study. These criteria indicate that there was a slower rate of decline of suitability with increasing velocity for Chinook and steelhead/rainbow trout juveniles than for Chinook salmon and steelhead/ rainbow trout fry.

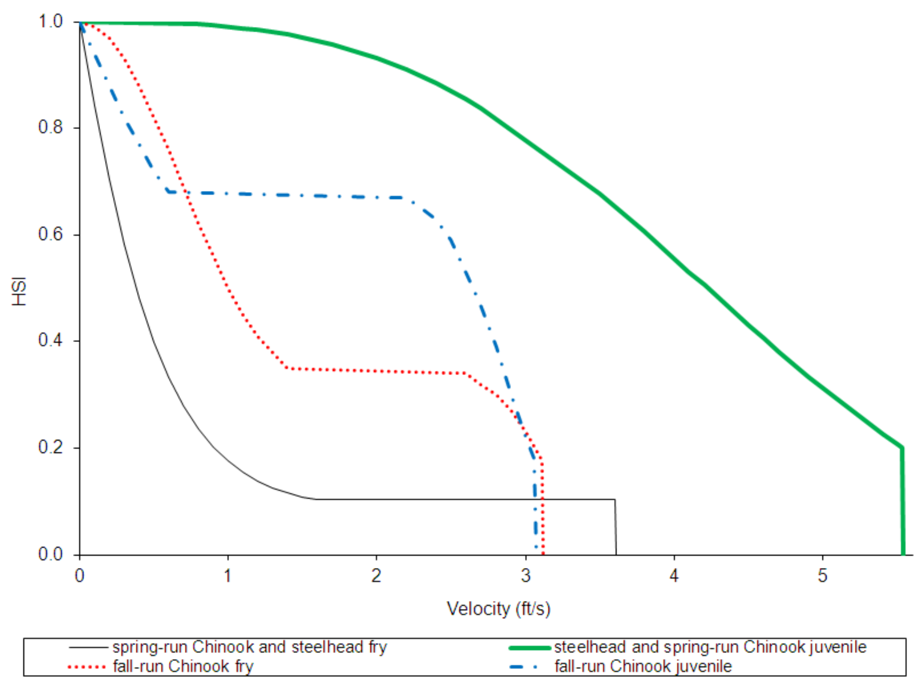


Figure 24. Comparison of cover HSC from this study. These criteria indicate that cobble had a lower suitability for fry than juveniles, but that there was a consistent selection of composite cover (instream woody plus overhead).

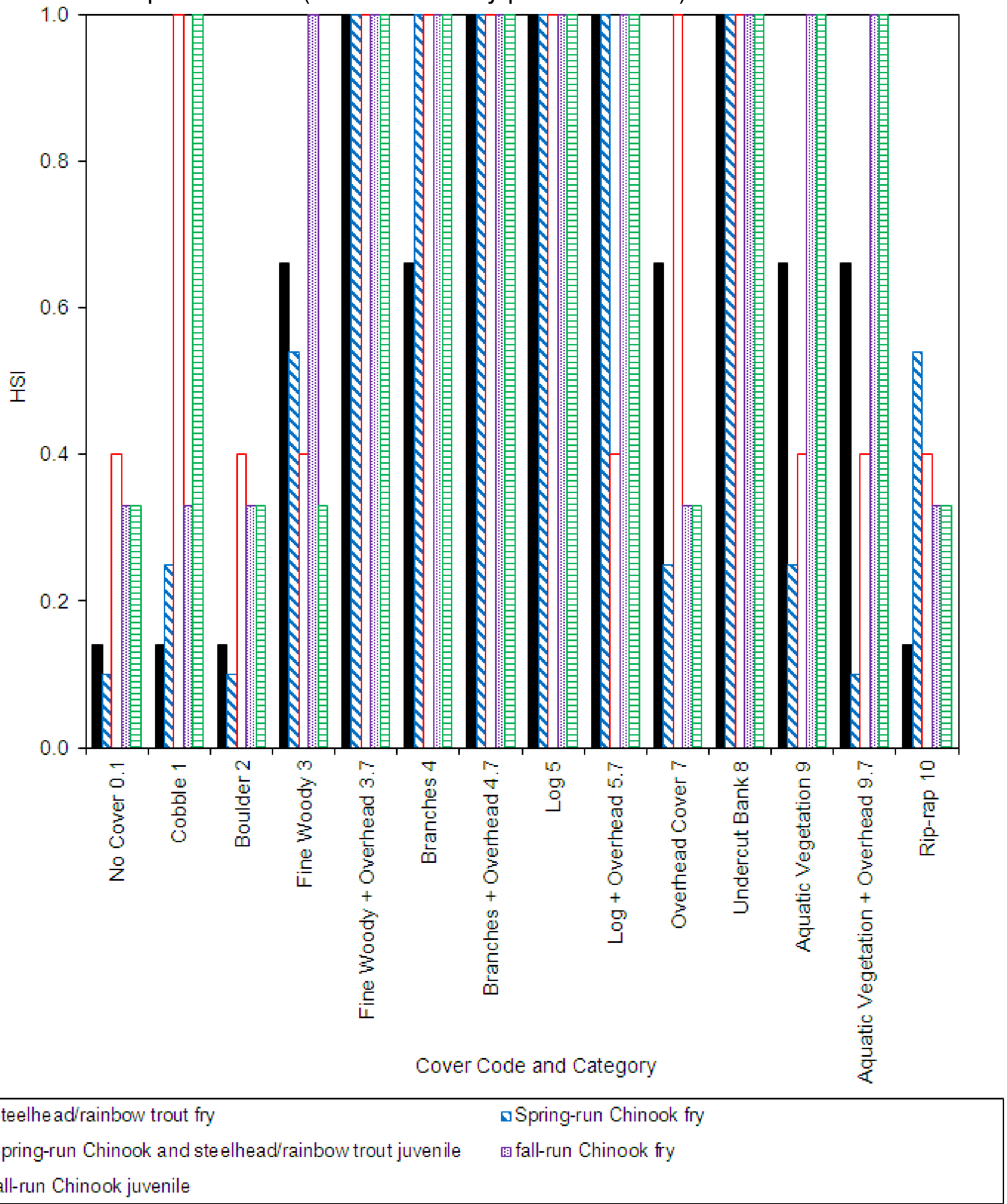


Figure 25. Comparison of adjacent velocity HSC from this study. These criteria indicate that adjacent velocity was most important for spring-run Chinook salmon and steelhead juveniles. There were no adjacent velocity criteria for spring-run Chinook salmon fry.

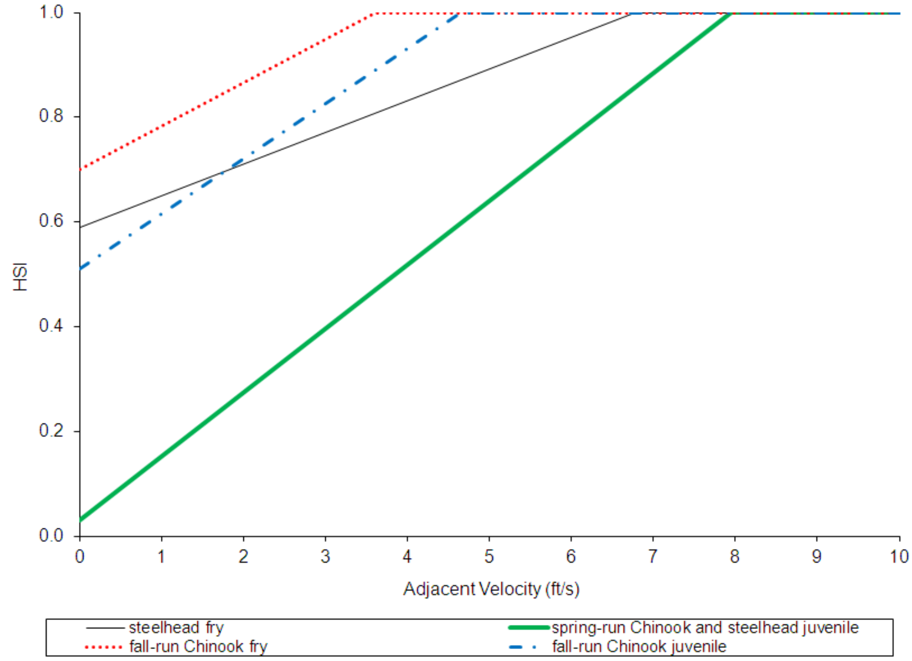


Figure 26. Comparison of fall-run Chinook salmon fry depth HSC from this study with other fall-run Chinook salmon fry depth HSC. The criteria from this study show high suitability for a wider range of depths than the other criteria.

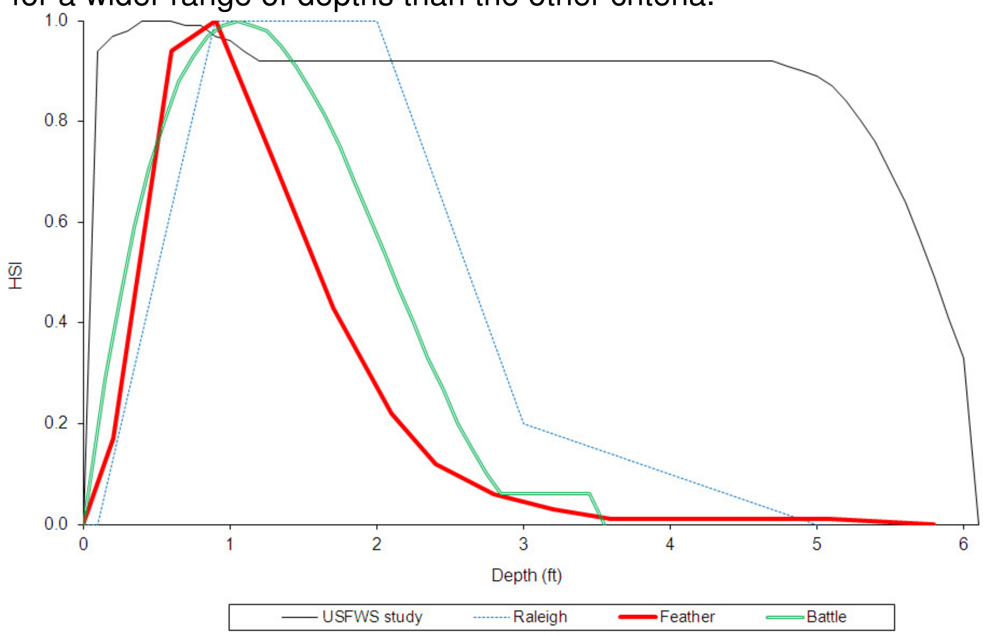


Figure 27. Comparison of fall-run Chinook salmon fry velocity HSC from this study with other fall-run Chinook salmon fry velocity HSC. The criteria from this study show non-zero suitability, albeit at low values, for faster conditions than other criteria.

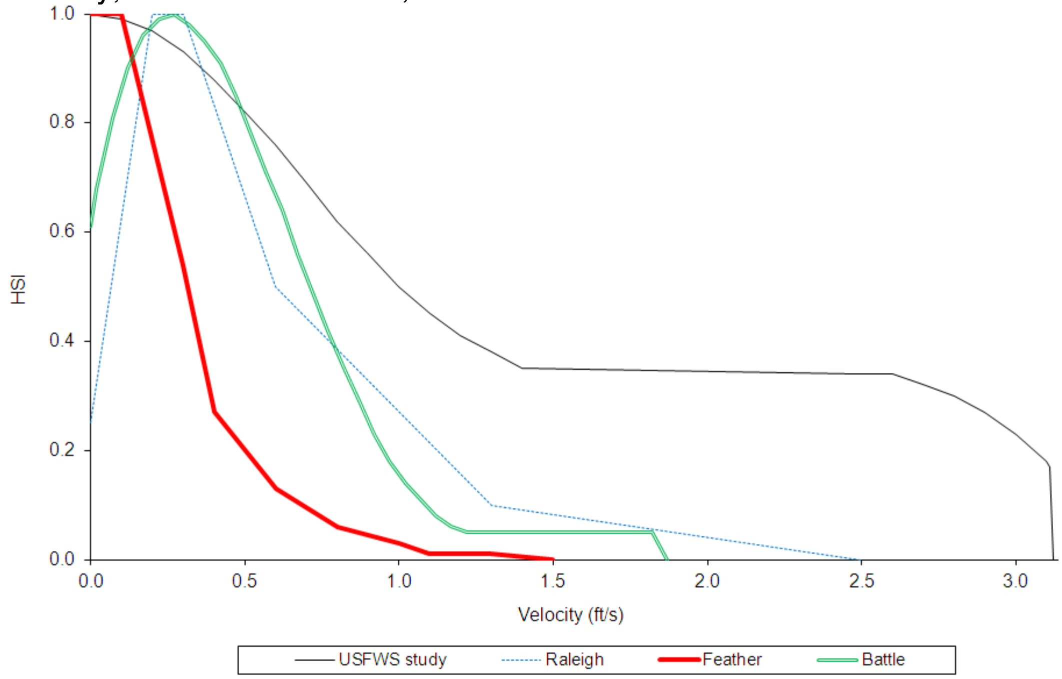


Figure 28. Comparison of fall-run Chinook salmon juvenile depth HSC from this study with other fall-run Chinook salmon juvenile depth HSC. The criteria from this study fall within the range of the other criteria.

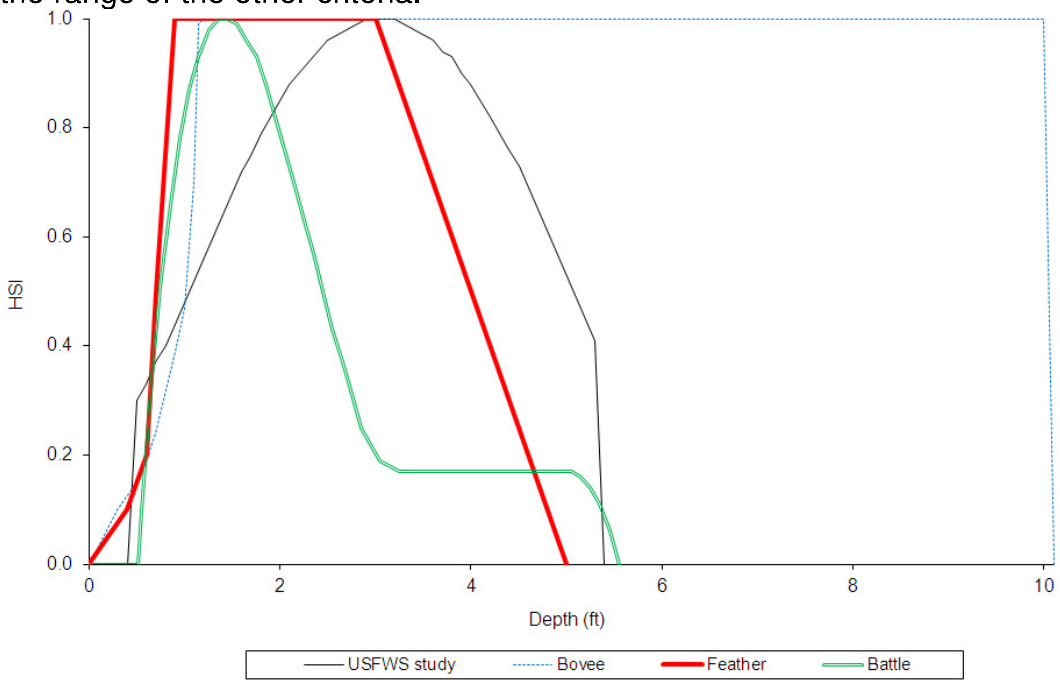


Figure 29. Comparison of fall-run Chinook salmon juvenile velocity HSC from this study with other fall-run Chinook salmon juvenile velocity HSC. The criteria from this study show relatively high suitability for faster conditions than other criteria.

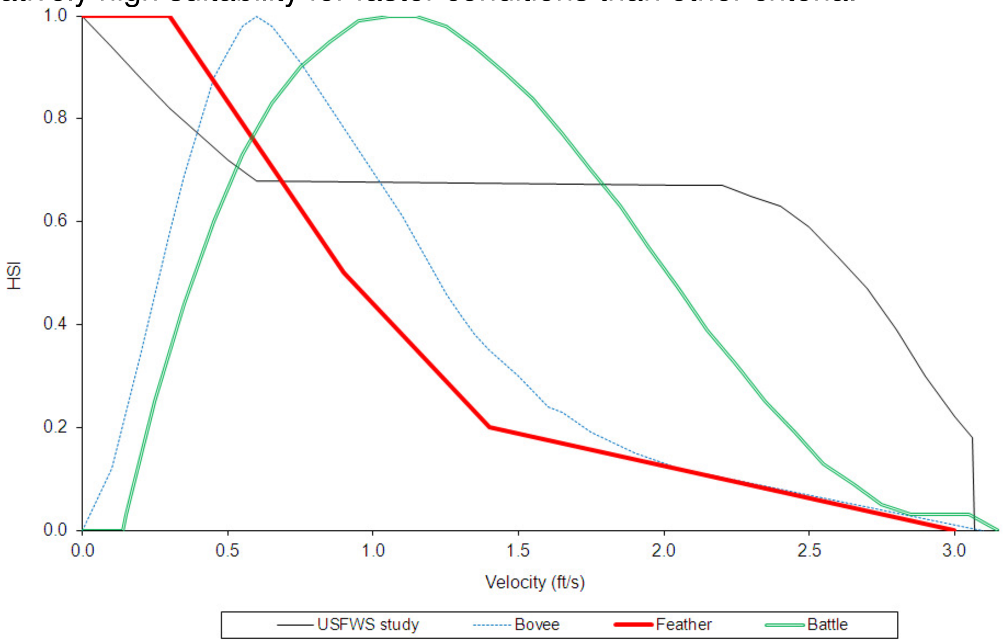


Figure 30. Comparison of fall-run Chinook salmon fry adjacent velocity HSC from this study with other Chinook salmon fry adjacent velocity HSC. The criteria indicate that adjacent velocity was less important for Clear Creek fall-run Chinook salmon juvenile than for Yuba River Chinook salmon juvenile.

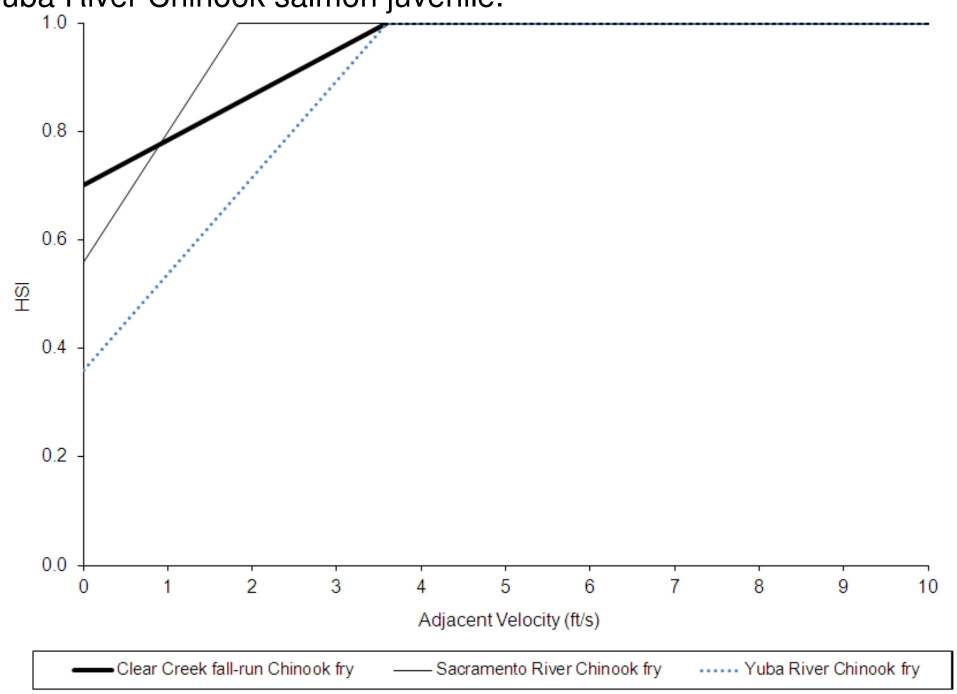
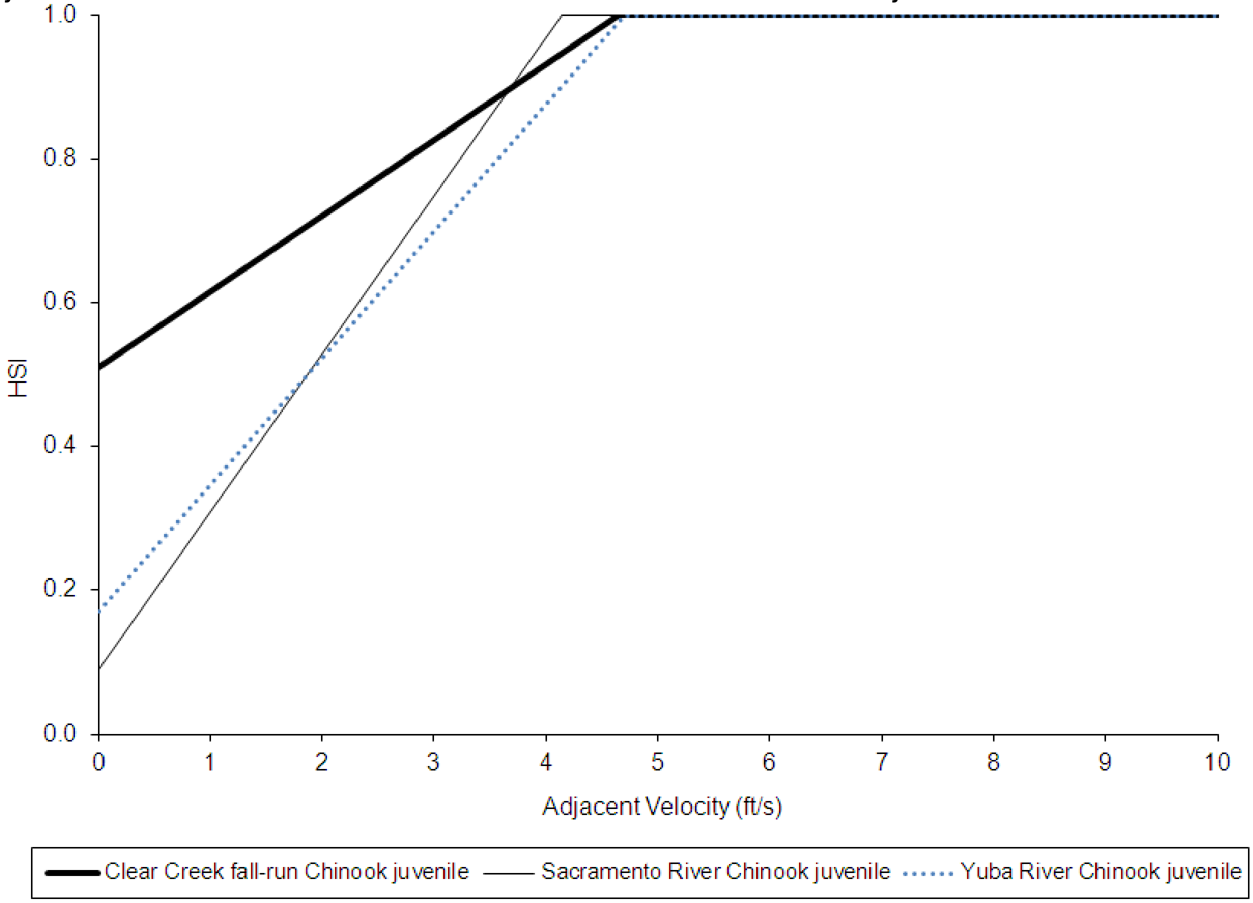


Figure 31. Comparison of fall-run Chinook salmon juvenile adjacent velocity HSC from this study with other Chinook salmon juvenile adjacent velocity HSC. The criteria indicate that adjacent velocity was less important for Clear Creek Chinook salmon juvenile than for Sacramento and Yuba River Chinook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



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

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

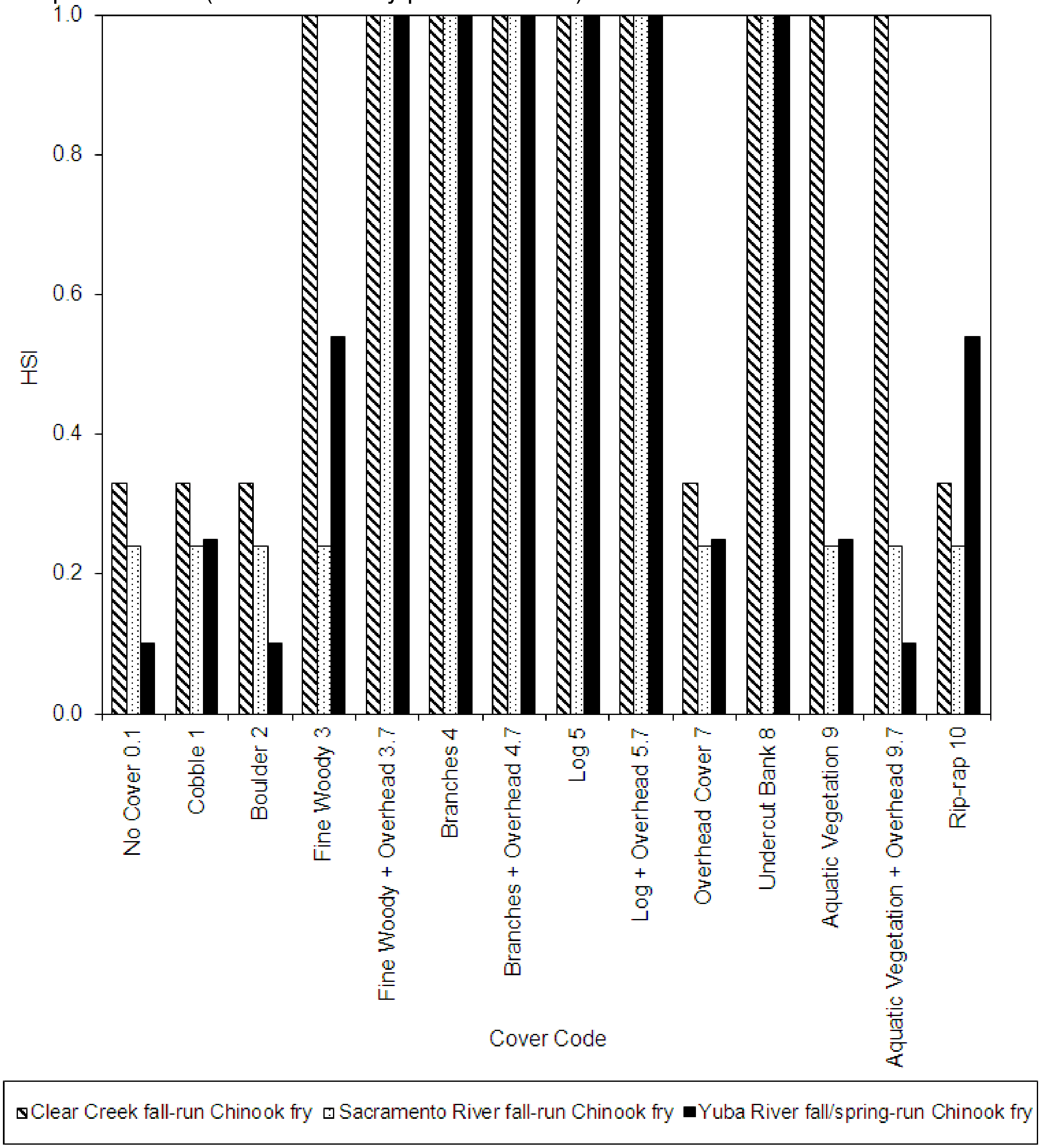
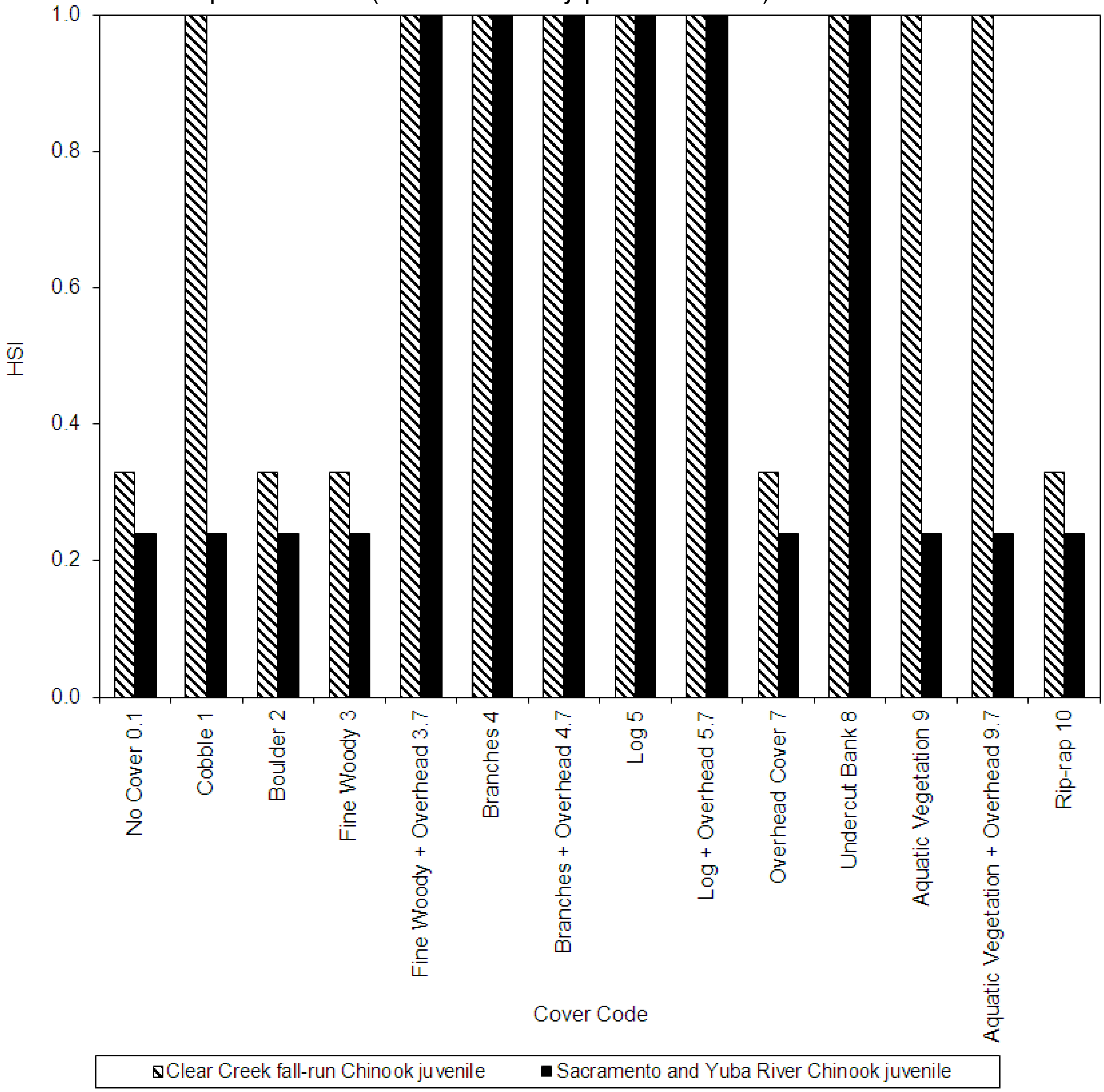


Figure 33. Comparison of fall-run Chinook salmon juvenile cover HSC from this study with other Chinook salmon juvenile cover HSC. These criteria indicate a consistent selection of composite cover (instream woody plus overhead).



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

Biological Validation

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

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

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

Habitat Simulation

There was considerable variation from site to site in the flow-habitat relationships shown in Appendix K. For example, the flow with the peak amount of habitat for the six glides in the Lower Alluvial Segment varied from 50 to 900 cfs (Figures 34 to 38). We attribute the variation from site to site to complex interactions of the combinations of availability and suitability of depth, velocity, adjacent velocity and cover, as they vary with flow. The overall flow-habitat relationships for each species/race/life stage, as shown in Figures 14 to 18, capture the inter-site variability in flow-habitat relationships by weighting the amount of habitat for each mesohabitat unit in each site by the proportion of each mesohabitat type present within the Lower Alluvial Segment.

An earlier study (California Department of Water Resources 1985) also modeled fall-run Chinook salmon and steelhead rearing habitat in Clear Creek between Whiskeytown Dam and the confluence with the Sacramento River for flows of 40 to 500 cfs. The previous study did not model spring-run Chinook salmon or fall-run Chinook salmon fry rearing habitat. A representative reach approach was used to place transects, instead of using habitat mapping to extrapolate to the entire segment. PHABSIM was used to model habitat, instead of two-dimensional models. As shown in Figures 39 to 42, the results from this study predict a peak amount of habitat at slightly lower or much higher flows than the California Department of Water Resources (1985) study. The difference between studies in the flow with the peak amount of habitat varied by species. The differences between the results of the two studies can primarily be attributed to the following: 1) the California Department of Water Resources (1985) study used HSC generated only from use data, as opposed to the criteria generated with logistic regression in this study; 2) the California Department of Water Resources (1985) study did not use cover or adjacent velocity criteria; and 3) the use of PHABSIM in the California Department of Water Resources (1985) study, versus 2- D modeling in this study. We conclude that the flow-habitat results in the California Department of Water Resources (1985) study were biased towards lower flows, since the HSC, generated only from use data and without cover or adjacent velocity criteria, were biased towards slower and shallower conditions.

Factors Causing Uncertainty

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

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

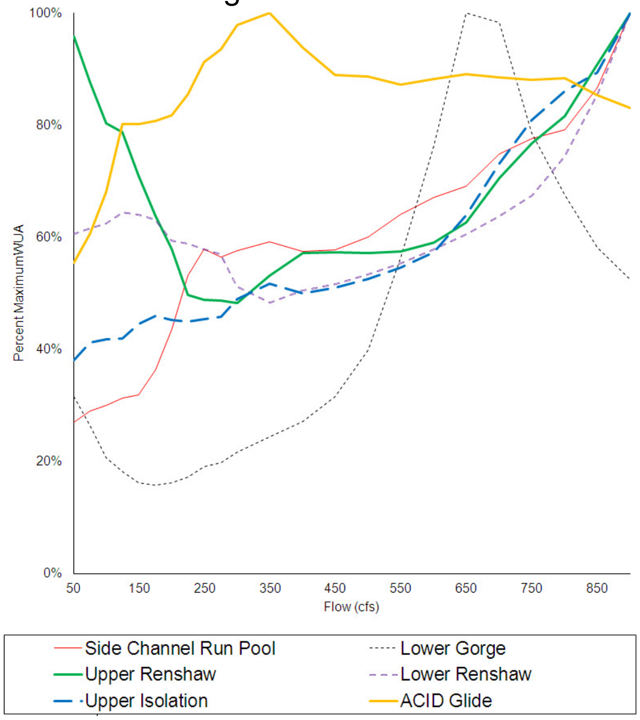


Figure 35. Comparison of spring-run Chinook salmon and steelhead/rainbow trout juvenile flow-habitat relationship for the six glides in the Lower Alluvial Segment.

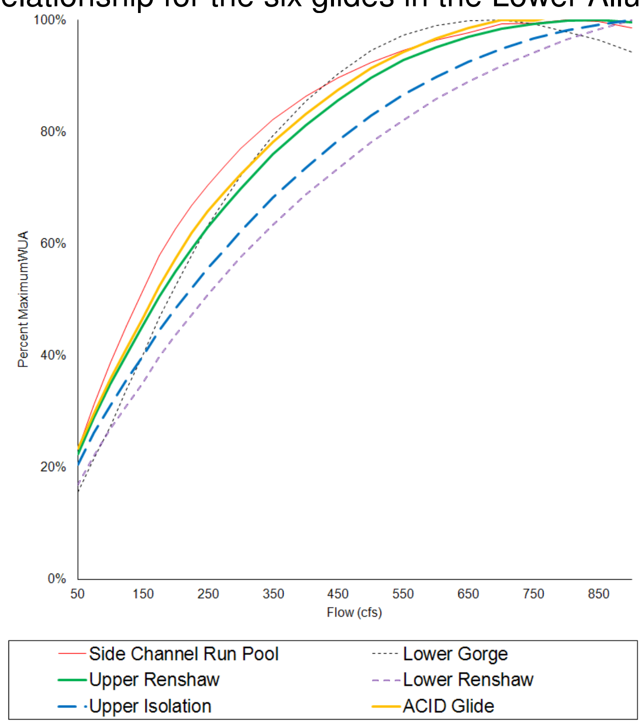


Figure 36. Comparison of steelhead/rainbow trout fry flow-habitat relationship for the six glides in the Lower Alluvial Segment.

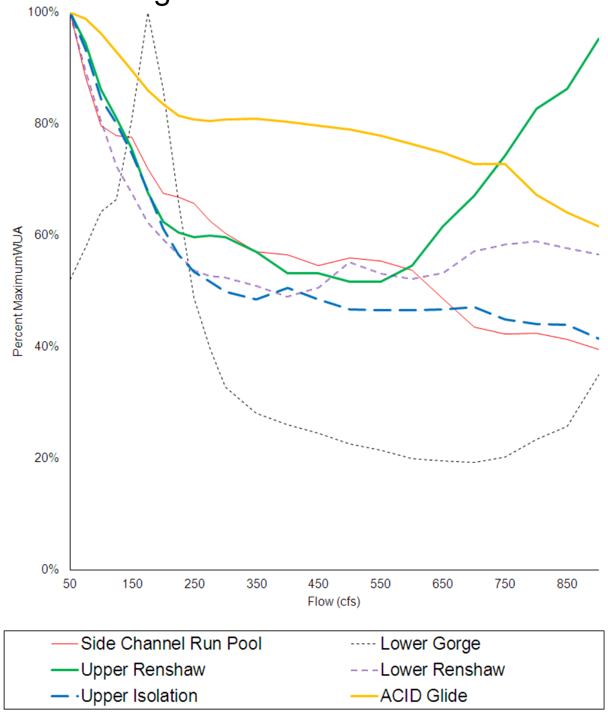


Figure 37. Comparison of fall-run Chinook salmon fry flow-habitat relationship for the six glides in the Lower Alluvial Segment.

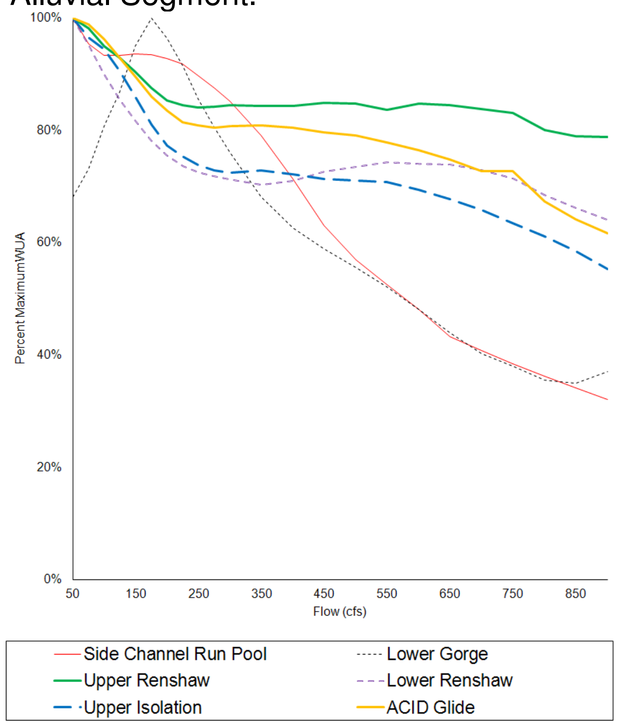


Figure 38. Comparison of fall-run Chinook salmon juvenile flow-habitat relationship for the six glides in the Lower Alluvial Segment .

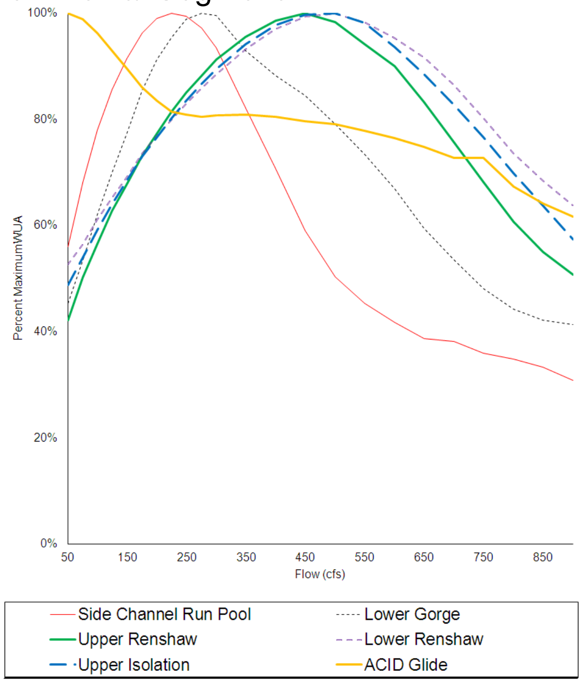


Figure 39. Comparison of steelhead/rainbow trout fry flow-habitat relationships from this study and the CDWR (1985) study. This study predicted the peak habitat at a slightly lower flow than the CDWR (1985) study.

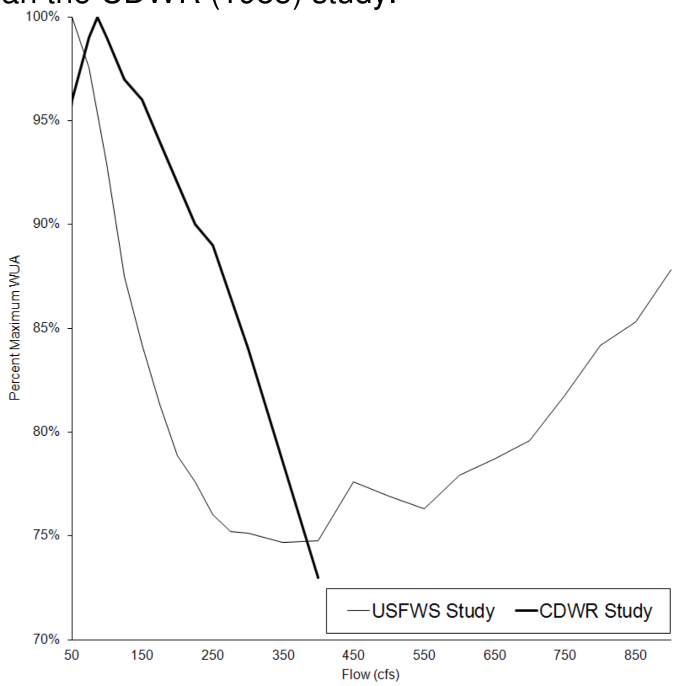


Figure 40. Comparison of spring-run Chinook salmon juvenile flow-habitat relationship from this study and fall-run Chinook salmon juvenile flow-habitat relationship from the CDWR (1985) study. This study predicted the peak habitat at a much higher flow than the CDWR (1985) study.

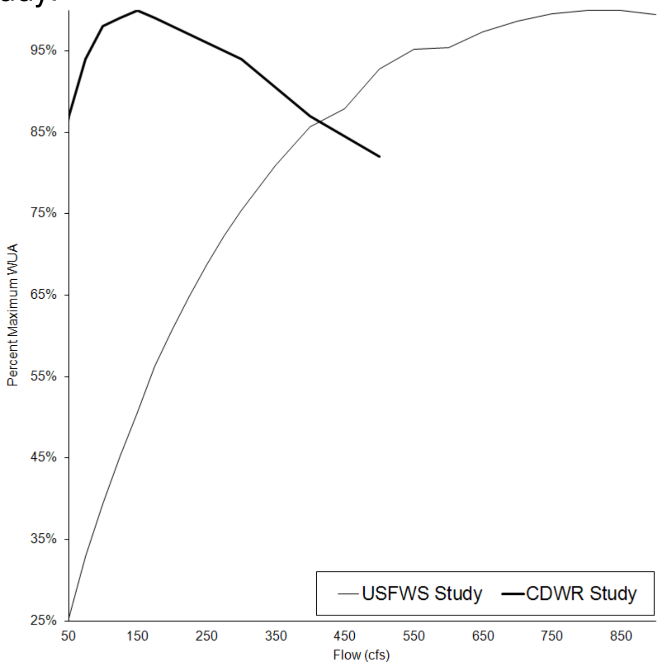


Figure 41. Comparison of fall-run Chinook salmon juvenile flow-habitat relationships from this study and the CDWR (1985) study. This study predicted the peak habitat at a much higher flow than the CDWR (1985) study.

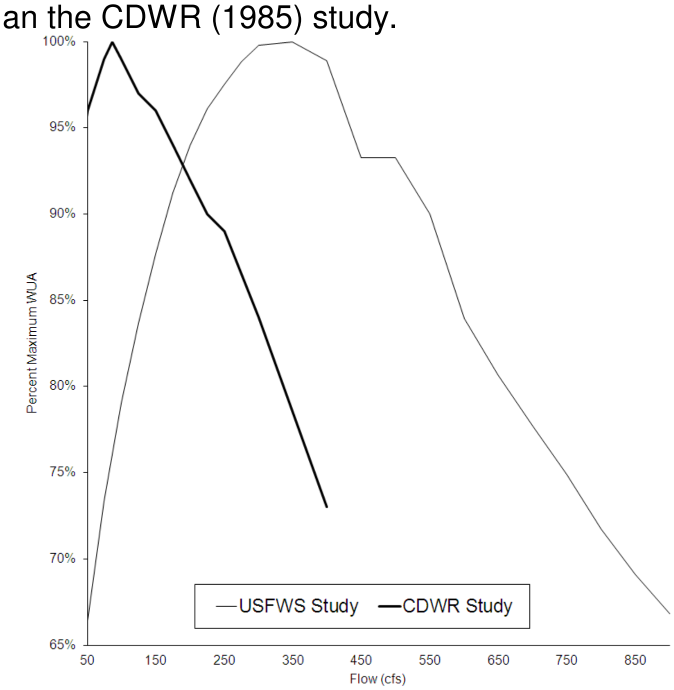
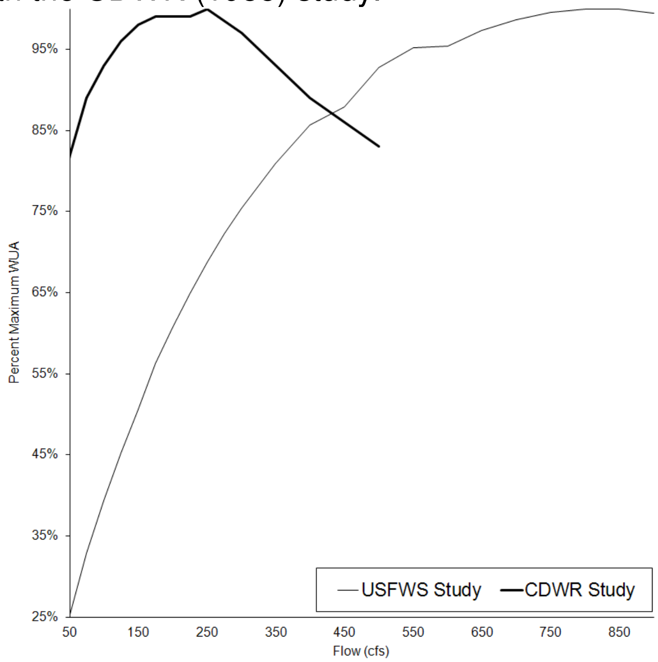


Figure 42. Comparison of steelhead/rainbow trout juvenile flow-habitat relationships from this study and the CDWR (1985) study. This study predicted the peak habitat at a much higher flow than the CDWR (1985) study.



between sampled versus population habitat suitability criteria data; and 7) potential biases in juvenile criteria due to survey techniques. Based on the number of study sites and the percentage of mesohabitat area found in the study sites, we believe that there is a low level of uncertainty associated with the extrapolation from the study sites to the entire lower alluvial segment.

We believe that over or under-predicted velocities at all sites would have a minimal effect on the overall flow-habitat relationships, given the high correlation between measured and predicted velocities. Specifically, the effects of over-predicted velocities would be cancelled out by the effect of under-predicted velocities, given the lack of bias in velocity predictions. The overall flow-habitat relationship is driven by the change in the distribution of depths and velocities with flow. The distribution of velocities would not be affected by over or under-predicted velocities because over-predicted velocities would have the opposite effect on the distribution of velocities as under-predicted velocities. Similarly, we believe that errors in bed bathymetry data, which would cause over-prediction or under-prediction of depths, would have a minimal effect on the overall flow-habitat relationships. Specifically, the effects of over-predicted depths would be cancelled out by the effect of under-predicted depths. The overall flow-habitat relationship is driven by the change in the distribution of depths and velocities with flow. The distribution of depths would not be affected by over or under-predicted depths because over-predicted depths would have the opposite effect on the distribution of depths as under-predicted depths.

The effects of discretization size and density of bed topography data on the flow-habitat relationships given in Appendix L are unknown but likely minor. Errors in velocity measurements used to develop habitat suitability criteria would likely be a minor source of uncertainty on the flow-habitat relationships given in Appendix L. Since errors in velocity measurement are random and not biased, effects of positive errors in velocity measurements would be cancelled out by the effect of negative errors in velocity measurements. The overall velocity habitat suitability curve is driven by the distribution of velocities. The distribution of velocities would not be affected by positive or negative errors in velocity measurements because positive errors in velocity measurements would have the opposite effect on the distribution of velocities as negative errors in velocity measurements.

The most likely source of uncertainty in the flow-habitat relationships given in Appendix L is the potential for difference between sampled versus population habitat suitability criteria data. The uncertainty from this factor could be quantified by a bootstrap analysis of the sampled HSC data to develop 95 percent confidence limit HSC, which could be applied to the hydraulic models of the ten study sites to determine 95 percent confidence limits for the flow-habitat relationships given in Appendix L. If juveniles were detecting the snorkelers and fleeing before we could observe them to collect HSC data, the HSC data could be biased towards fish that are more in the open, versus fish that are closer to cover. The likely effect of such a bias would be to overestimate the habitat value of no cover. We are unable to quantify what effect such a bias would have on the resulting flow-habitat relationships, other than it would tend to shift the peak of the curve to higher flows.

CONCLUSION

The model developed in this study is predictive for flows ranging from 50 to 900 cfs. The results of this study can be used to evaluate 276 different hydrograph management scenarios (each of the 23 simulation flows in each of the 12 rearing months). For example, increasing flows from 200 cfs to 300 cfs in September would result in an increase of 6 % of habitat during this month for fall-run Chinook salmon juvenile rearing in the Lower Alluvial Segment. Based on the conceptual model presented in the introduction, this increase in rearing habitat could increase fry and juvenile growth and survival, increasing rearing success which could result in an increase in spring-run Chinook salmon and steelhead/rainbow trout populations. We do not feel that there are any significant limitations of the model, within the context of the assumptions given in the introduction and the overall capabilities of models of habitat for aquatic organisms (Gore and Nestler 1998, Hudson et al. 2003, Maughan and Barrett 1991). This study supported and achieved the objective of producing models predicting the availability of physical habitat in the Lower Alluvial segment of Clear Creek for spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing over a range of stream flows. The results of this study are intended to support or revise the flow recommendations in the introduction. The results of this study suggest that the flow recommendations in the CVPIA AFRP during the spring-run and fall-run Chinook salmon and steelhead/rainbow trout rearing period of October-September (150-200 cfs) may not be close to achieving maximum habitat availability and productivity for rearing spring-run Chinook salmon and steelhead/rainbow trout in Clear Creek (51 to 84 % of maximum WUA), but may be close to achieving maximum habitat availability and productivity for rearing fall-run Chinook salmon in Clear Creek (88 to 94 % of maximum WUA) . Given the much larger population size of fall-run Chinook salmon, versus spring-run Chinook salmon (CDFG 2012) and steelhead, habitat is much more likely to be limiting for fall-run Chinook salmon.

REFERENCES

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

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

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

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

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

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

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

CDFG 2012. Grandtab. California Central Valley Sacramento and San Joaquin River Systems Chinook Salmon Escapement Hatcheries and Natural Areas. http://www.calfish.org/LinkClick.aspx?fileticket=k5ZkkcnoxZg%3d&tabid=104&mid=524

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Thomas R. Payne and Associates (TRPA). 1998. Battle Creek fisheries studies. Task 2: habitat suitability criteria. Draft report to CDFG, Redding, CA.

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

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

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

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

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

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

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

U.S. Fish and Wildlife Service. 2011a. Flow-habitat relationships for fall-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Clear Creek Road and the Sacramento River. U.S. Fish and Wildlife Service: Sacramento, CA.

U.S. Fish and Wildlife Service. 2011b. Flow-habitat relationships for spring-run Chinook salmon and steelhead/rainbow trout rearing in Clear Creek between Whiskeytown Dam and Clear Creek Road. U.S. Fish and Wildlife Service: Sacramento, CA.

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

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

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

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

APPENDIX A
HABITAT MAPPING DATA

Habitat distribution identified in the Clear Creek Lower Alluvial Segment

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
1	Main Channel Glide	9,468
2	Main Channel Run	16,646
3	Main Channel Riffle	9,113
4	Side Channel Pool	2,994
5	Side Channel Run	654
6	Side Channel Riffle	689
7	Main Channel Run	20,365
8	Main Channel Pool	13,333
9	Main Channel Run	65,995
10	Main Channel Pool	50,269
11	Side Channel Pool	2,470
12	Main Channel Run	9,586
13	Main Channel Riffle	19,734
14	Main Channel Run	9,833
15	Main Channel Pool	9,772
16	Main Channel Run	26,270
17	Main Channel Pool	34,806
18	Side Channel Run	9,017
19	Side Channel Run	5,713
20	Main Channel Run	21,026
21	Main Channel Pool	58,489
22	Main Channel Run	9,873
23	Main Channel Run	13,119
24	Main Channel Run	115,852
25	Side Channel Pool	5,106
26	Side Channel Glide	1,999
27	Side Channel Riffle	773
28	Side Channel Pool	3,469
29	Side Channel Riffle	694
30	Main Channel Pool	10,085
31	Main Channel Run	32,109
32	Side Channel Run	5,104
33	Main Channel Run	9,943
34	Main Channel Pool	8,133
35	Main Channel Run	8,972

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
36	Main Channel Pool	9,694
37	Side Channel Run	1,466
38	Side Channel Pool	1,320
39	Main Channel Glide	9,778
40	Main Channel Pool	2,447
41	Main Channel Run	47,456
42	Main Channel Pool	9,985
43	Side Channel Run	1,070
44	Side Channel Pool	820
45	Side Channel Run	995
46	Side Channel Pool	862
47	Main Channel Run	26,416
48	Cascade	2,510
49	Main Channel Run	30,480
50	Main Channel Pool	13,799
51	Main Channel Run	5,148
52	Side Channel Pool	1,861
53	Side Channel Pool	2,939
54	Side Channel Pool	1,432
55	Side Channel Run	1,310
56	Side Channel Pool	1,170
57	Side Channel Run	1,675
58	Side Channel Pool	570
59	Cascade	22,470
60	Main Channel Pool	11,801
61	Main Channel Run	2,040
62	Main Channel Pool	10,524
63	Main Channel Glide	1,785
64	Main Channel Glide	3,477
65	Main Channel Run	11,528
66	Main Channel Pool	7,993
67	Main Channel Run	9,243
68	Main Channel Pool	7,775
69	Main Channel Glide	7,644
70	Main Channel Pool	23,504
71	Main Channel Riffle	3,159
72	Main Channel Run	11,471

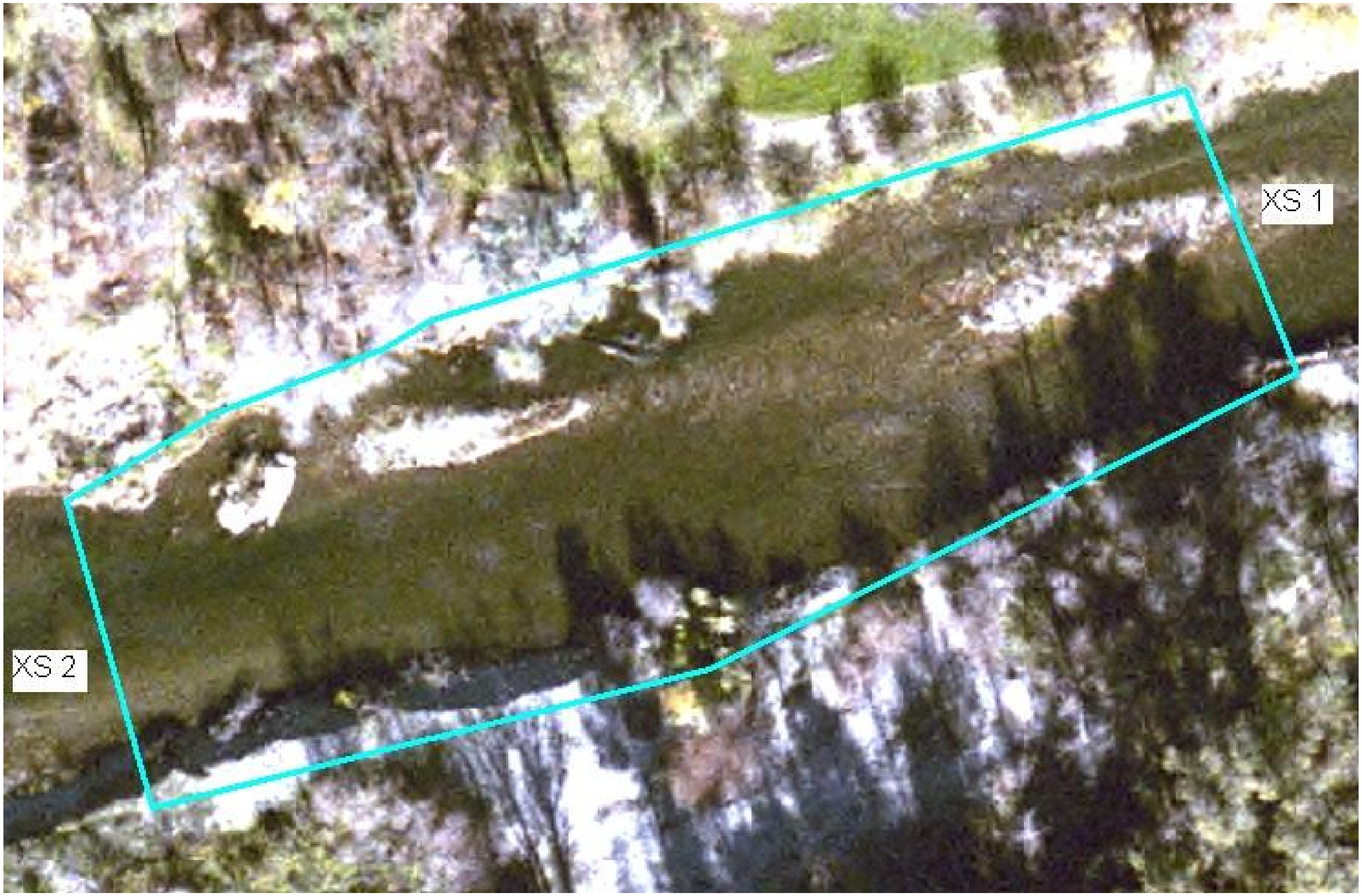
Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
73	Main Channel Pool	3,593
74	Main Channel Pool	8,575
75	Side Channel Run	847
76	Main Channel Run	26,112
77	Main Channel Glide	7,909
78	Main Channel Run	13,603
79	Side Channel Run	955
80	Side Channel Glide	692
81	Side Channel Run	1,211
82	Side Channel Pool	1,224
83	Main Channel Run	6,163
84	Main Channel Pool	13,536
85	Side Channel Pool	2,384
86	Side Channel Run	1,050
87	Main Channel Run	25,123
88	Main Channel Glide	111,370
89	Main Channel Run	143,517
90	Main Channel Glide	31,119
91	Main Channel Riffle	5,461
92	Main Channel Run	33,022
93	Main Channel Riffle	4,824
94	Main Channel Run	27,704
95	Main Channel Riffle	5,177
96	Main Channel Pool	26,466
97	Main Channel Glide	12,462
98	Main Channel Run	20,847
99	Main Channel Glide	19,602
100	Main Channel Run	38,390
101	Main Channel Pool	4,222
102	Main Channel Glide	6,036
103	Main Channel Riffle	16,532
104	Side Channel Riffle	1,968
105	Side Channel Run	685
106	Side Channel Pool	3,022
107	Side Channel Run	2,293
108	Side Channel Glide	911
109	Side Channel Pool	725

Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
110	Main Channel Pool	15,923
111	Main Channel Glide	14,089
112	Main Channel Riffle	6,682
113	Main Channel Run	8,349
114	Main Channel Riffle	6,014
115	Main Channel Run	129,041
	Restoration Reach	
117	Main Channel Run	6,974
118	Main Channel Pool	10,749
119	Main Channel Glide	9,097
120	Main Channel Pool	24,725
121	Main Channel Glide	11,420
122	Main Channel Run	17,246
123	Main Channel Pool	15,181
124	Main Channel Glide	7,470
125	Main Channel Pool	32,214
126	Main Channel Glide	7,454
127	Main Channel Run	5,680
128	Main Channel Glide	14,845
129	Main Channel Run	9,984
130	Side Channel Run	269
131	Side Channel Pool	7,716
132	Side Channel Run	166
133	Main Channel Glide	127,340
134	Main Channel Pool	23,062
135	Main Channel Pool	14,922
136	Main Channel Run	13,125
137	Main Channel Pool	20,368
138	Side Channel Pool	7,050
139	Side Channel Run	7,001
140	Main Channel Run	34,880
141	Main Channel Pool	98,723
142	Main Channel Riffle	7,287
143	Main Channel Run	12,938
144	Main Channel Pool	35,932
145	Main Channel Run	7,519
146	Main Channel Pool	15,074

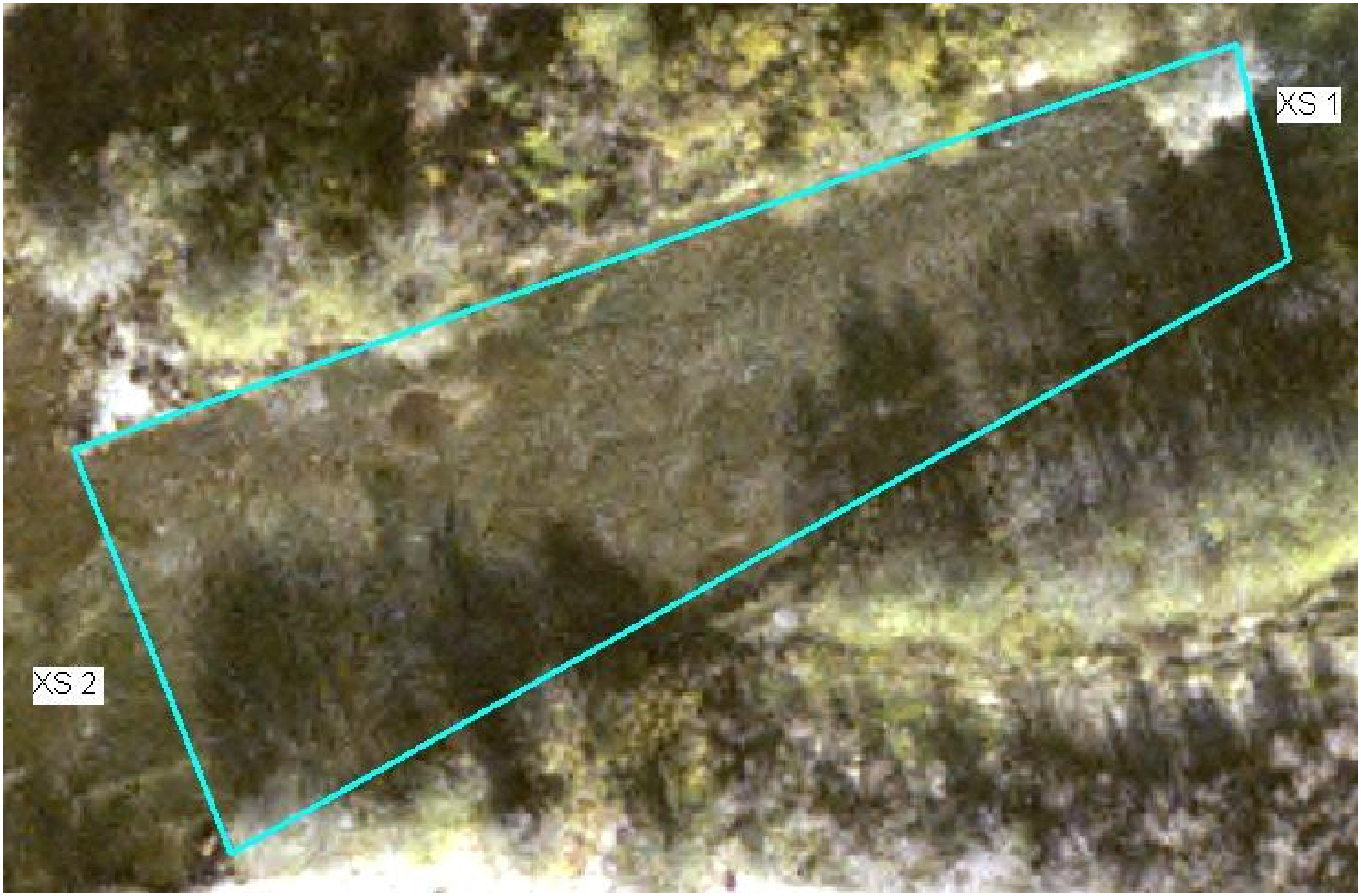
Mesohabitat Unit #	Mesohabitat Type	Mesohabitat Unit Area (m^2)
147	Side Channel Run	4,335
148	Main Channel Run	16,051
149	Side Channel Pool	3,063
150	Main Channel Glide	9,692
151	Main Channel Run	17,646
152	Main Channel Glide	39,019
153	Main Channel Pool	24,030
154	Main Channel Run	24,066
155	Main Channel Pool	12,732
156	Side Channel Run	2,396
157	Side Channel Pool	933
158	Side Channel Run	1,426
159	Side Channel Pool	1,045
160	Side Channel Run	10,456
161	Main Channel Run	15,114
162	Main Channel Pool	41,796
163	Main Channel Pool	68,109
164	Main Channel Glide	51,740
165	Main Channel Riffle	14,269
166	Main Channel Run	2,719

APPENDIX B
STUDY SITE AND TRANSECT LOCATIONS

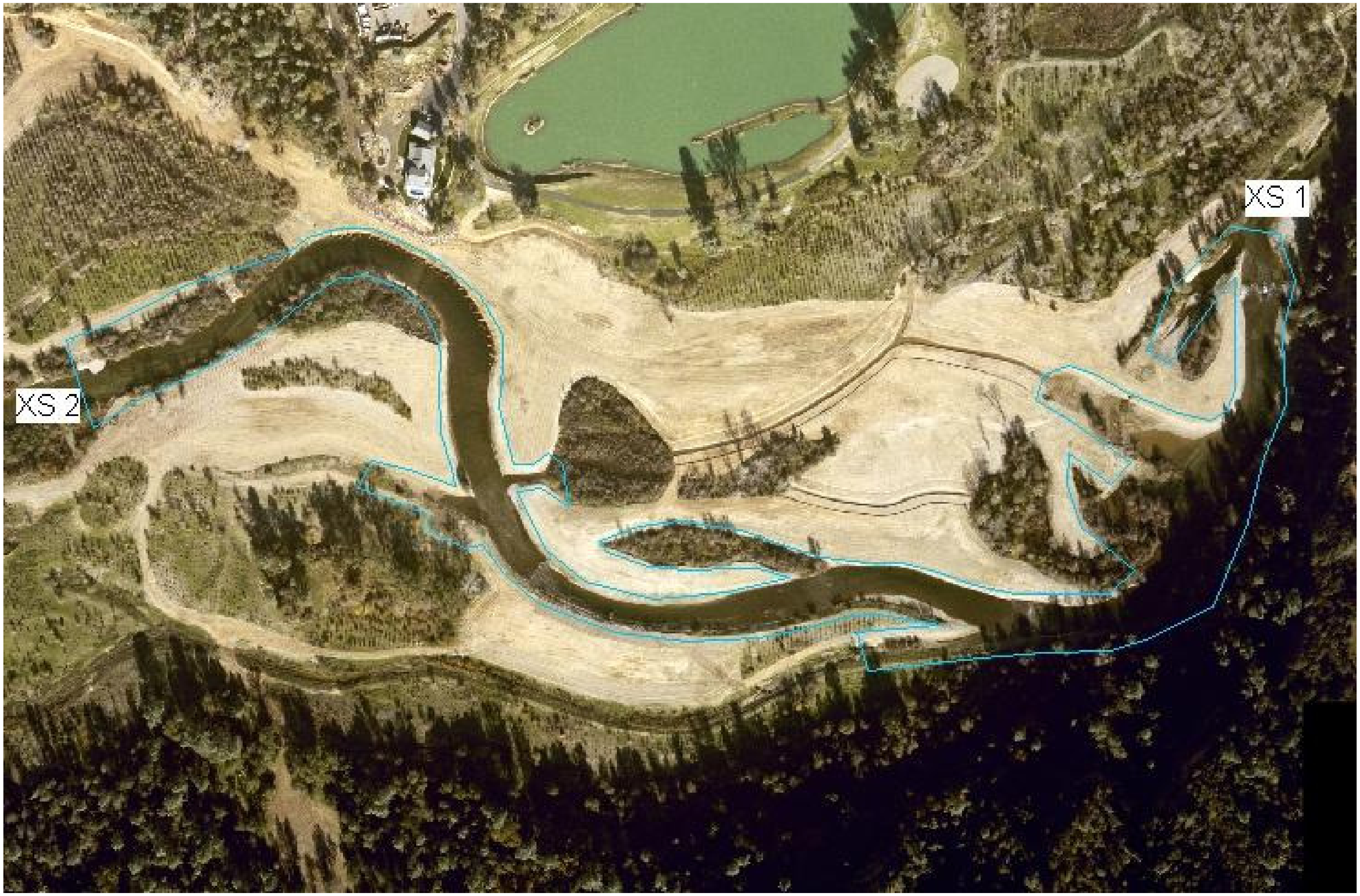
SIDE CHANNEL RUN POOL STUDY SITE



NORTH STATE RIFFLE STUDY SITE

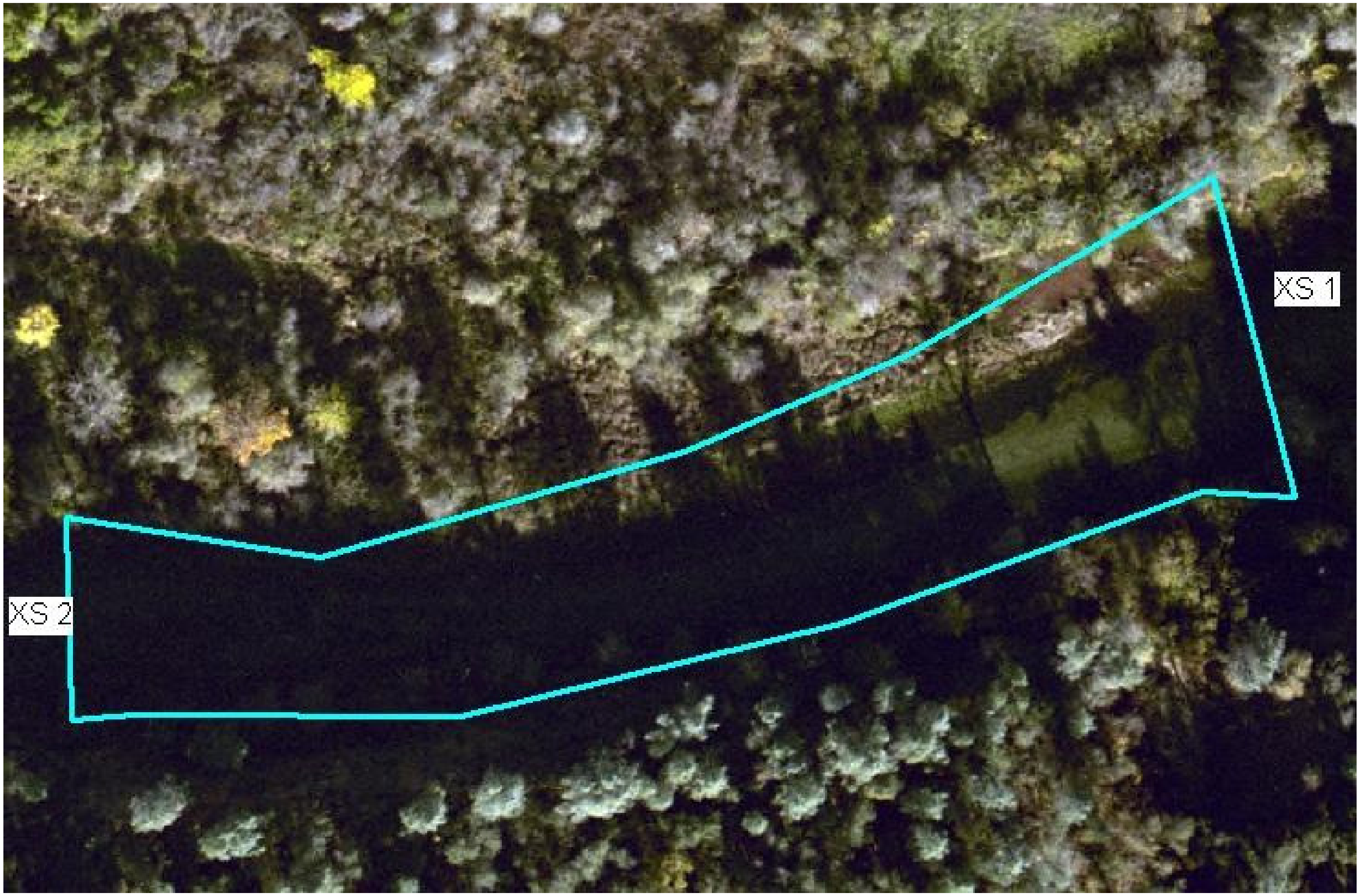


STUDY SITE 3B



TARZAN POOL STUDY SITE

ACID GLIDE STUDY SITE



APPENDIX C
RHABSIM WSEL CALBRATION

Stage of Zero Flow Values

Study Site	XS # 1 SZF	XS # 2 SZF
Side Channel Run Pool	87.7	89.1
North State Riffle	94.1	95.6
Restoration Site 3B	45.1	57.0
Tarzan Pool	93.2	93.4
ACID Glide	94.7	94.7

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range	Calibration Flows	Method	Parameters
Side Channel Run Pool	1	50-225	81, 201, 246	MANSQ	CalQ = 81, β = 0.5
Side Channel Run Pool	1	250-900	246, 404, 650	IFG4	- - -
Side Channel Run Pool	2	50-900	81, 201, 246, 398, 650	IFG4	- - -
North State Riffle	1	50-900	79, 208, 378, 570	IFG4	- - -
North State Riffle	2	50-900	79, 208, 378, 568	IFG4	- - -
Restoration Site 3B	1	50-900	86.9, 226, 434, 630	IFG4	- - -
Restoration Site 3B	2	50-900	86.9, 215, 433, 651	IFG4	- - -
Tarzan Pool	1	50-900	94, 228, 445, 643	IFG4	- - -
Tarzan Pool	2	50-900	94, 228, 439, 646	IFG4	- - -
ACID Glide	1, 2	50-225	95, 230	IFG4	- - -
ACID Glide	1	250-900	230, 445, 645	IFG4	- - -
ACID Glide	2	250-900	230, 445, 650	IFG4	- - -

Side Channel Run Pool Study Site[26]

XS	%MEAN ERROR	Calculated vs Given Discharge (%) 81	201	246	Difference (measured vs. pred. WSELs) 81	201	246
1	3.9	0.0	0.0	11.8	0.00	0.00	0.06

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 246	404	650	Difference (measured vs. pred. WSELs) 246	404	650
1	2.55	0.7	0.5	1.0	0.5	0.08	0.02	0.06

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 81	201	246	398	650	Difference (measured vs. pred. WSELs) 81	201	246	398	650
2	3.75	7.6	10.2	12.4	2.4	5.8	7.6	0.06	0.05	0.08	0.02	0.06

North State Riffle Study Site

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 79	208	378	570	Difference (measured vs. pred. WSELs) 79	208	378	570
1	2.66	2.4	2.6	4.9	0.1	2.1	0.01	0.04	0.00	0.02

XS	BETA COEFF.	%MEAN ERROR	Calculated vs Given Discharge (%) 79	208	378	568	Difference (measured vs. pred. WSELs) 79	208	378	568
2	3.17	2.5	2.4	5.3	1.8	9.2	0.01	0.03	0.01	0.01

[26] Both the percentage difference between calculated and given discharge and difference (measured versus predicted WSEL, feet) are absolute values.

Restoration Study Site 3B

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	86.9	226	434	630	86.9	226	434	630
1	2.23	4.7	3.5	4.3	5.3	5.6	0.03	0.05	0.08	0.10

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	86.9	215	433	651	86.9	215	433	651
2	2.88	9.5	10.8	16.5	4.0	7.5	0.06	0.10	0.03	0.08

Tarzan Pool Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	94	228	445	643	94	228	445	643
1	2.40	4.2	3.8	5.6	2.9	4.4	0.06	0.06	0.04	0.07

	BETA	%MEAN	Calculated vs Given Discharge (%)				Difference (measured vs. pred. WSELs)			
XS	COEFF.	ERROR	94	228	439	646	94	228	439	646
2	2.25	4.5	4.1	6.0	3.1	4.6	0.03	0.07	0.05	0.09

ACID Glide Study Site

	BETA	%MEAN	Calculated vs Given Discharge (%)		Difference (measured vs. pred. WSELs)	
XS	COEFF.	ERROR	95	230	95	230
1	7.2	0.0	0.0	0.0	0.00	0.00
2	7.0	0.0	0.0	0.0	0.00	0.00

	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	230	445	645	230	445	645
1	2.59	1.2	0.7	1.8	1.1	0.01	0.02	0.01

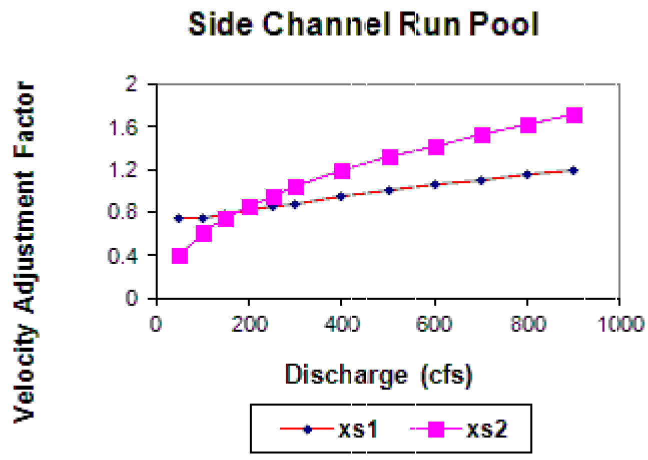
	BETA	%MEAN	Calculated vs Given Discharge (%)			Difference (measured vs. pred. WSELs)		
XS	COEFF.	ERROR	230	445	650	230	445	650
2	2.50	1.5	0.9	2.2	1.3	0.01	0.02	0.02

APPENDIX D
VELOCITY ADJUSTMENT FACTORS

Side Channel Run Pool Study Site

Velocity Adjustment Factors

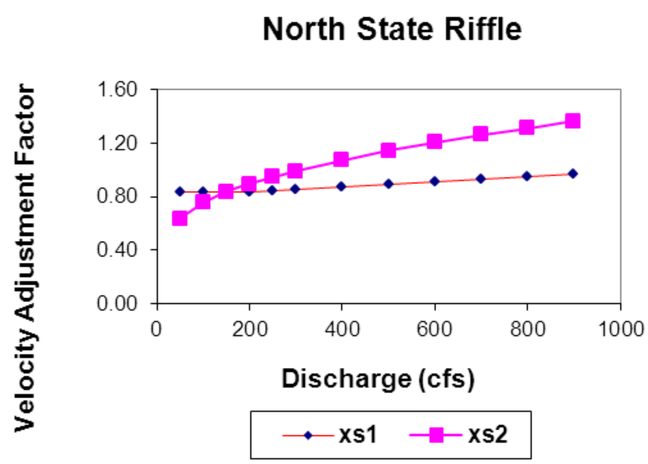
Discharge	Xsec 1	Xsec 2
50	0.74	0.41
100	0.75	0.61
150	0.78	0.75
200	0.82	0.86
250	0.85	0.96
300	0.88	1.04
400	0.95	1.19
500	1.00	1.32
600	1.06	1.43
700	1.10	1.53
800	1.15	1.63
900	1.19	1.71



North State Riffle Study Site

Velocity Adjustment Factors

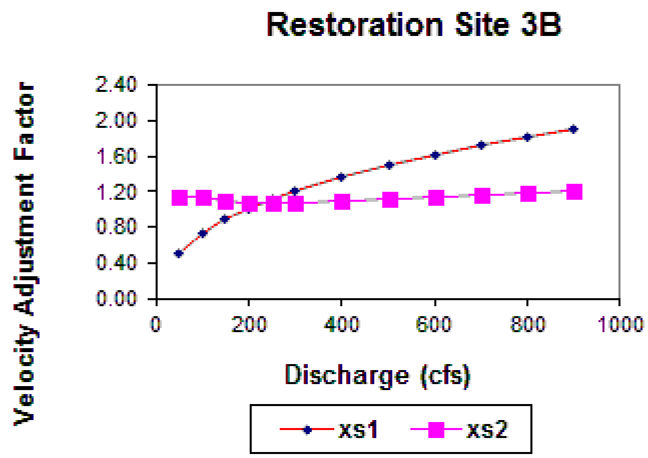
Discharge	Xsec 1	Xsec 2
50	0.84	0.64
100	0.84	0.76
150	0.84	0.84
200	0.84	0.90
250	0.85	0.95
300	0.86	0.99
400	0.88	1.07
500	0.90	1.14
600	0.92	1.21
700	0.94	1.26
800	0.95	1.31
900	0.97	1.36



Restoration Study Site 3B

Velocity Adjustment Factors

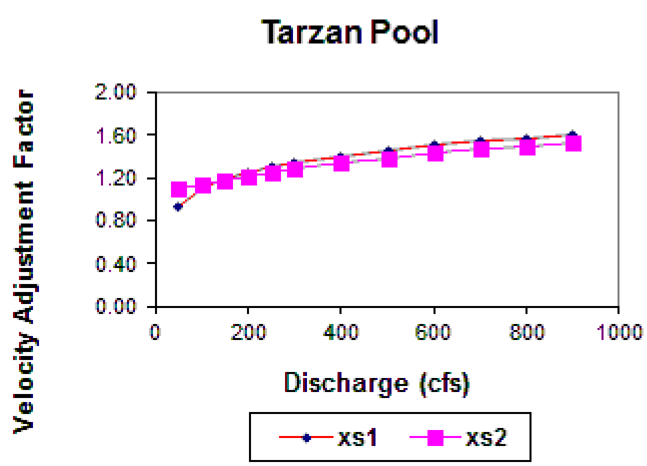
Discharge	Xsec 1	Xsec 2
50	0.50	1.14
100	0.73	1.14
150	0.89	1.09
200	1.01	1.07
250	1.12	1.07
300	1.21	1.07
400	1.37	1.09
500	1.50	1.11
600	1.61	1.13
700	1.72	1.15
800	1.82	1.18
900	1.91	1.20



Tarzan Pool Study Site

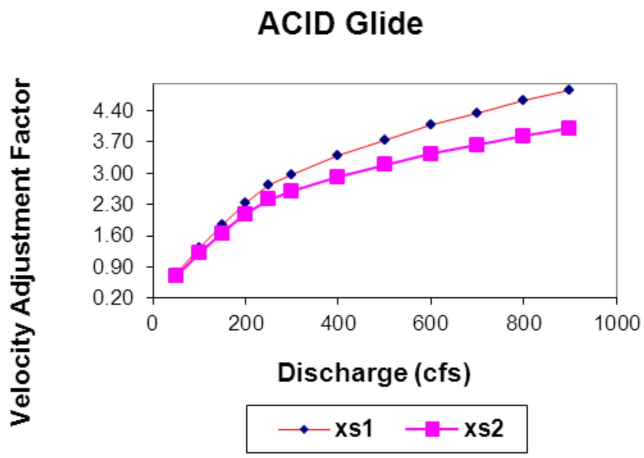
Velocity Adjustment Factors

Discharge	Xsec 1	Xsec 2
50	0.93	1.10
100	1.10	1.14
150	1.19	1.18
200	1.25	1.22
250	1.30	1.25
300	1.34	1.28
400	1.41	1.34
500	1.46	1.39
600	1.50	1.43
700	1.54	1.47
800	1.58	1.50
900	1.61	1.53



ACID Glide Study Site

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
50	0.75	0.69
100	1.32	1.20
150	1.84	1.66
200	2.33	2.08
250	2.73	2.42
300	2.97	2.60
400	3.39	2.92
500	3.76	3.19
600	4.07	3.43
700	4.36	3.64
800	4.62	3.83
900	4.86	4.01

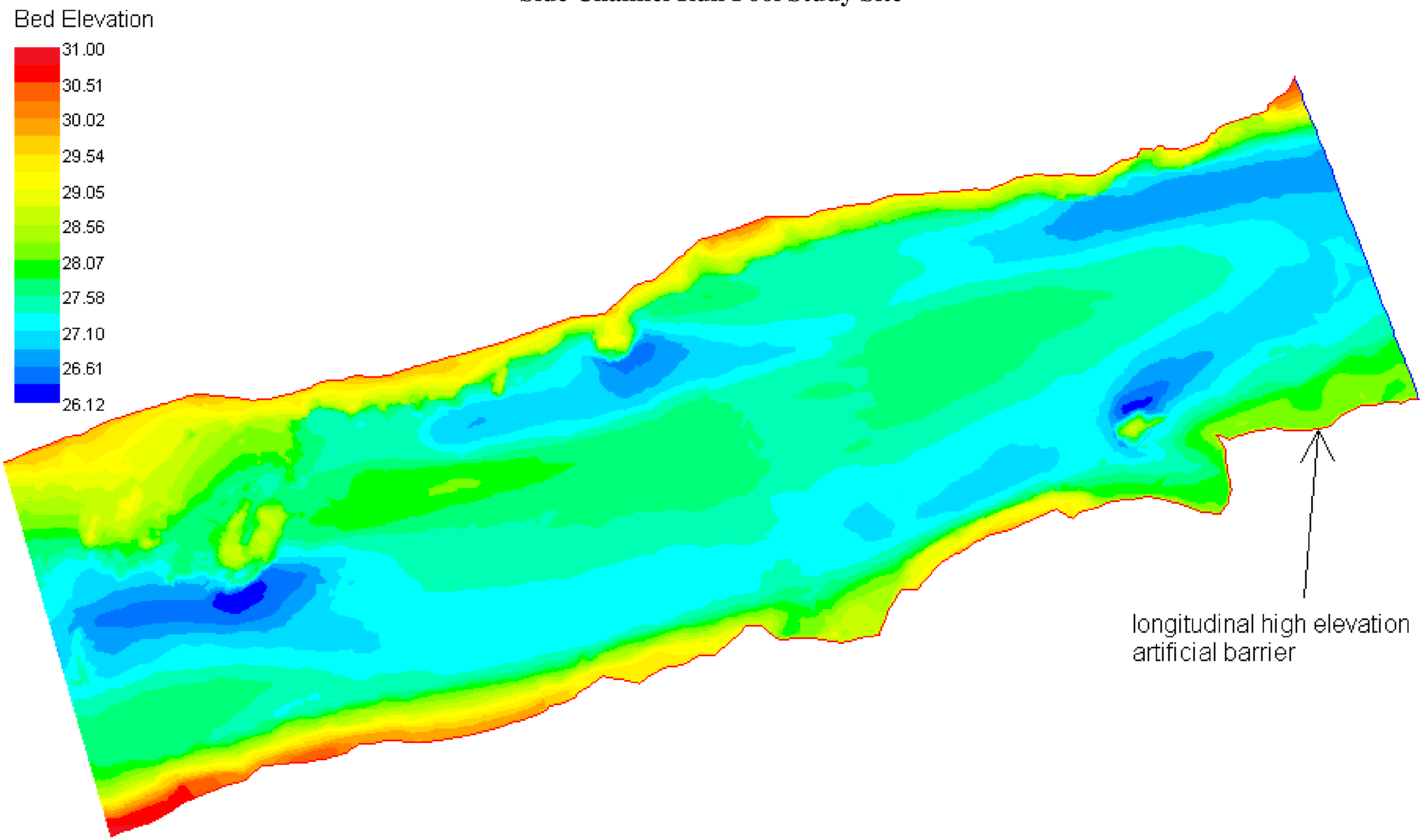


APPENDIX E
BED TOPOGRAPHY OF STUDY SITES[27]

---

[27] Elevations of each site are relative to an arbitrary datum of 100 feet (30.5 m).

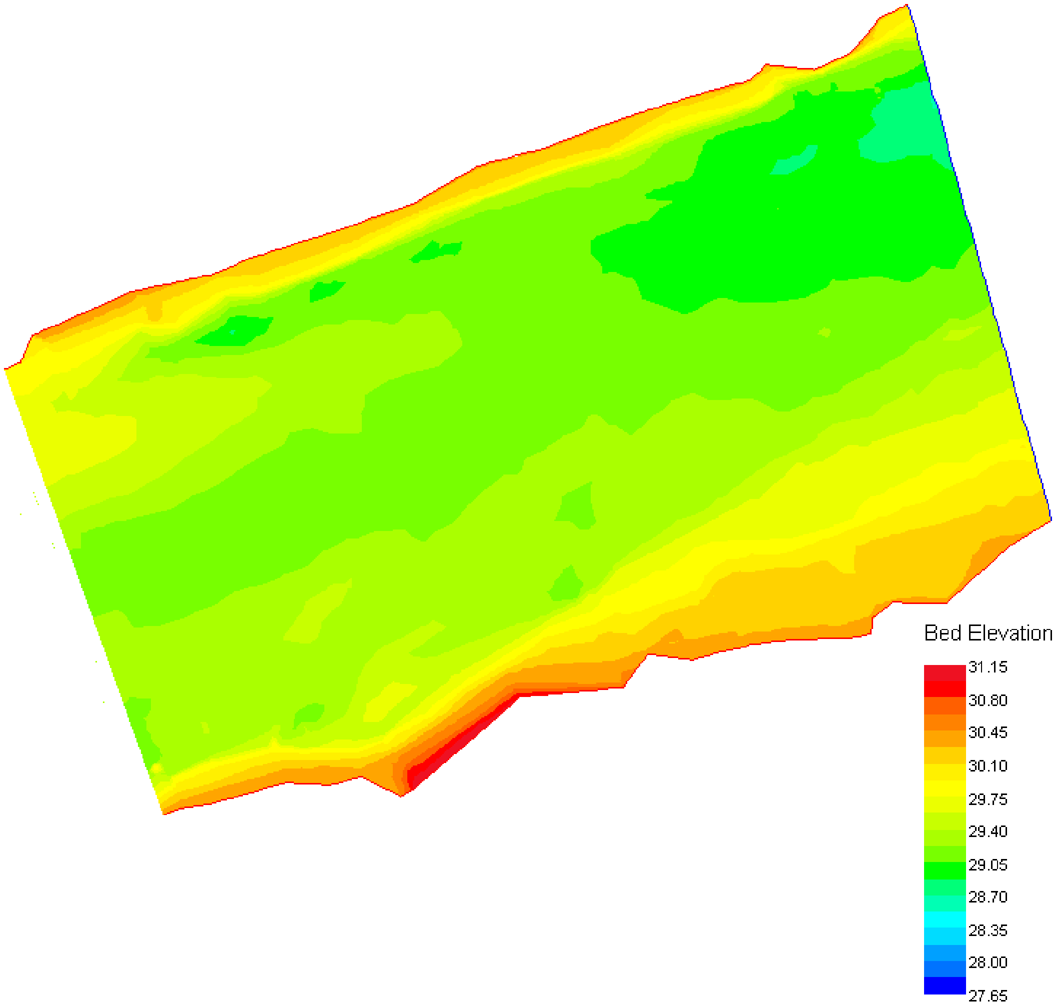
Side Channel Run Pool Study Site



Units of Bed Elevation are meters.

Scale: 1: 634

North State Riffle Study Site

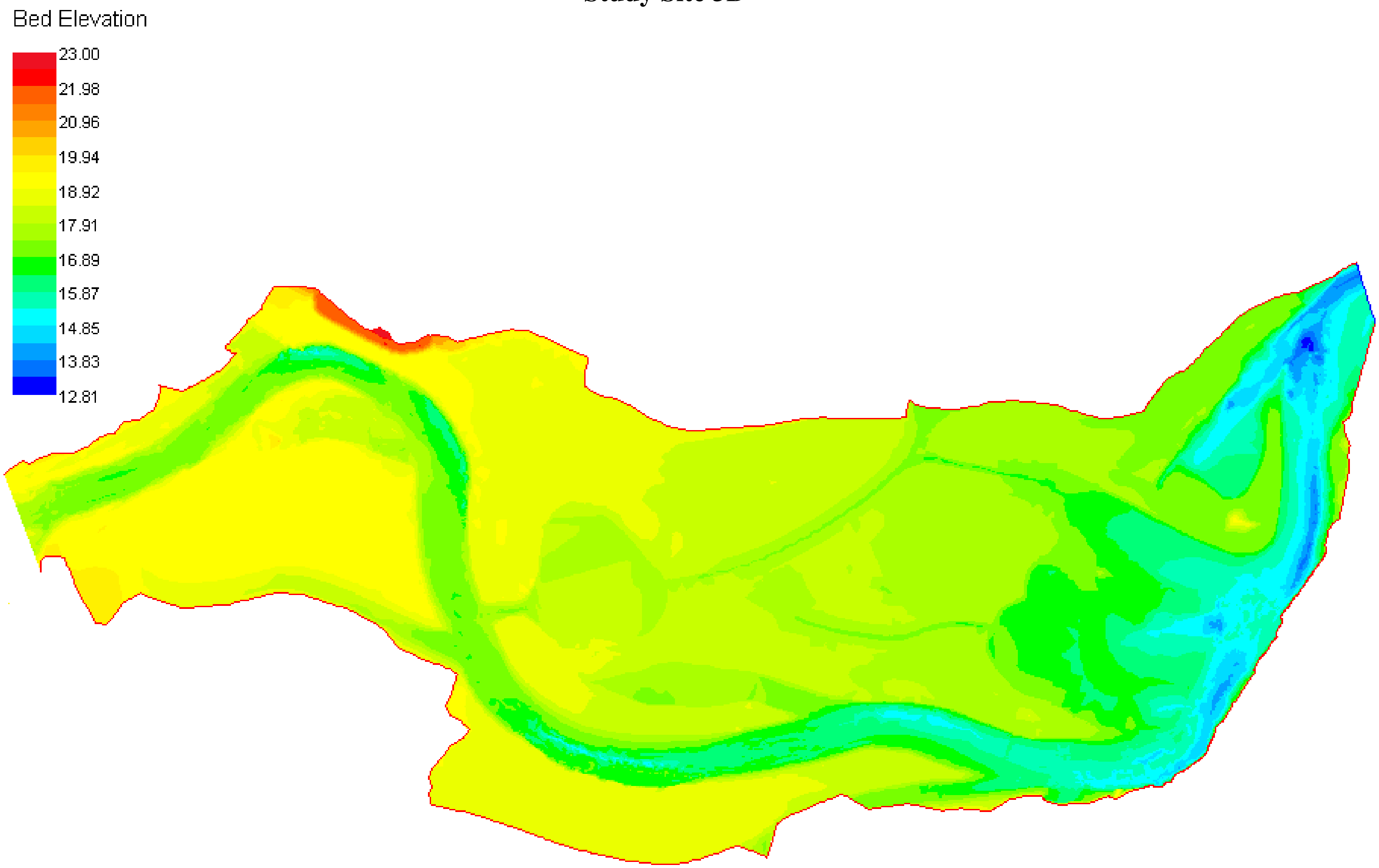


Units of Bed Elevation are meters.

Scale: 1: 512

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

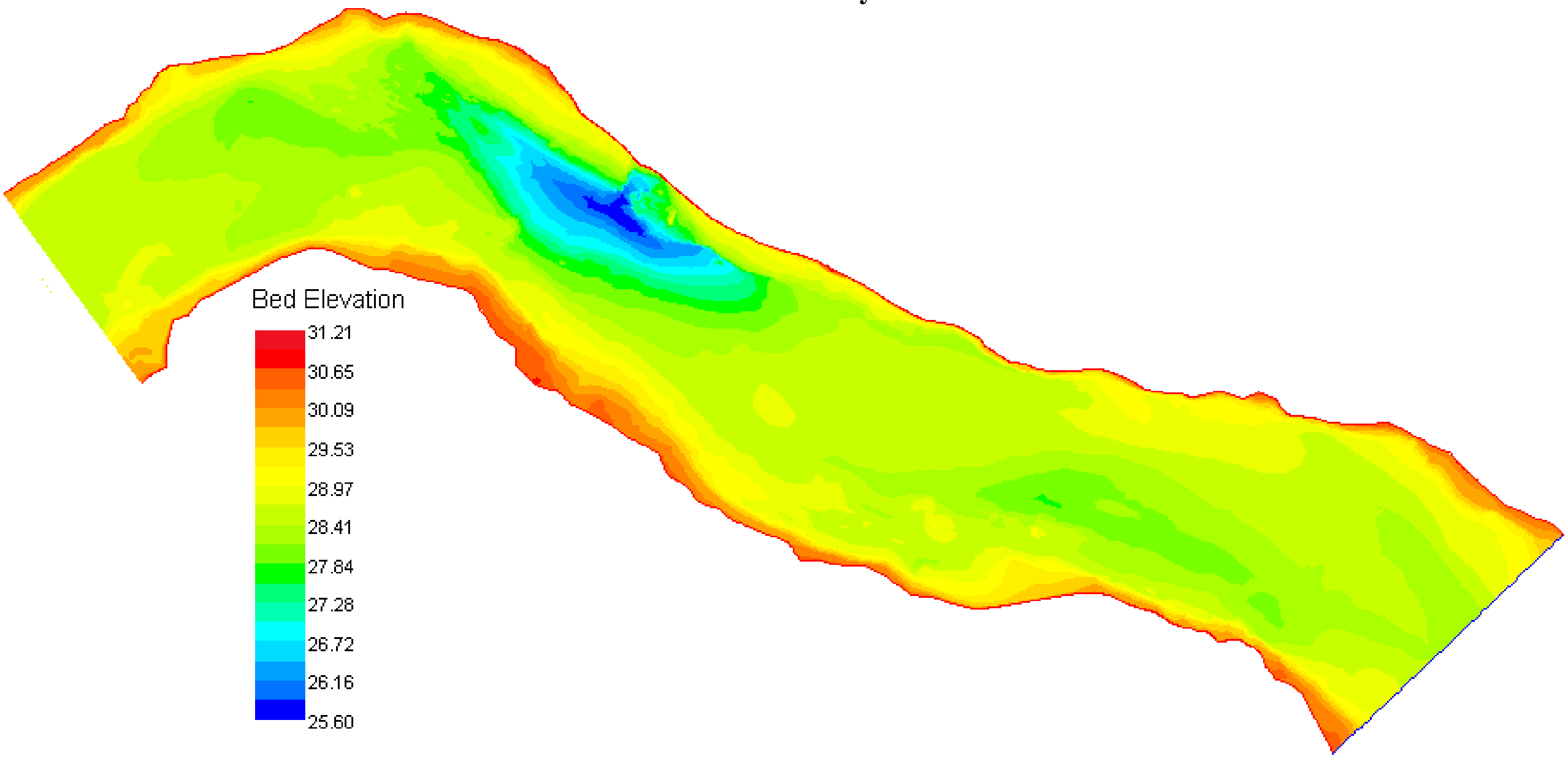
Study Site 3B



Units of Bed Elevation are meters.

Scale: 1: 1,720

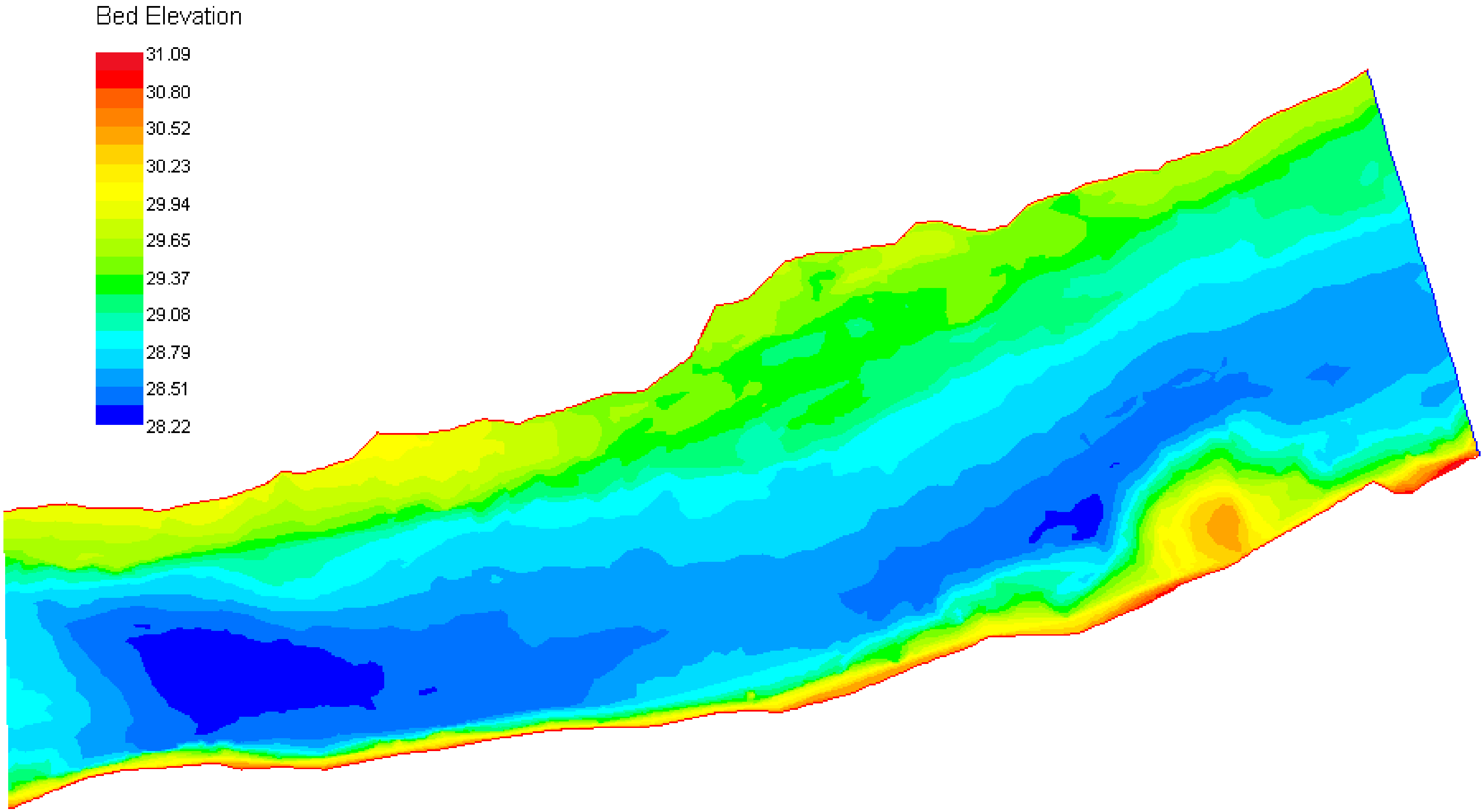
Tarzan Pool Study Site



Units of Bed Elevation are meters.

Scale: 1: 518

ACID Glide Study Site

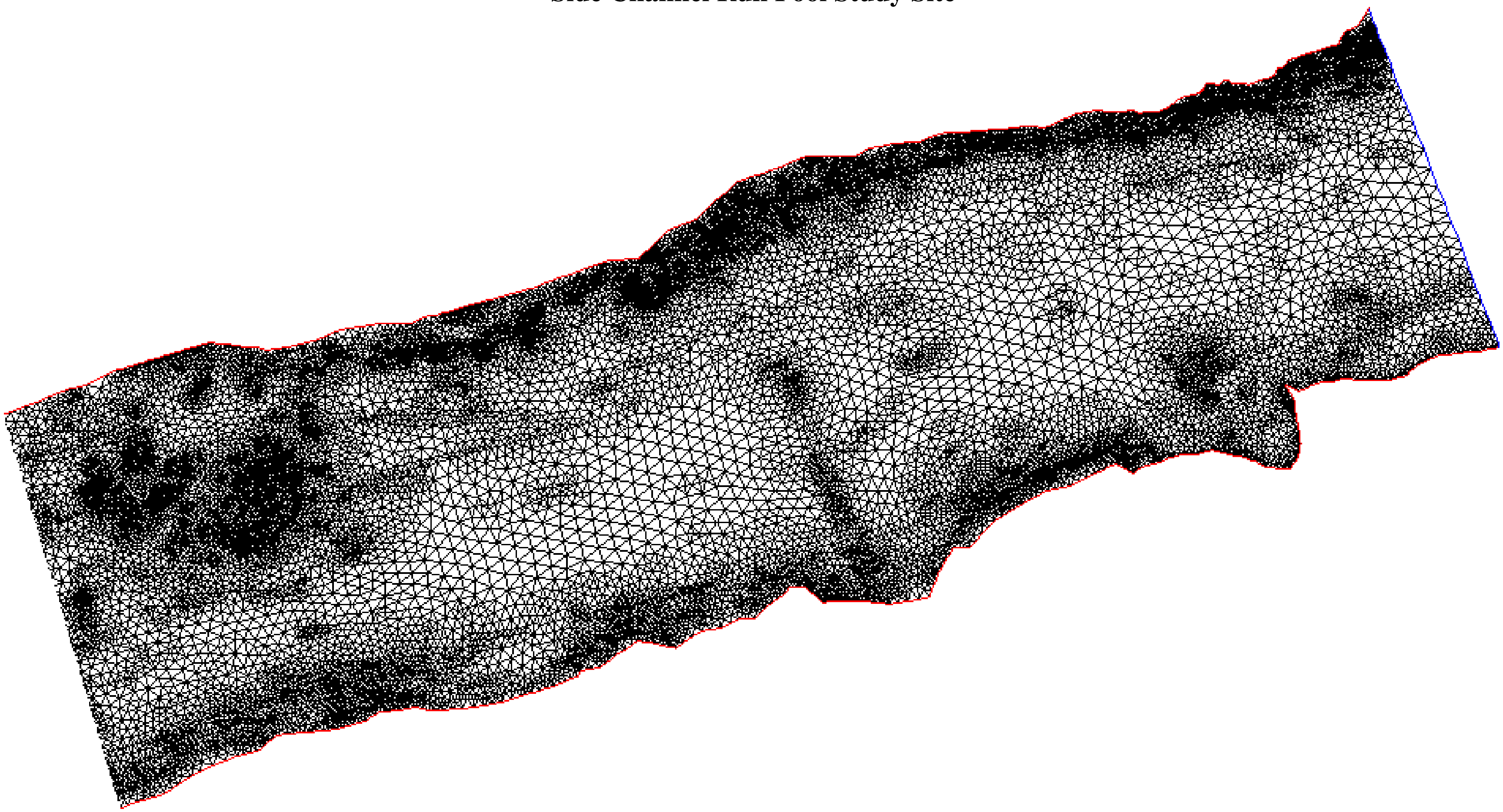


Units of Bed Elevation are meters.

Scale: 1: 520

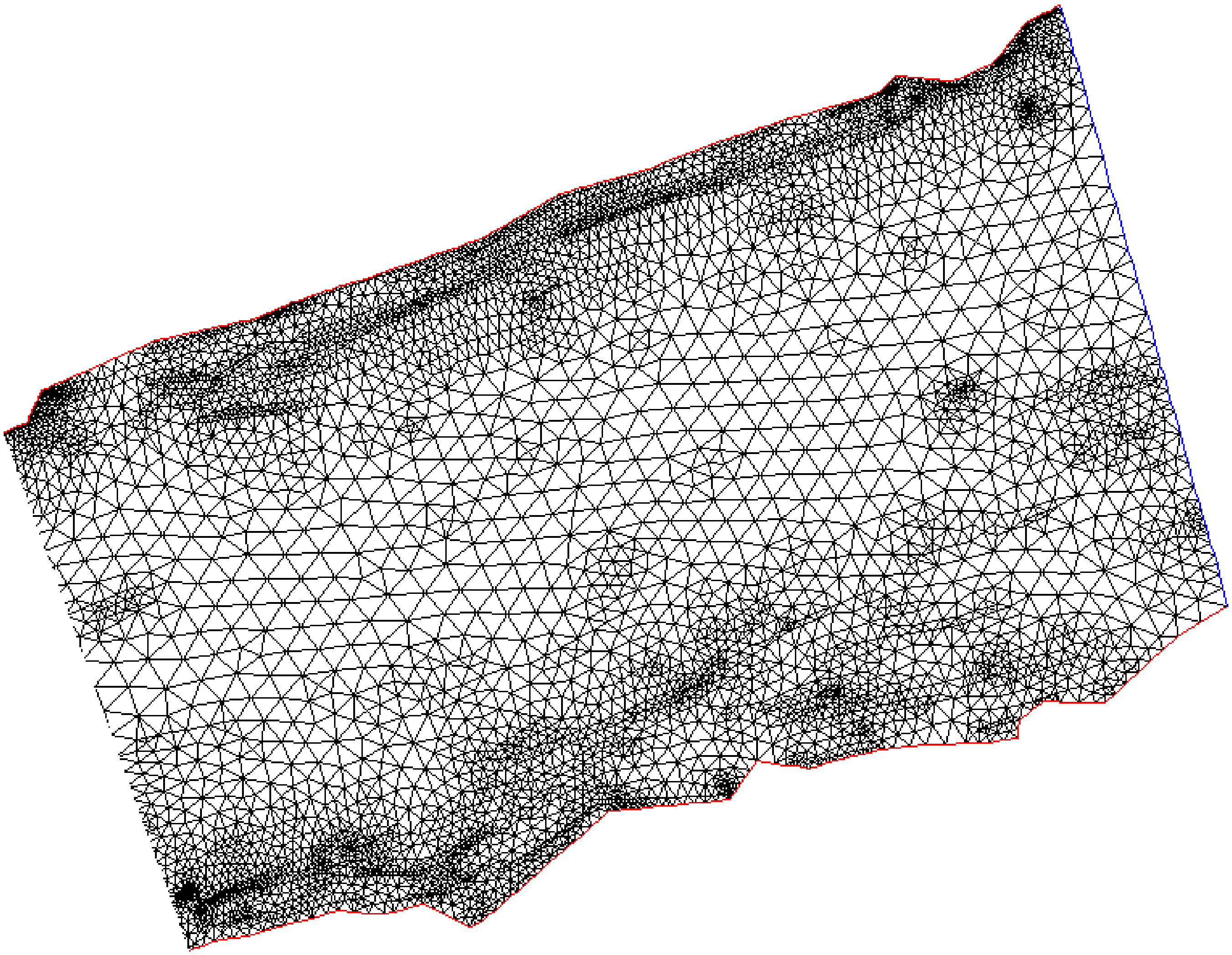
APPENDIX F
COMPUTATIONAL MESHES OF STUDY SITES

Side Channel Run Pool Study Site



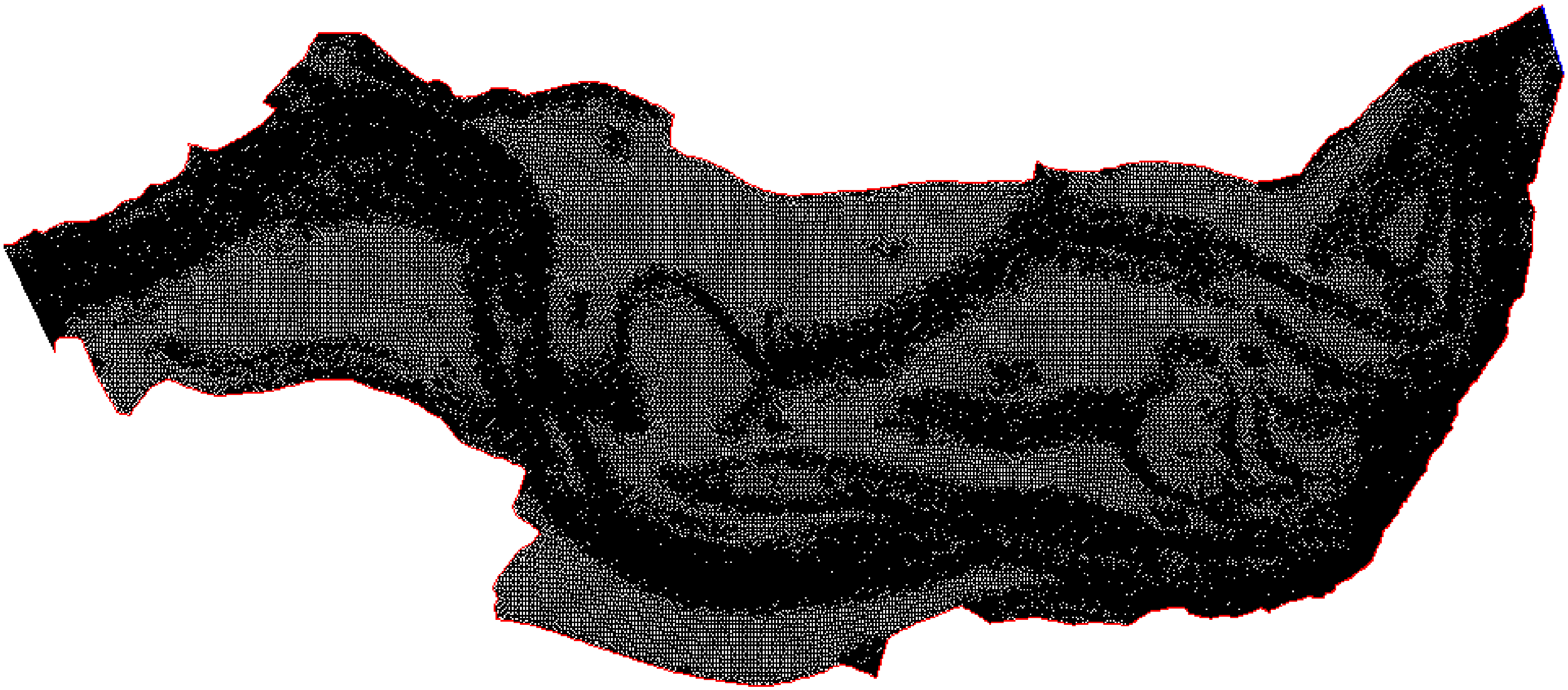
Scale: 1: 634

North State Riffle Study Site



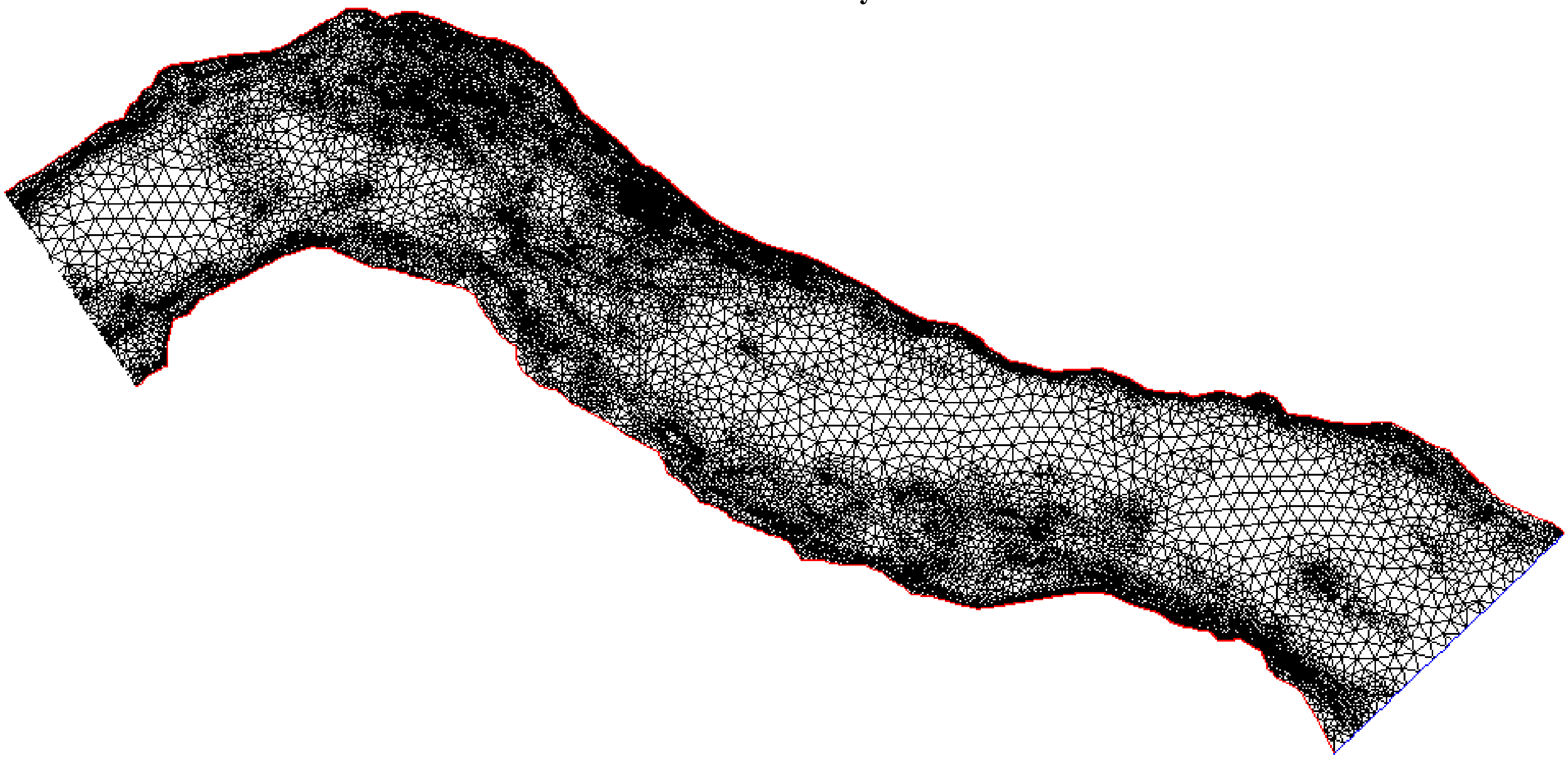
Scale: 1: 399

Study Site 3B



Scale: 1: 1,588

Tarzan Pool Study Site



Scale: 1: 518

ACID Glide Study Site

Scale: 1: 539

APPENDIX G
2-D WSEL CALIBRATION

Calibration Statistics[28]

Site Name	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Side Channel Run Pool	74.2%	27,300	0.30	0.02%	<0.000001	2.74
North State Riffle	95.0%	11,943	0.30	0.06%	0.000006	3.07
Restoration Site 3B	77.7%	98,241	0.30	0.7%	0.000001	10.17
Tarzan Pool	90.7%	26,172	0.30	0.01%	<0.000001	8.72
ACID Glide	93.4%	18,624	0.30	0.01%	<0.000001	1.45

[28] QI = Quality Index, Net Q = Net Flow, Sol Δ = Solution change, Max F = Maximum Froude Number

Side Channel Run Pool

XSEC	BR Mult[29]	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	1.2	0.01	0.04	0.06

North State Riffle

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	0.8	0.02	0.05	0.12

Restoration Site 3B

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	0.48	0.05	0.06	0.15
2LB	0.48	0.01	0.04	0.06
2RB	0.48	0.02	0.02	0.09

Tarzan Pool

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	3.0	0.04	0.04	0.09

ACID Glide

XSEC	BR Mult	Difference (measured vs. pred. WSELs, absolute value, feet) Average	Standard Deviation	Maximum
2	1.0	0.04	0.02	0.07

[29] BR Mult = Bed Roughness Multiplier

APPENDIX H
VELOCITY VALIDATION STATISTICS

Site Name	Number of Observations	Correlation Between Measured and Simulated Velocities
Side Channel Run Pool	64	0.90
North State Riffle	92	0.88
Restoration Site 3B	116	0.52
Tarzan Pool	87	0.75
ACID Glide	91	0.84

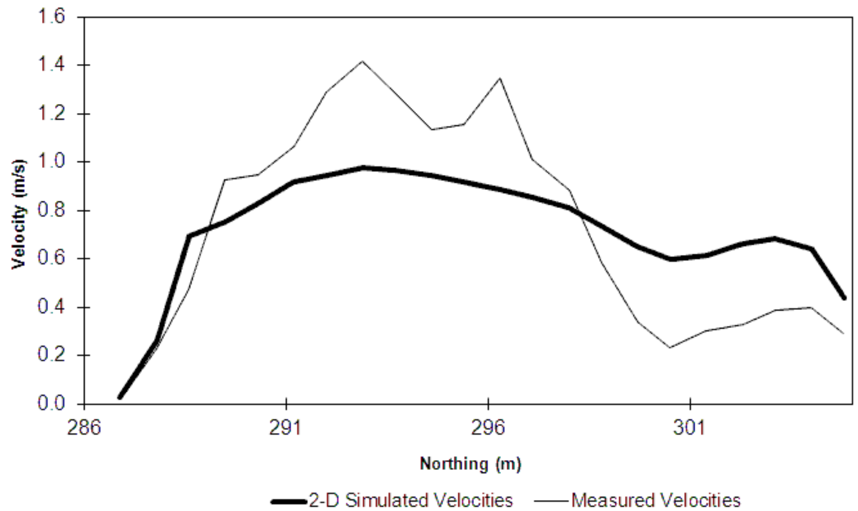
Measured Velocities less than 3 ft/s
Difference (measured vs. pred. velocities, absolute value, ft/s)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Side Channel Run Pool	52	0.35	0.34	1.20
North State Riffle	56	0.41	0.36	1.87
Restoration Site 3B	95	1.08	1.16	6.12
Tarzan Pool	87	0.36	0.27	1.04
ACID Glide	91	0.38	0.34	1.49

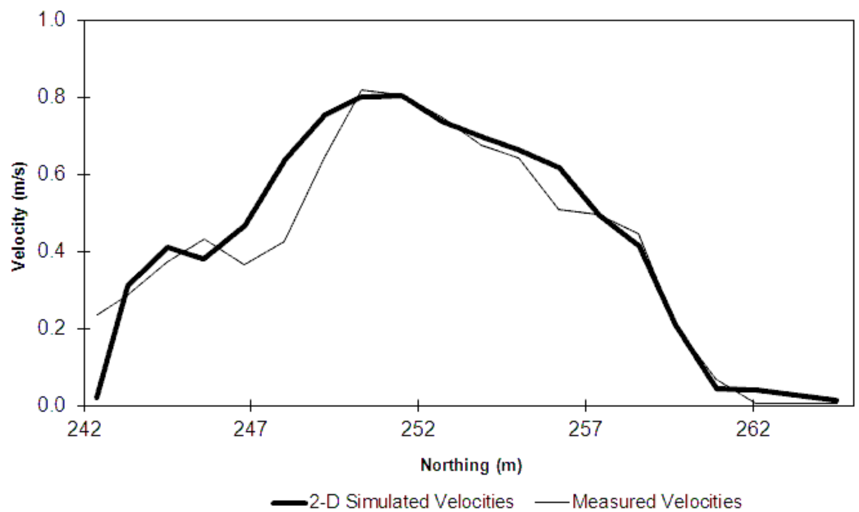
Measured Velocities greater than 3 ft/s
Percent difference (measured vs. pred. velocities)

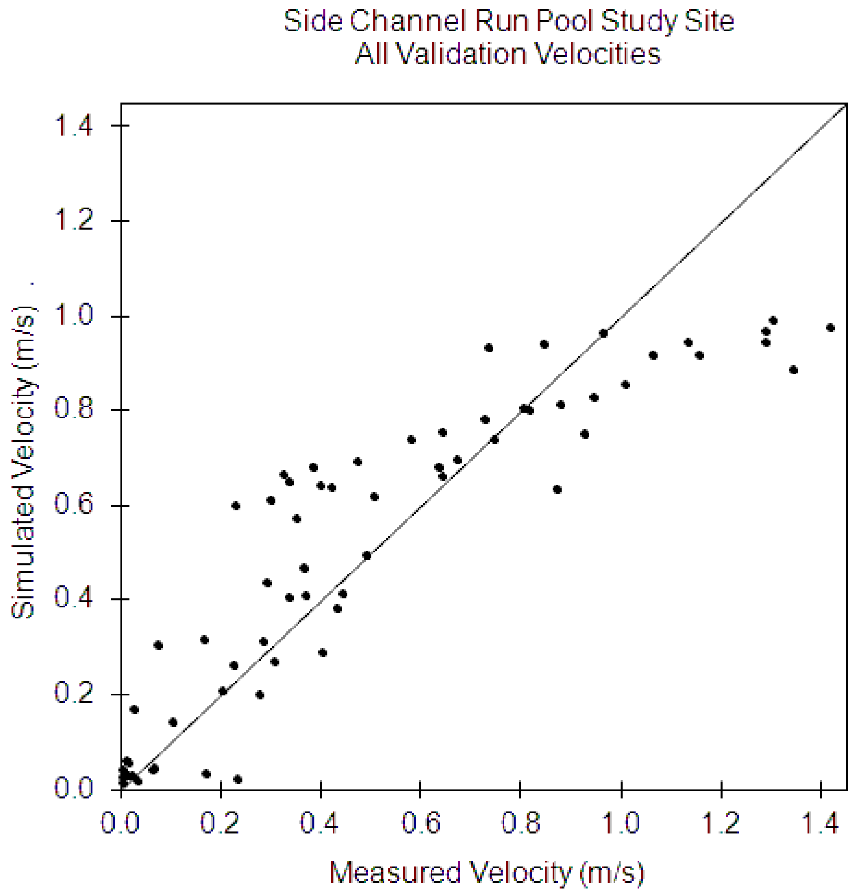
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Side Channel Run Pool	12	26%	14%	52%
North State Riffle	36	10%	10%	37%
Restoration Site 3B	21	22%	17%	55%
Tarzan Pool	0	--	--	--
ACID Glide	0	--	--	--

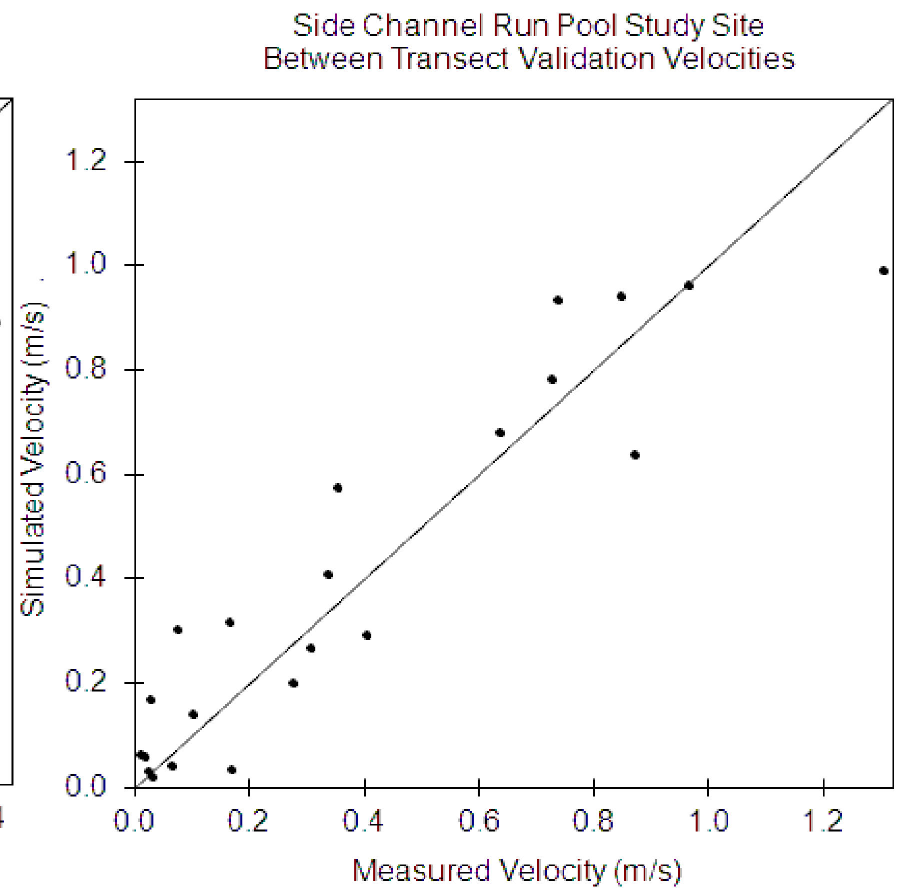
Side Channel Run Pool Site XS1, Q = 246 cfs

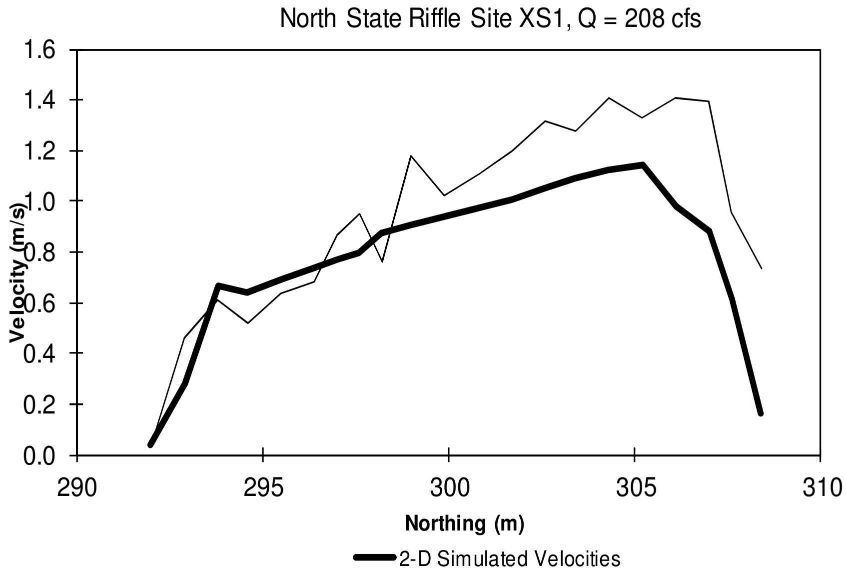


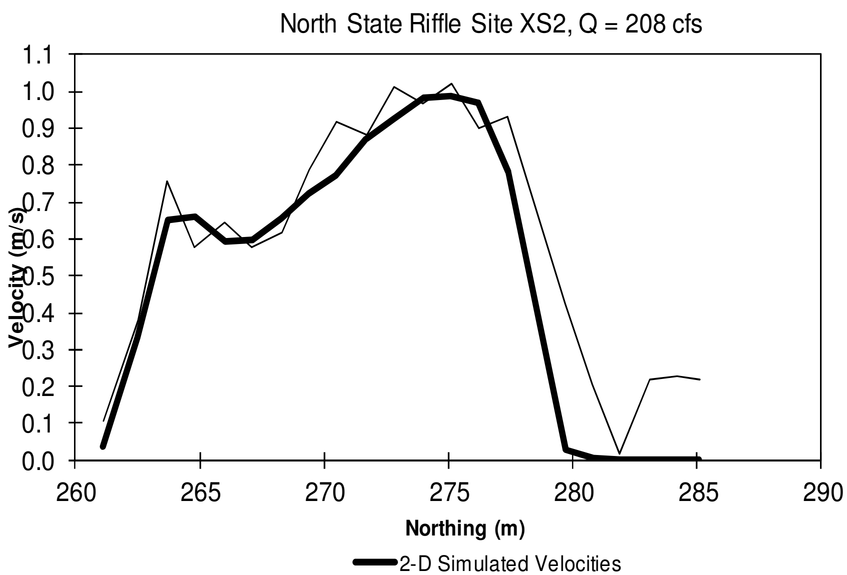
Side Channel Run Pool Site XS2, Q = 246 cfs

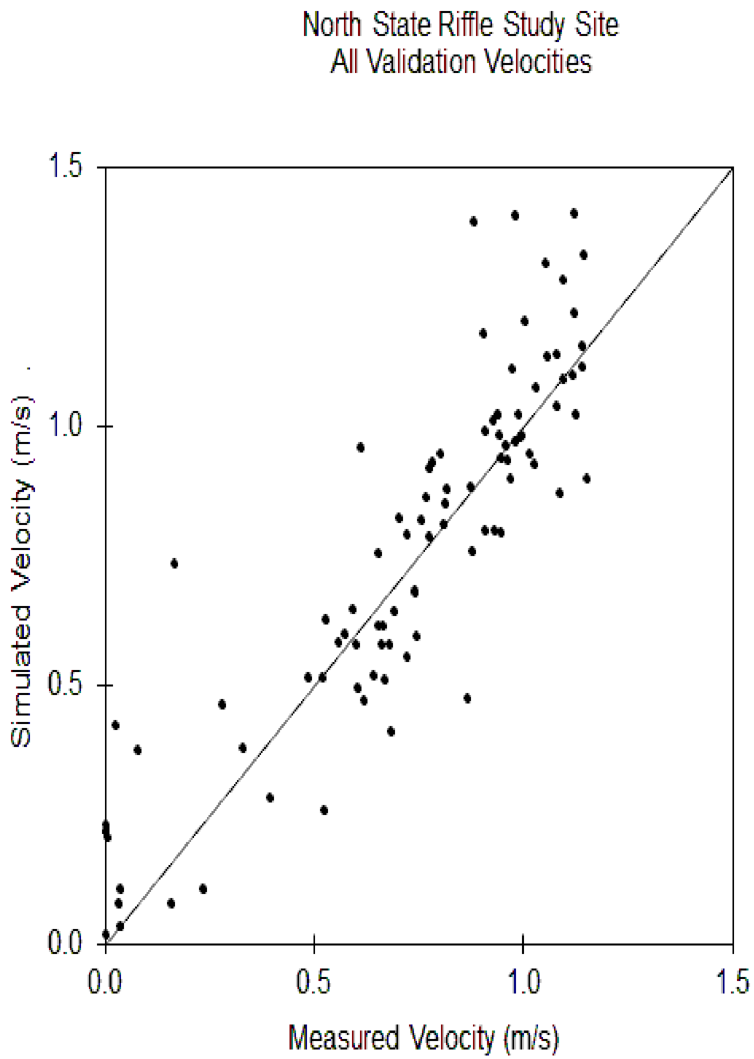


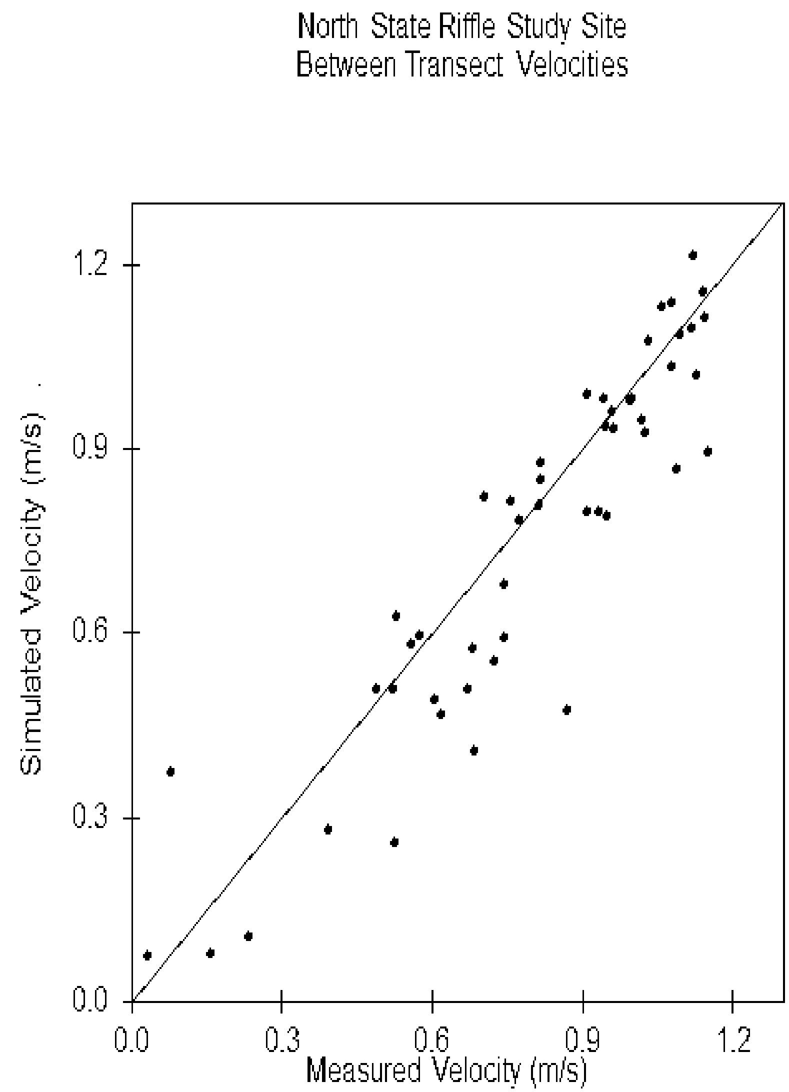

Side Channel Run Pool Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

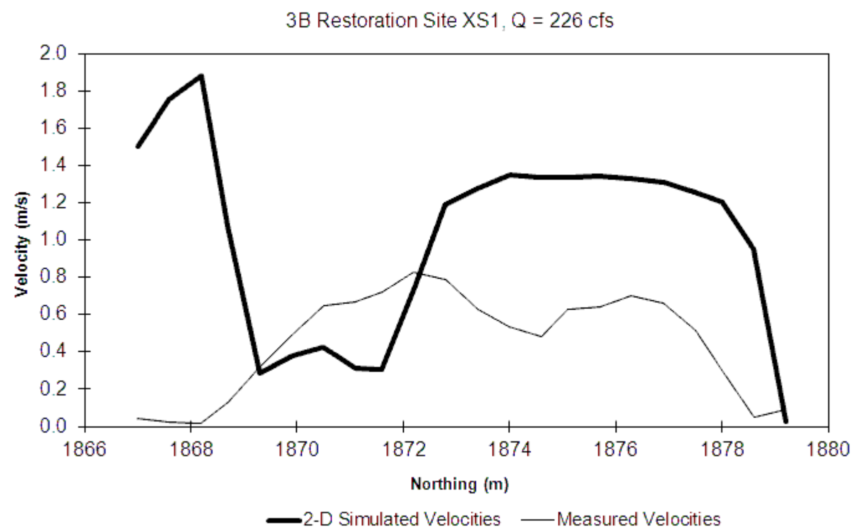

Side Channel Run Pool Study Site
Between Transect Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2

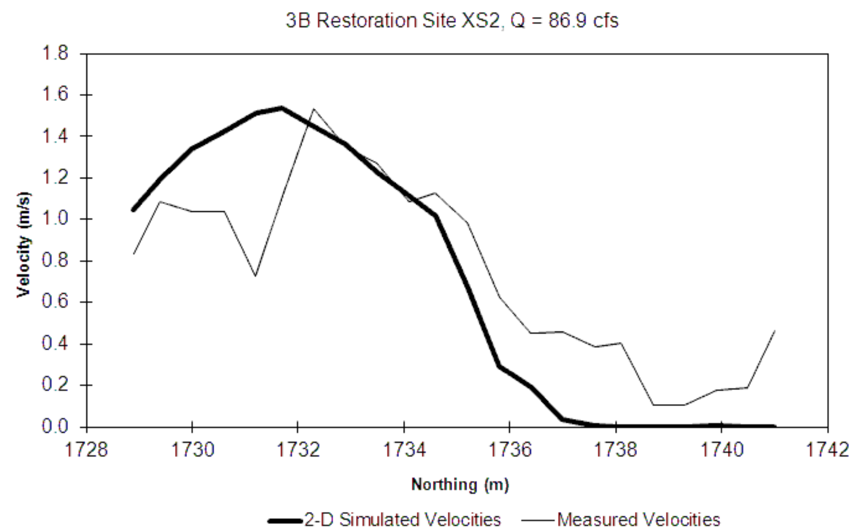

North State Riffle Site XS1, Q = 208 cfs
Velocity (m/s)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
290
295
300
305
310
Northing (m)
2-D Simulated Velocities

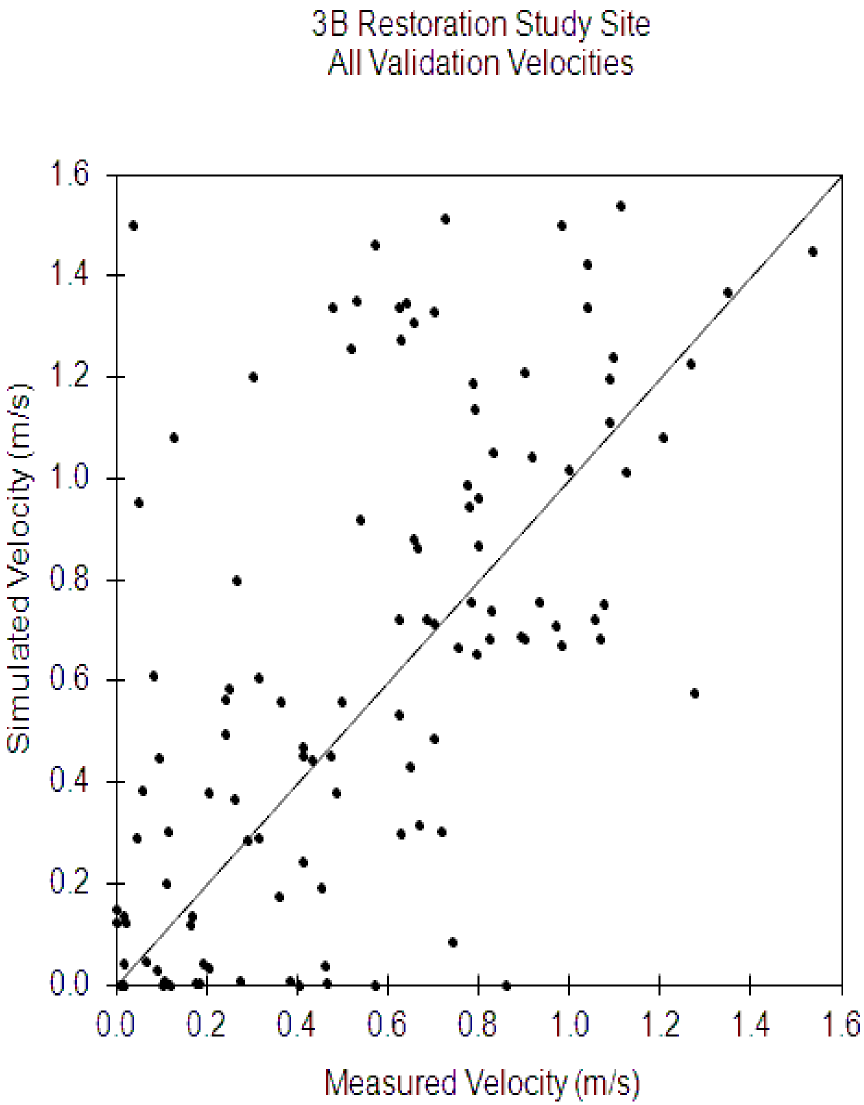

North State Riffle Site XS2, Q = 208 cfs
Velocity (m/s)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
260
265
270
275
280
285
290
Northing (m)
2-D Simulated Velocities

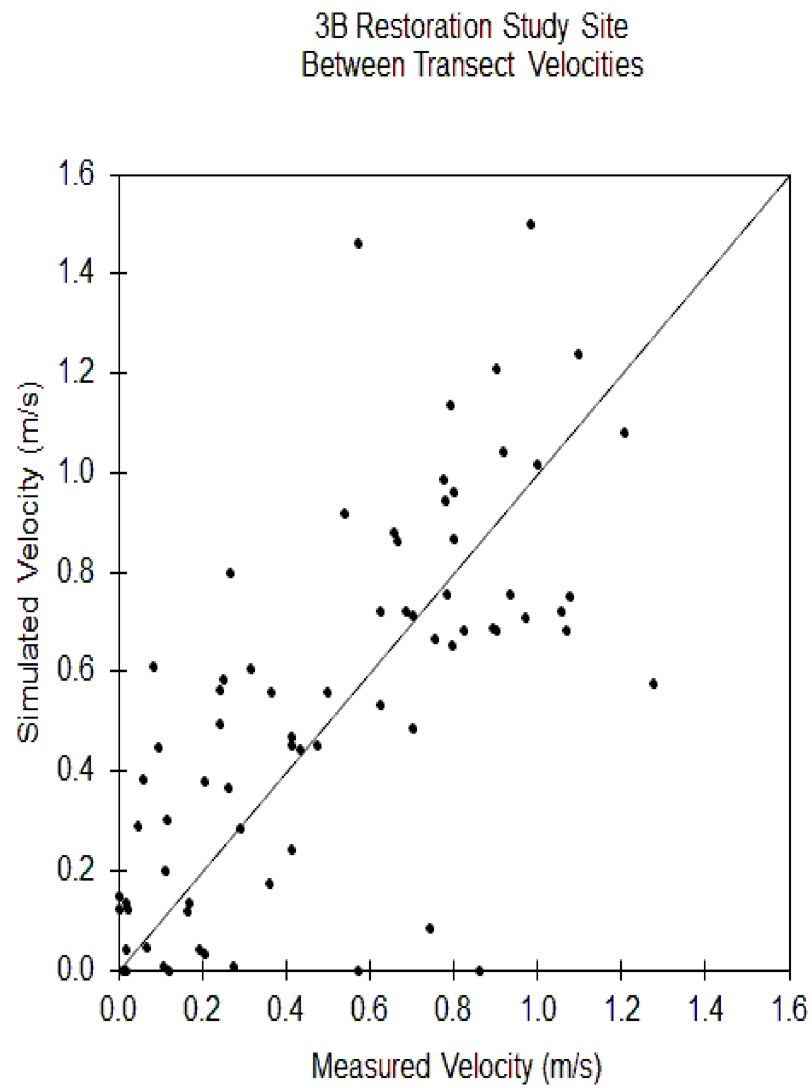

North State Riffle Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5

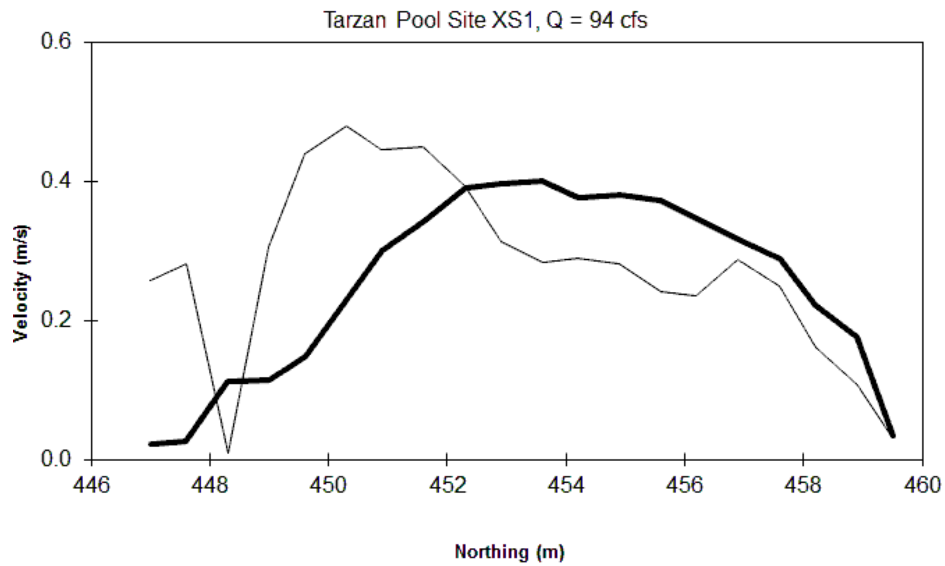

North State Riffle Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.3
0.6
0.9
1.2

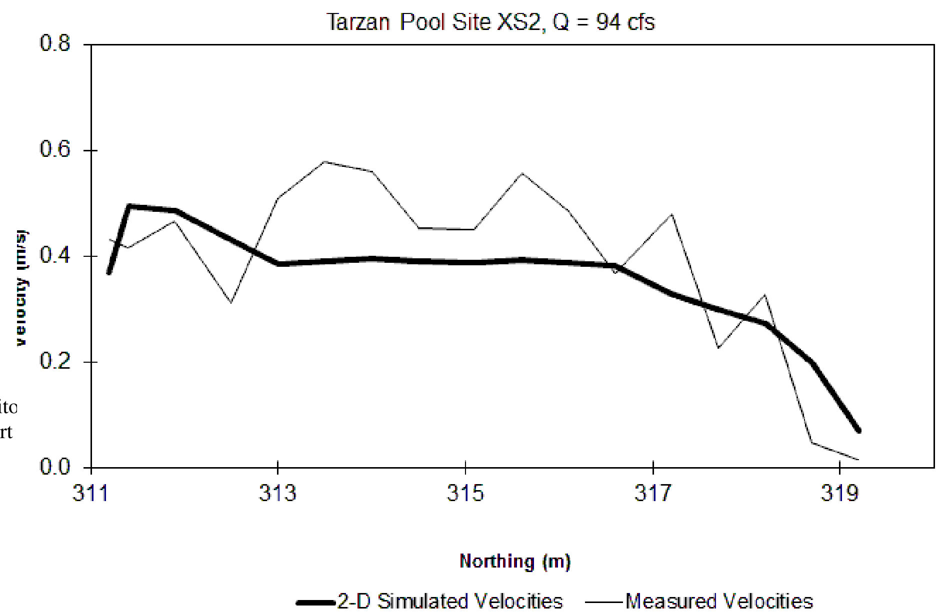

3B Restoration Site XS1, Q = 226 cfs
Velocity (m/s)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1866
1868
1870
1872
1874
1876
1878
1880
Northing (m)
2-D Simulated Velocities
Measured Velocities

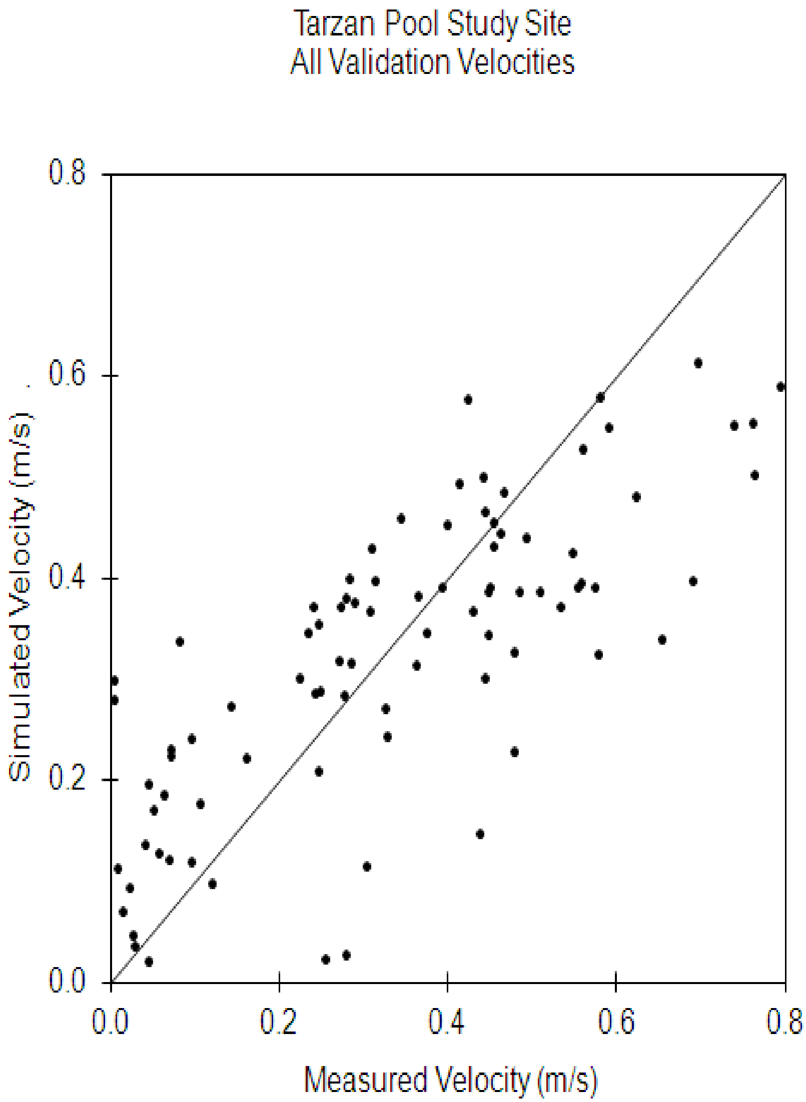

3B Restoration Site XS2, Q = 86.9 cfs
Velocity (m/s)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1728
1730
1732
1734
1736
1738
1740
1742
Northing (m)
2-D Simulated Velocities
Measured Velocities

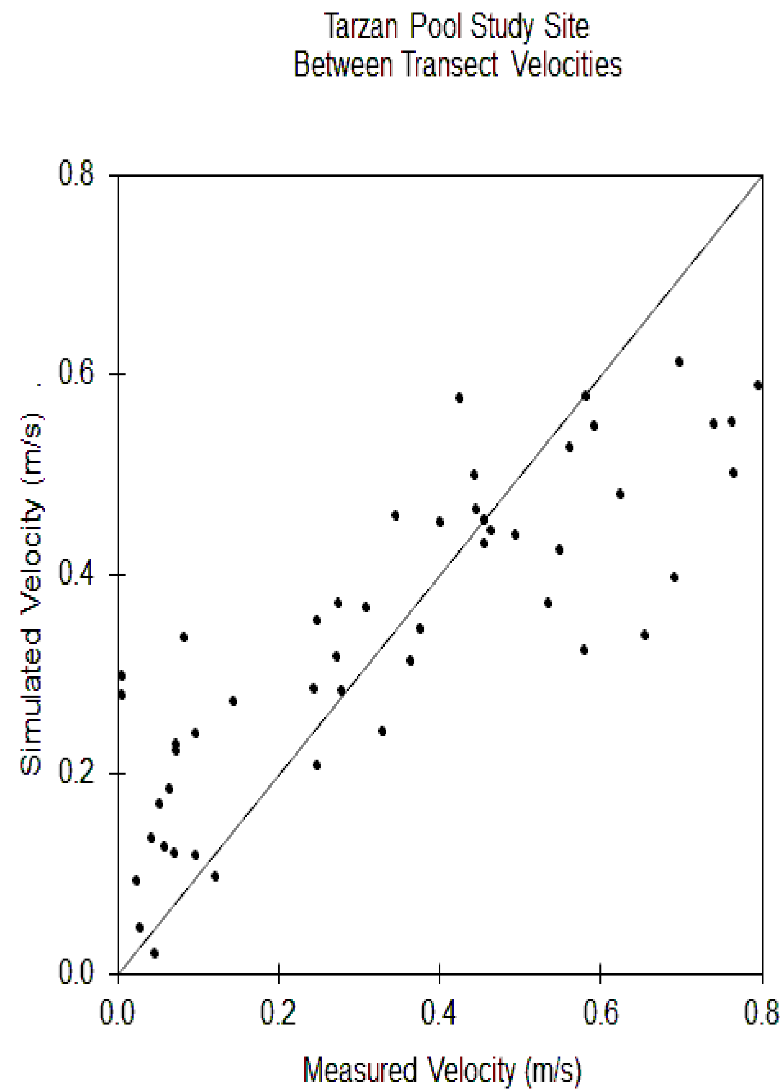

3B Restoration Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

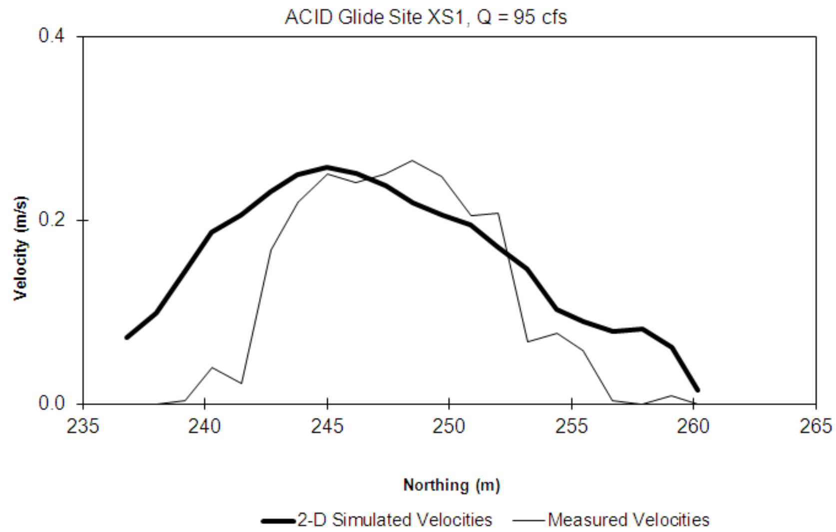

3B Restoration Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

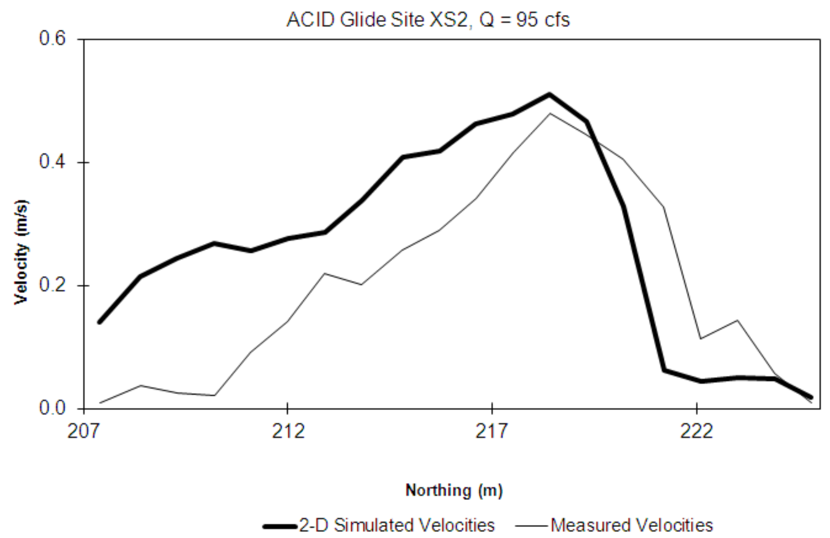

Tarzan Pool Site XS1, Q = 94 cfs
Velocity (m/s)
0.6
0.4
0.2
0.0
446
448
450
452
454
456
458
460
Northing (m)

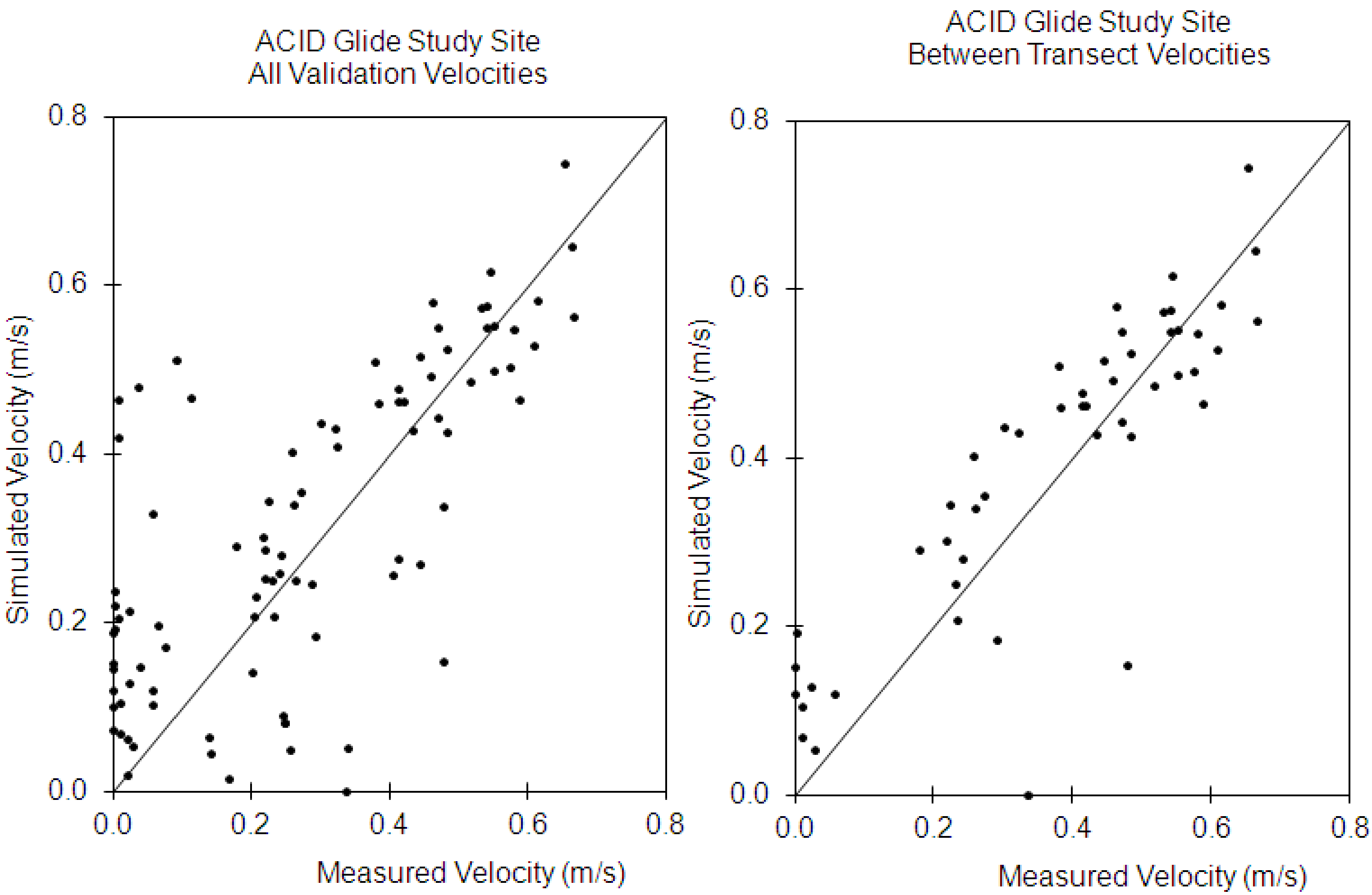

Tarzan Pool Site XS2, Q = 94 cfs
Velocity (m/s)
0.8
0.6
0.4
0.2
0.0
311
313
315
317
319
Northing (m)
2-D Simulated Velocities
Measured Velocities


Tarzan Pool Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8


Tarzan Pool Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8


ACID Glide Site XS1, Q = 95 cfs
0.4
0.2
0.0
Velocity (m/s)
235
240
245
250
255
260
265
Northing (m)
2-D Simulated Velocities
Measured Velocities


ACID Glide Site XS2, Q = 95 cfs
0.6
0.4
0.2
0.0
Velocity (m/s)
207
212
217
222
Northing (m)
2-D Simulated Velocities
Measured Velocities


ACID Glide Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
ACID Glide Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

APPENDIX I
SIMULATION STATISTICS[30]

[30] Net Q = Net Flow, Sol Δ = Solution change, Max F = Maximum Froude Number

Side Channel Run Pool

Flow (cfs)	Net Q	Sol Δ	Max F
50	10.6%	<0.000001	0.97
75	0.8%	<0.000001	0.92
100	0.6%	<0.000001	0.96
125	0.4%	<0.000001	0.97
150	0.3%	<0.000001	1.00
175	0.2%	<0.000001	1.14
200	0.2%	<0.000001	1.17
225	0.2%	<0.000001	1.25
250	0.1%	0.000006	1.08
275	0.1%	<0.000001	1.01
300	0.1%	<0.000001	1.03
350	0.04%	<0.000001	1.13
400	0.1%	<0.000001	1.61
450	0.4%	<0.000001	1.23
500	0.5%	<0.000001	1.62
550	0.5%	<0.000001	2.38
600	0.0%	0.000005	2.47
650	2.8%	0.000004	2.72
700	0.6%	0.000004	2.04
750	0.5%	<0.000001	2.31
800	0.4%	0.000006	1.84
850	0.3%	<0.000001	1.75
900	0.3%	<0.000001	1.77

North State Riffle

Flow (cfs)	Net Q	Sol Δ	Max F
50	2.2%	0.000002	1.00
75	1.2%	0.000008	0.93
100	1.2%	<0.000001	1.15
125	0.7%	0.000004	1.21
150	0.5%	<0.000001	1.11
175	0.4%	0.000005	1.03
200	0.3%	0.000003	1.00
225	0.3%	<0.000001	10.59
250	0.2%	<0.000001	11.29
275	0.2%	0.000005	8.91
300	0.2%	<0.000001	8.32
350	0.2%	<0.000001	9.23
400	0.2%	0.000009	8.39
450	0.2%	<0.000001	16.78
500	0.01%	0.000001	10.88
550	0.1%	<0.000001	8.44
600	0.1%	<0.000001	7.06
650	0.1%	<0.000001	5.79
700	0.1%	<0.000001	4.80
750	0.1%	<0.000001	3.97
800	0.1%	<0.000001	3.37
850	0.1%	<0.000001	3.05
900	0.1%	0.000006	3.07

Restoration Site 3B

Flow (cfs)	Net Q	Sol Δ	Max F
50	10.6%	0.000008	2.59
75	9.9%	0.000003	2.39
100	5.9%	0.000002	15.41
125	4.7%	0.000006	4.53
150	18.4%	0.000005	5.68
175	1.7%	0.000001	5.15
200	1.4%	0.000006	4.04
225	0.5%	0.000001	9.26
250	0.5%	0.000008	4.59
275	1.3%	<0.000001	3.83
300	0.6%	0.000005	7.36
350	2.5%	0.000001	15.31
400	4.8%	0.000002	5.98
450	0.7%	0.000003	3.91
500	7.1%	0.000008	23.66
550	5.5%	<0.000001	11.12
600	0.4%	0.000001	8.70
650	0.9%	0.000001	10.17
700	2.1%	0.000007	11.60
750	2.4%	<0.000001	12.40
800	3.3%	0.000008	10.96
850	2.1%	<0.000001	9.15
900	2.0%	0.000009	7.73

Tarzan Pool

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.5%	<0.000001	0.39
75	0.3%	<0.000001	0.48
100	0.3%	<0.000001	0.47
125	0.2%	<0.000001	0.53
150	0.1%	<0.000001	0.73
175	0.1%	<0.000001	0.63
200	0.1%	<0.000001	1.22
225	0.1%	<0.000001	1.09
250	0.1%	<0.000001	1.30
275	0.1%	<0.000001	1.08
300	0.1%	0.000006	3.47
350	0.04%	<0.000001	1.49
400	0.1%	<0.000001	1.84
450	0.04%	<0.000001	279
500	0.03%	<0.000001	0.82
550	0.03%	<0.000001	0.89
600	0.03%	<0.000001	27.04
650	0.03%	<0.000001	15.22
700	0.02%	<0.000001	21.52
750	0.01%	<0.000001	21.73
800	0.01%	<0.000001	8.58
850	0.01%	<0.000001	6.09
900	0.01%	<0.000001	8.72

ACID Glide

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.1%	0.000001	0.47
75	0.1%	<0.000001	0.41
100	0.1%	0.000003	0.49
125	0.1%	<0.000001	0.49
150	0.07%	<0.000001	0.68
175	0.05%	<0.000001	0.73
200	0.05%	<0.000001	0.71
225	0.03%	<0.000001	0.84
250	0.03%	<0.000001	0.94
275	0.03%	<0.000001	0.73
300	0.03%	<0.000001	0.73
350	0.03%	<0.000001	0.72
400	0.02%	<0.000001	1.06
450	0.01%	<0.000001	0.87
500	0.09%	0.000001	1.24
550	0.01%	<0.000001	1.47
600	0.01%	<0.000001	1.58
650	0.01%	<0.000001	1.45
700	0.02%	<0.000001	1.13
750	0.02%	<0.000001	1.08
800	0.02%	<0.000001	1.03
850	0.02%	<0.000001	0.99
900	0.02%	<0.000001	0.95

APPENDIX J
HABITAT SUITABILITY CRITERIA

Fall-run Chinook Salmon Fry Rearing

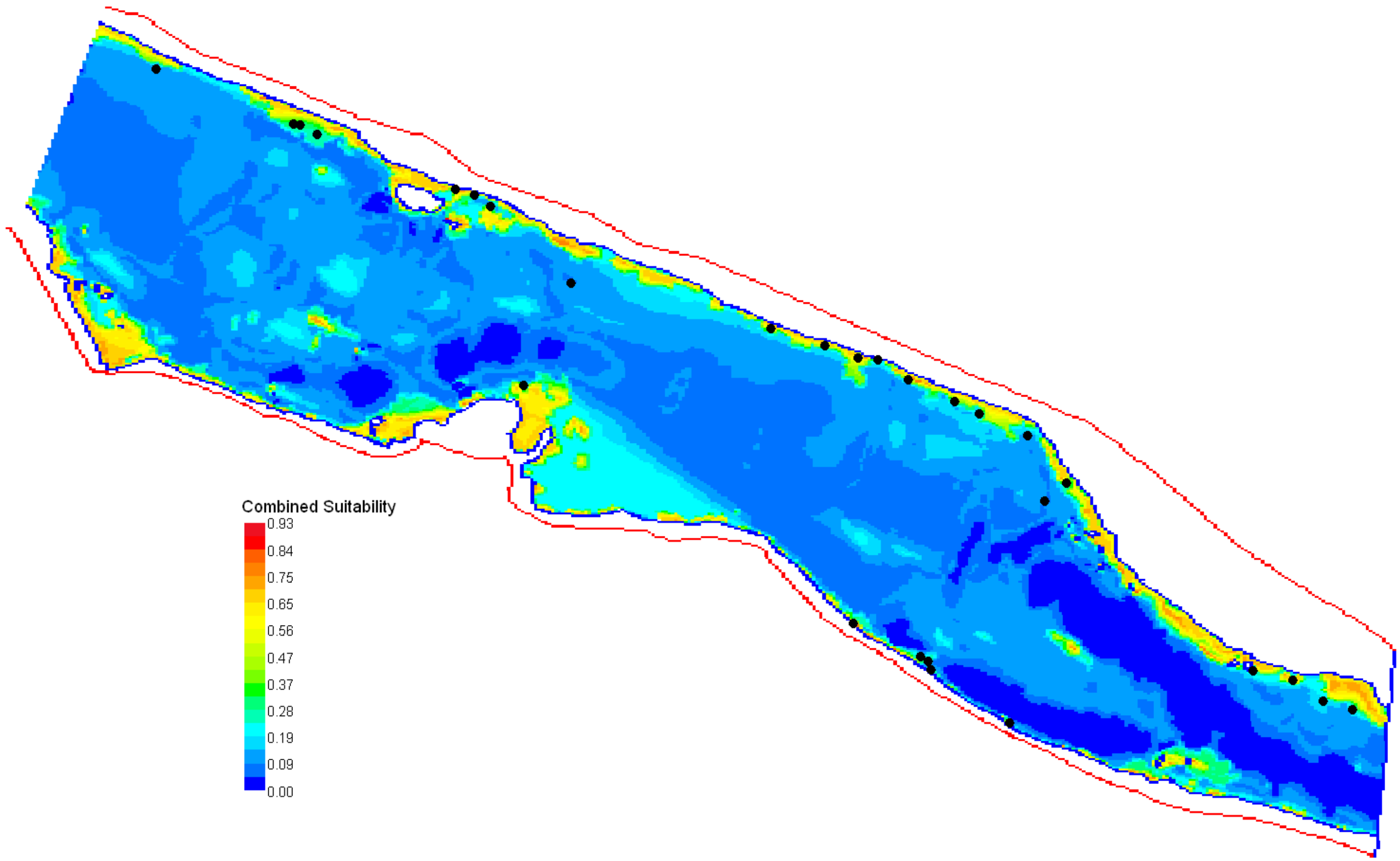
Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.70
0.10	0.99	0.1	0.94	0.1	0.33	3.60	1.00
0.20	0.97	0.2	0.97	1	0.33	100	1.00
0.30	0.93	0.3	0.98	2	0.33		
0.40	0.88	0.4	1.00	3	1.00		
0.50	0.82	0.5	1.00	3.7	1.00		
0.60	0.76	0.6	1.00	4	1.00		
0.70	0.69	0.7	0.99	4.7	1.00		
0.80	0.62	0.8	0.99	5	1.00		
0.90	0.56	0.9	0.97	5.7	1.00		
1.00	0.50	1.0	0.96	7	0.33		
1.10	0.45	1.1	0.94	8	1.00		
1.20	0.41	1.2	0.92	9	1.00		
1.30	0.38	4.7	0.92	9.7	1.00		
1.40	0.35	4.8	0.91	10	0.33		
2.50	0.34	4.9	0.90	11	0.00		
2.60	0.34	5.0	0.89	100	0.00		
2.70	0.32	5.1	0.87				
2.80	0.30	5.2	0.84				
2.90	0.27	5.3	0.80				
3.00	0.23	5.4	0.76				
3.10	0.18	5.5	0.70				
3.11	0.17	5.6	0.64				
3.12	0.00	5.7	0.57				
100	0.00	5.8	0.49				
		5.9	0.41				
		6.0	0.33				
		6.1	0.00				
		100	0.00				

Fall-run Chinook Salmon Juvenile Rearing

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0.00	1.00	0.0	0.00	0	0.00	0.00	0.51
0.10	0.94	0.4	0.00	0.1	0.33	4.65	1.00
0.20	0.88	0.5	0.30	1	1.00	100	1.00
0.30	0.82	0.6	0.33	2	0.33		
0.40	0.77	0.7	0.37	3	0.33		
0.50	0.72	0.8	0.40	3.7	1.00		
0.60	0.68	1.6	0.72	4	1.00		
2.10	0.67	1.7	0.75	4.7	1.00		
2.20	0.67	1.8	0.79	5	1.00		
2.30	0.65	2.1	0.88	5.7	1.00		
2.40	0.63	2.5	0.96	7	0.33		
2.50	0.59	2.9	1.00	8	1.00		
2.60	0.53	3.2	1.00	9	1.00		
2.70	0.47	3.6	0.96	9.7	1.00		
2.80	0.39	3.7	0.94	10	0.33		
2.90	0.30	3.8	0.93	11	0.00		
3.00	0.22	3.9	0.90	100	0.00		
3.06	0.18	4.0	0.88				
3.07	0.00	4.2	0.82				
100	0.00	4.3	0.79				
		4.4	0.76				
		4.5	0.73				
		5.3	0.41				
		5.4	0.00				
		100	0.00				

APPENDIX K
RIVER2D COMBINED SUITABILITY OF FRY AND JUVENILE LOCATIONS

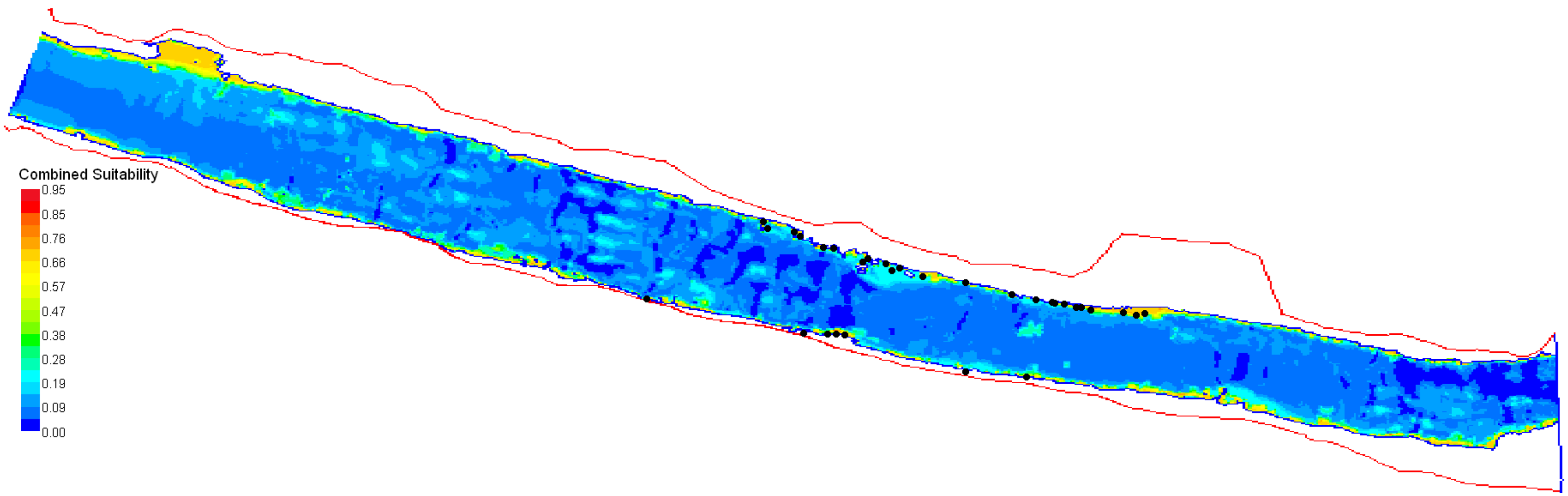
UPPER ISOLATION STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 230 CFS



Fry locations: ●

Scale: 1: 917

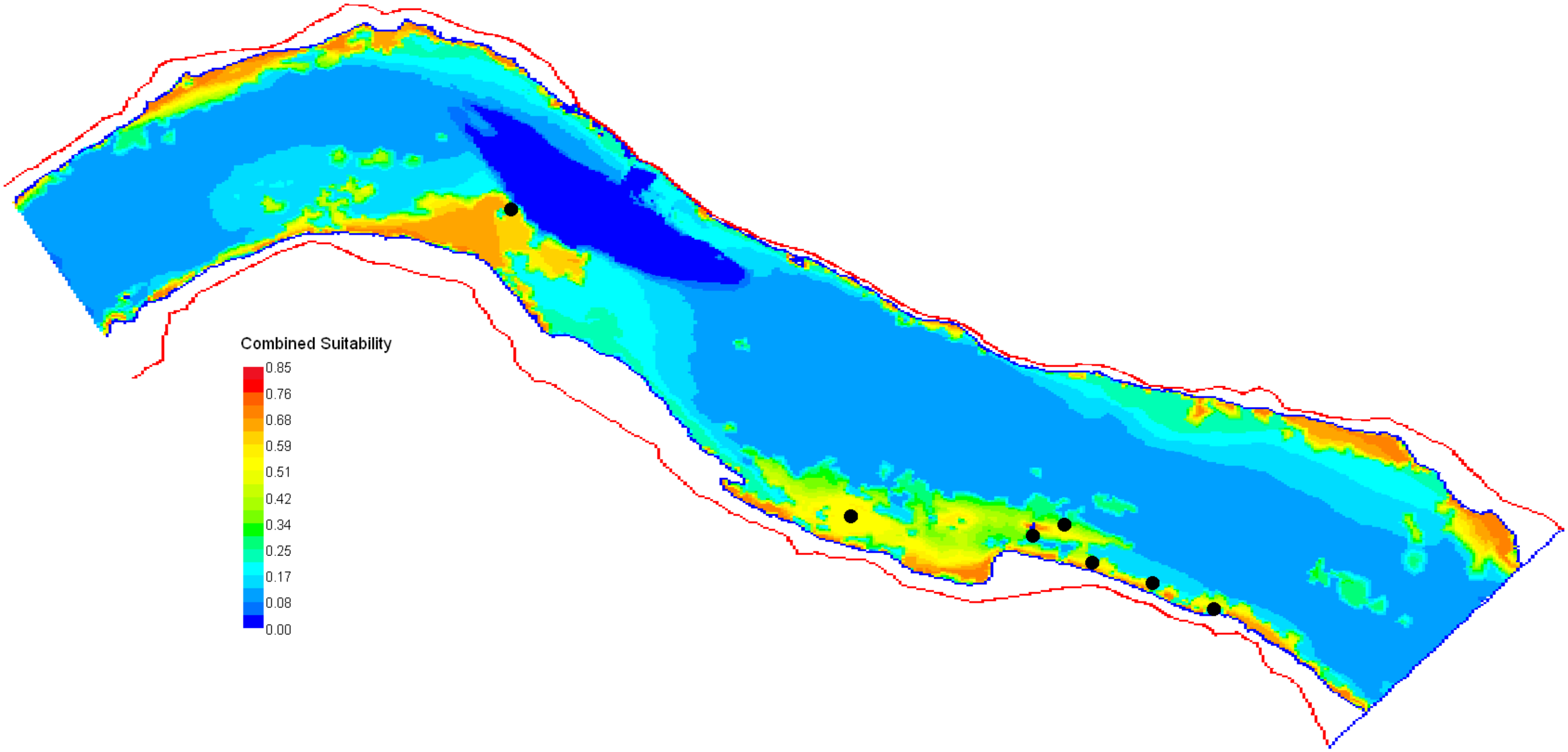
LOWER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 229 CFS



Fry locations: ●

Scale: 1: 1,481

TARZAN POOL STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 168 CFS

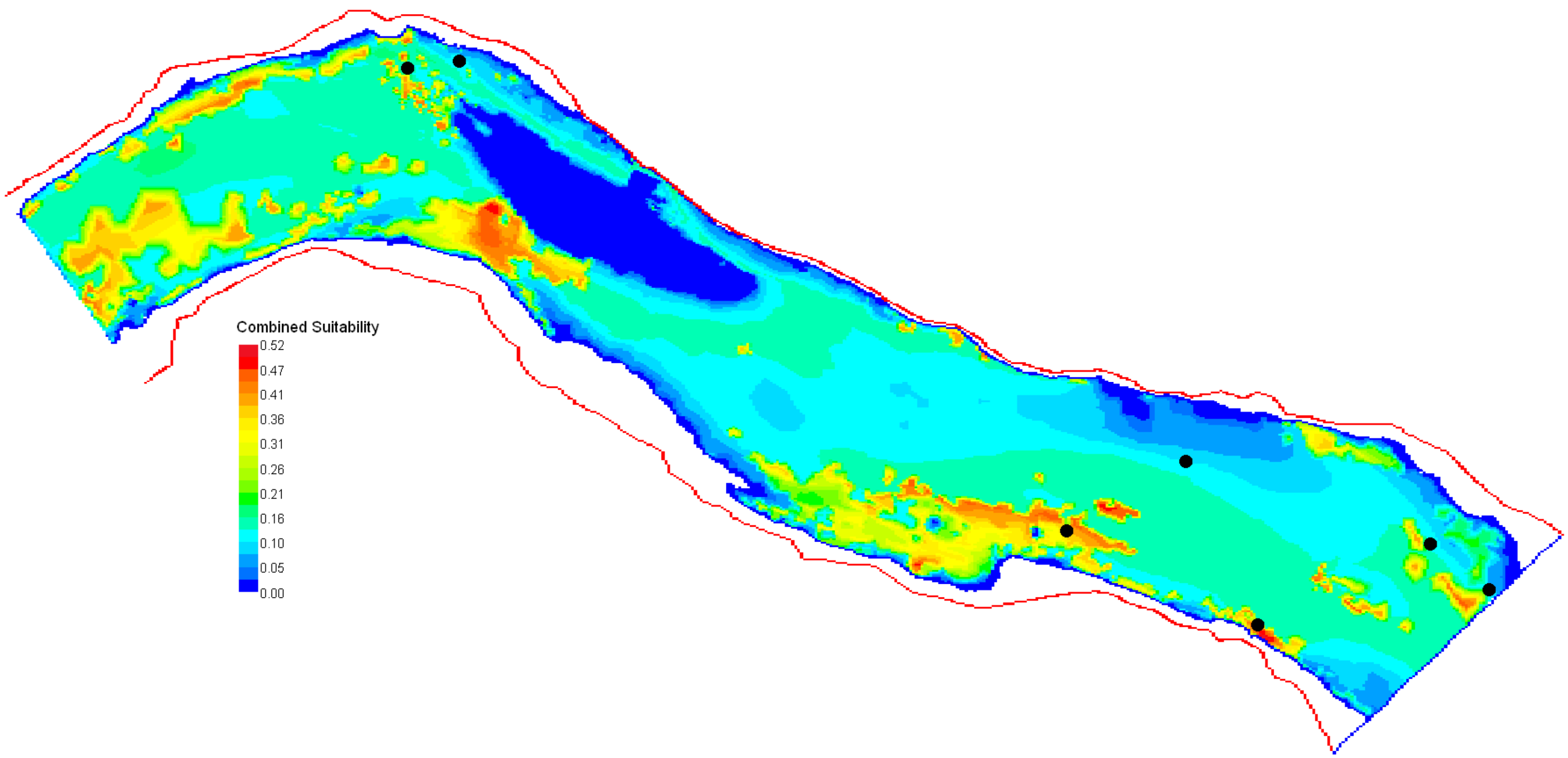


Fry locations: ●

Scale: 1: 518

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

TARZAN POOL STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 168 CFS

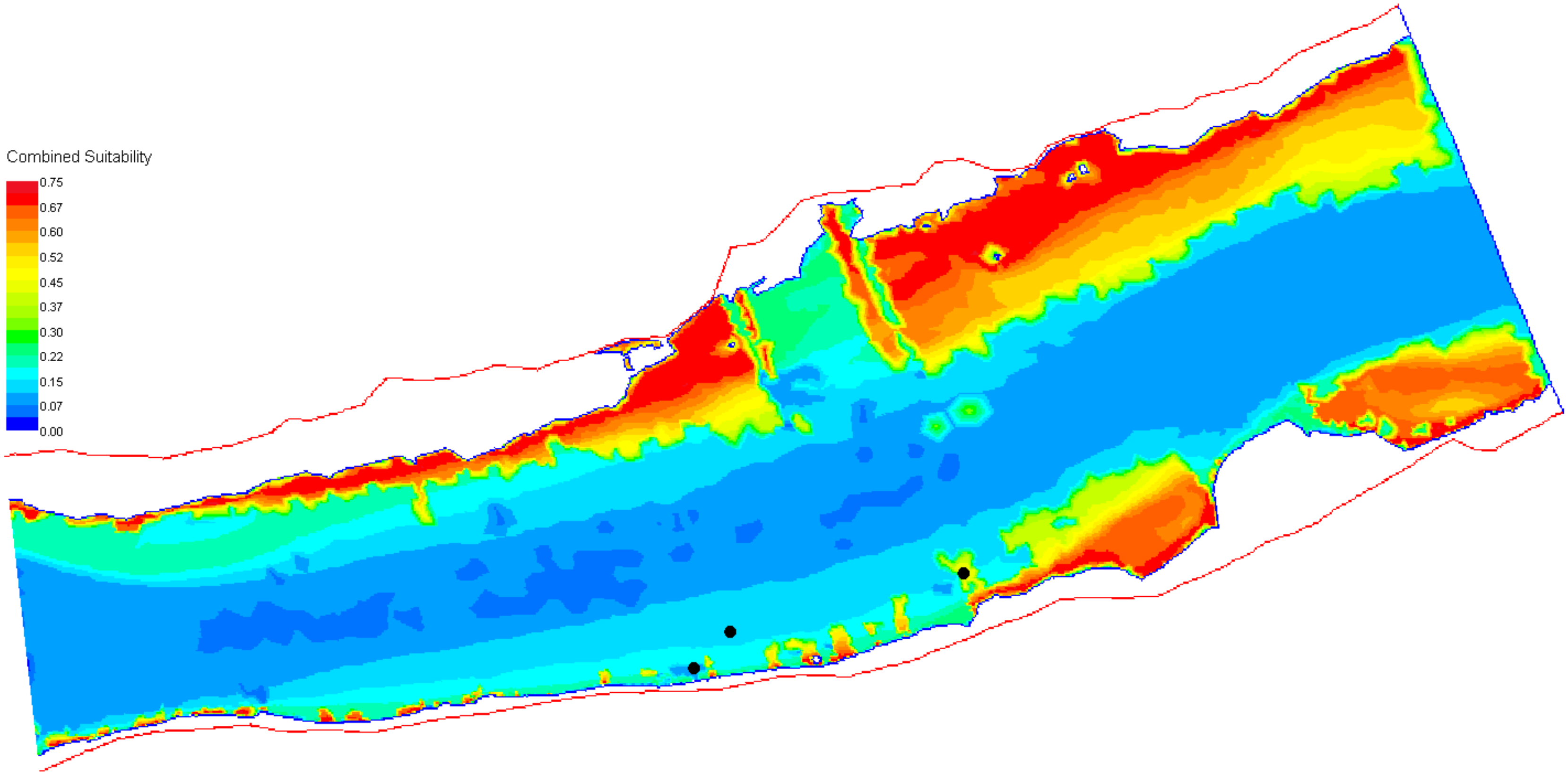


Juvenile locations: ●

Scale: 1: 518

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

ACID GLIDE STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING[31], FLOW = 168 CFS

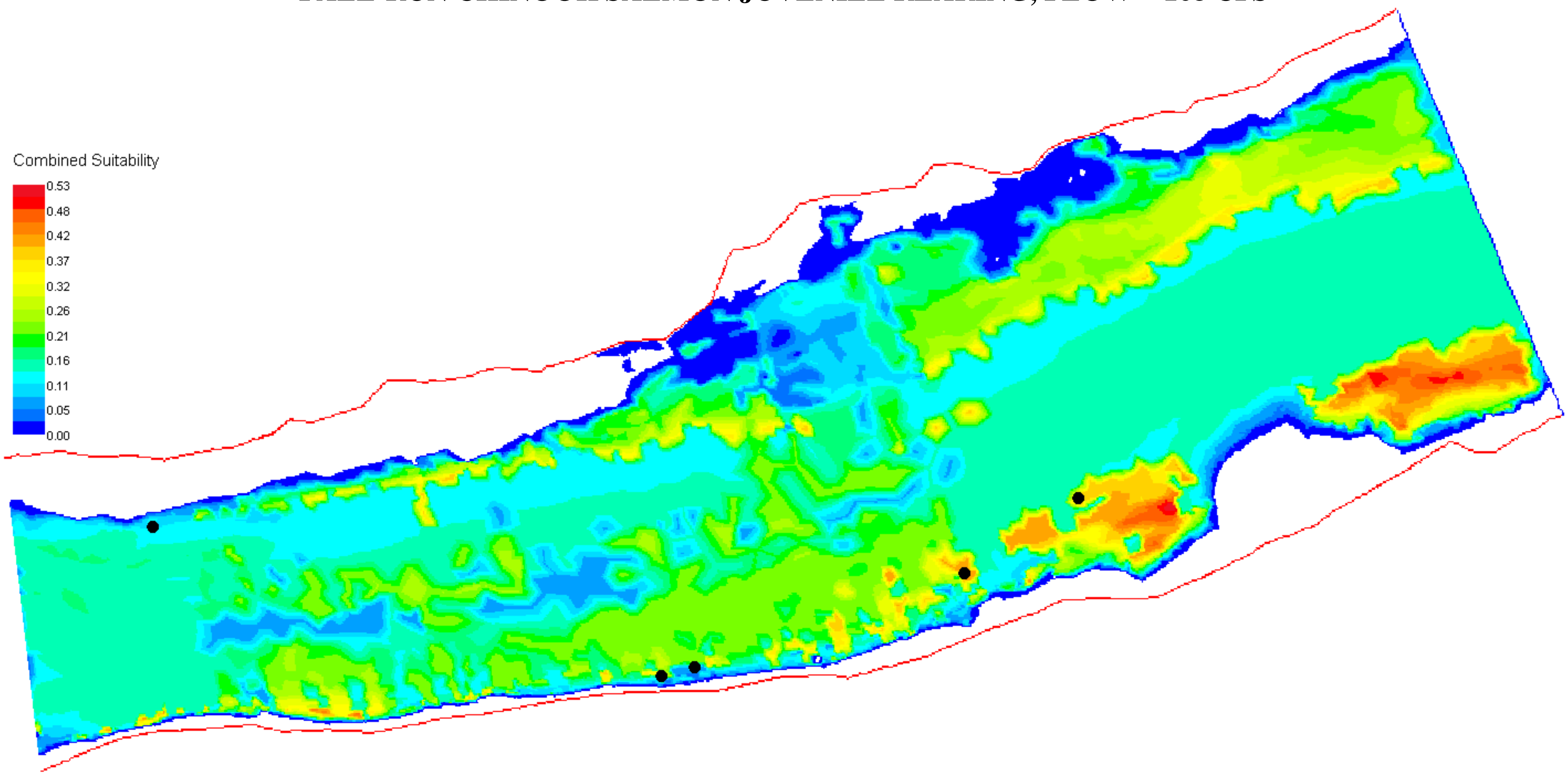


Fry locations: ●

Scale: 1: 527

31 The pattern of suitability in the upper center is due to a rectilinear patch of no cover (with a fry suitability of 0.33), with aquatic vegetation (with a fry suitability of 1.0) located both downstream and upstream of the area without cover.

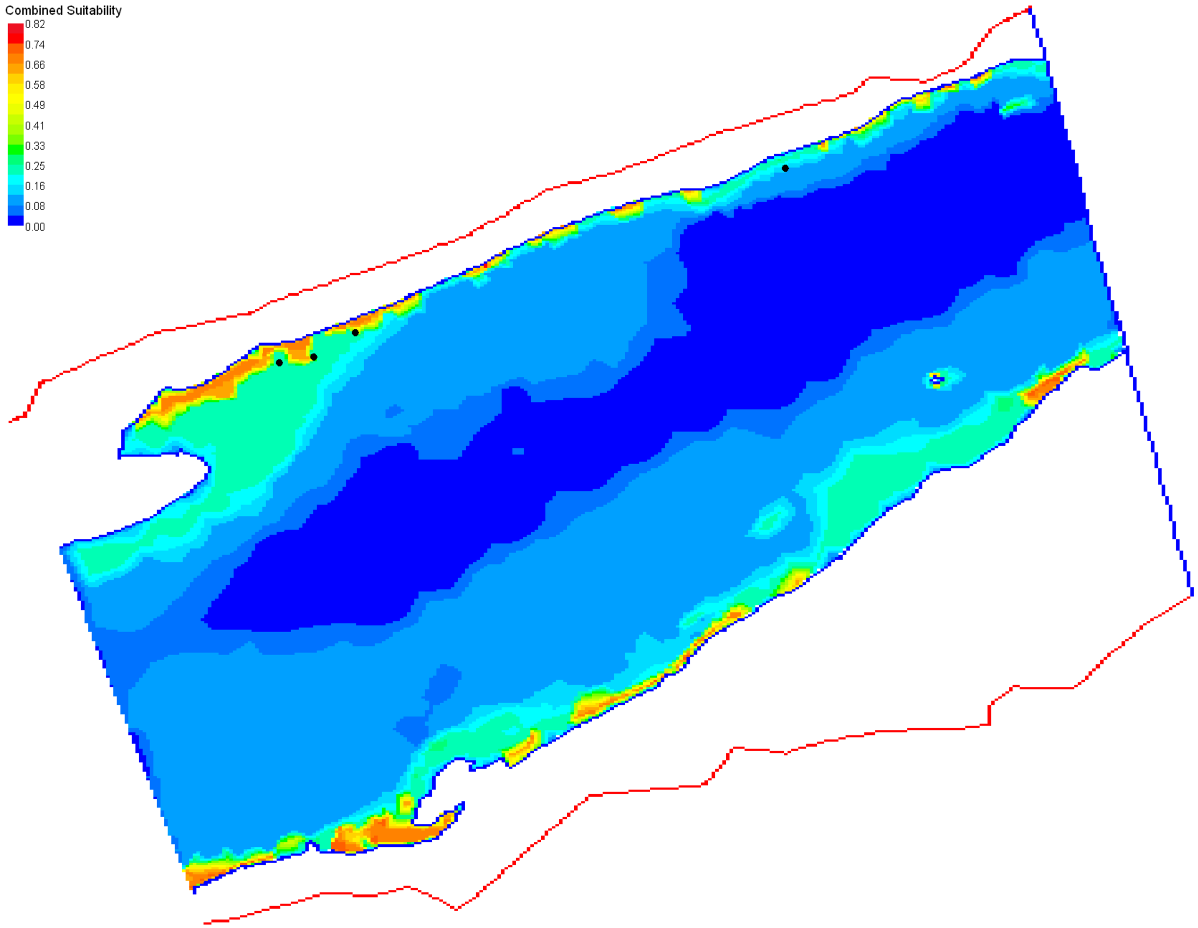
ACID GLIDE STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 168 CFS



Juvenile locations: ●

Scale: 1: 505

NORTH STATE RIFFLE STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 172 CFS

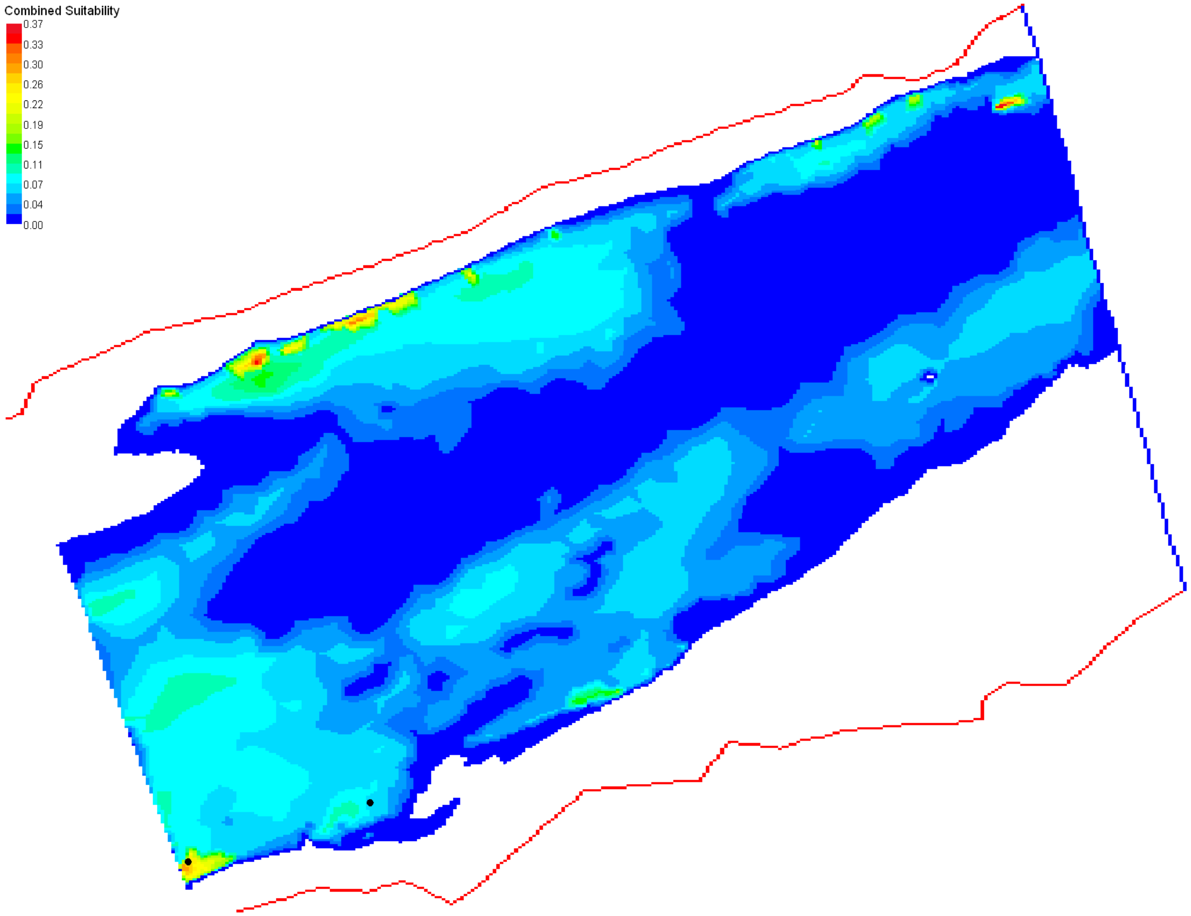


Fry locations: ●

Scale: 1: 452

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

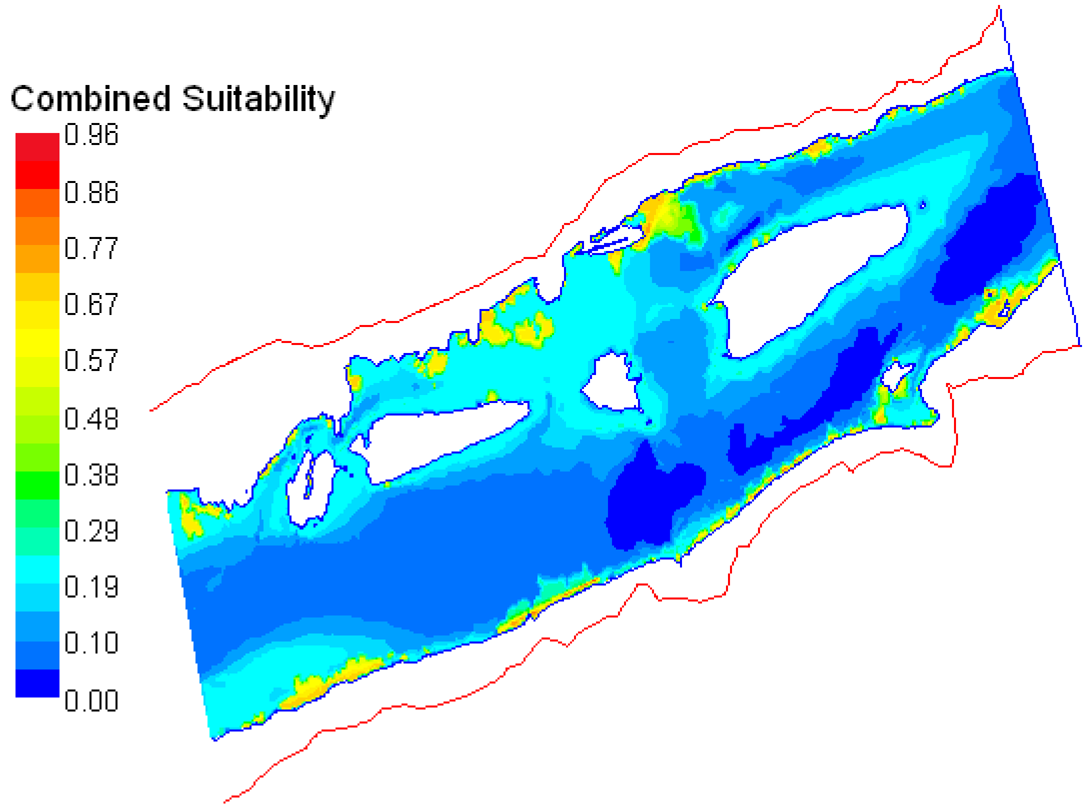
NORTH STATE RIFFLE STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 172 CFS



Juvenile locations: ●

Scale: 1: 452

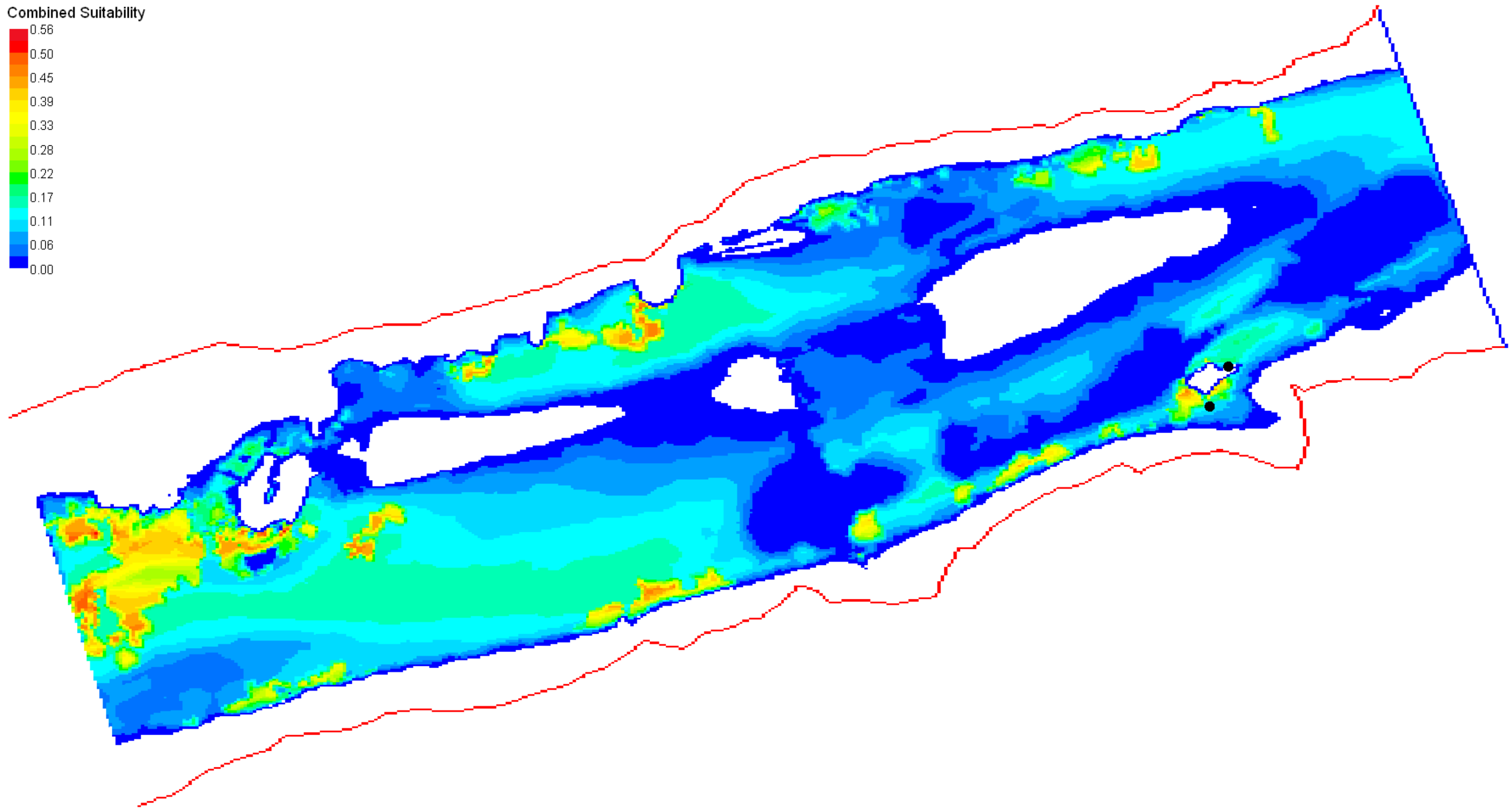
SIDE CHANNEL RUN POOL STUDY SITE
FALL-RUN CHINOOK SALMON FRY REARING, FLOW = 173 CFS



Fry locations: ●

Scale: 1: 761

SIDE CHANNEL RUN POOL STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 173 CFS

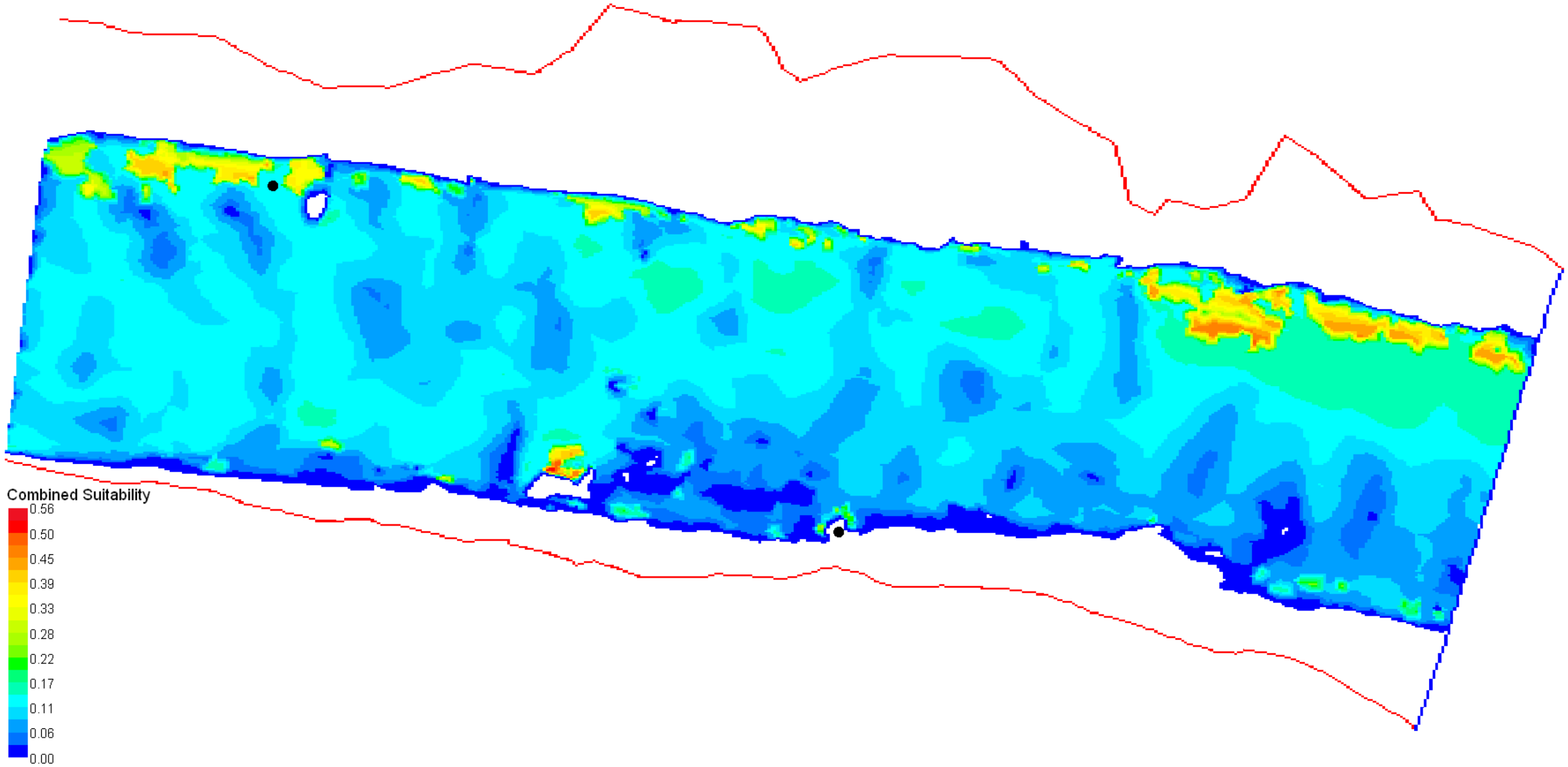


Juvenile locations: ●

Scale: 1: 634

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

UPPER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 153 CFS

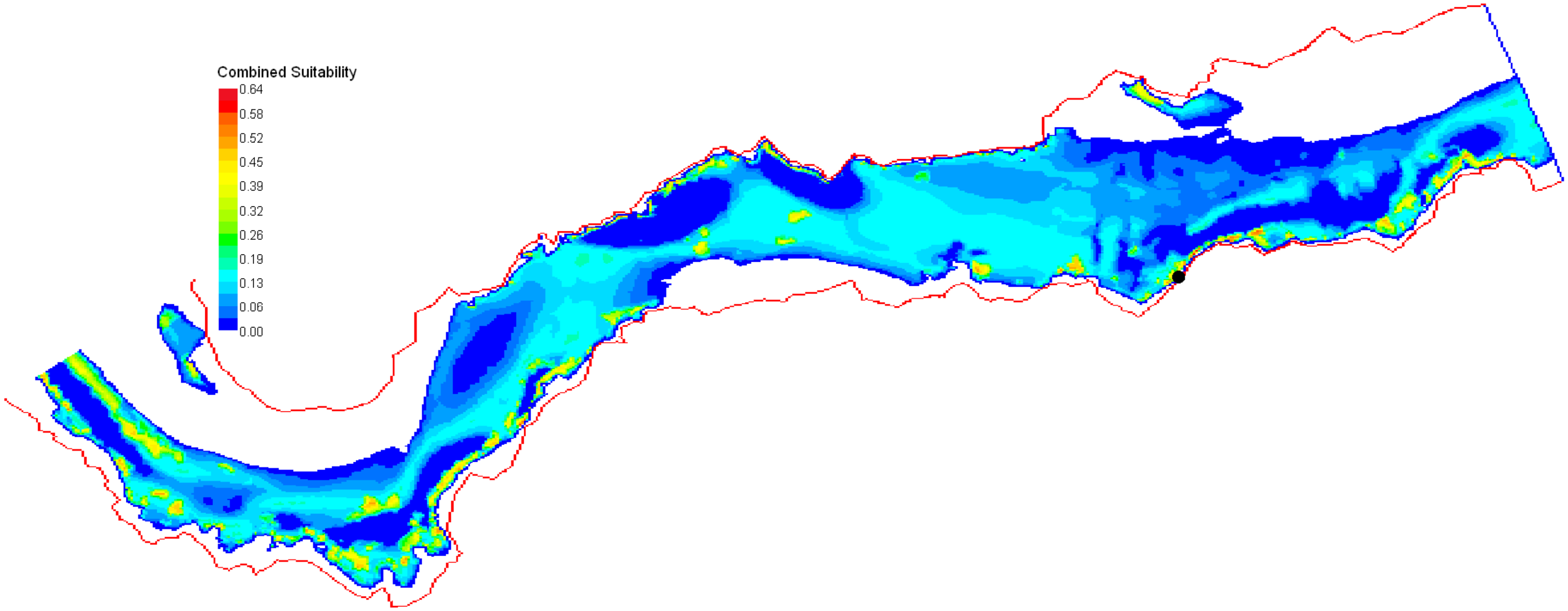


Juvenile locations: ●

Scale: 1: 471

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

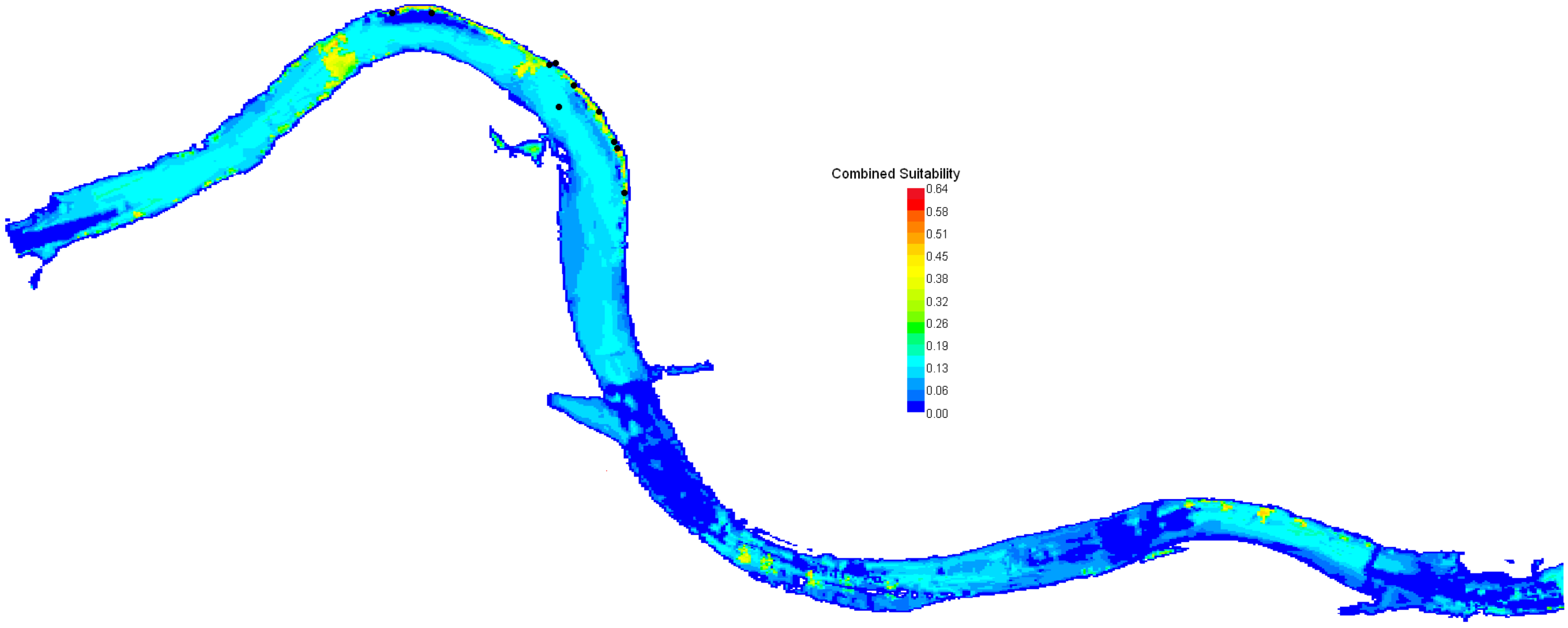
LOWER GORGE STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 204 CFS



Juvenile locations: ●

Scale: 1: 1,276

3B STUDY SITE
FALL-RUN CHINOOK SALMON JUVENILE REARING, FLOW = 189 CFS



Juvenile locations: ●

Scale: 1: 2,944

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Rearing Draft Report
January 11, 2013

APPENDIX L
HABITAT MODELING RESULTS

Spring-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	2,640	1,856	1,882	6,140	2,407
75	2,700	1,864	1,720	5,996	2,352
100	2,868	1,887	1,576	6,010	2,320
125	2,973	1,925	1,546	6,098	2,348
150	2,940	1,950	1,392	6,019	2,323
175	2,854	1,958	1,253	5,891	2,294
200	2,765	1,935	1,138	5,668	2,348
225	2,743	2,055	976	5,645	2,412
250	2,646	2,034	960	5,738	2,634
275	2,496	1,890	958	5,862	2,961
300	2,475	1,769	948	5,761	3,070
350	2,516	1,689	1,043	5,833	2,851
400	2,329	1,704	1,123	6,171	2,847
450	2,317	1,724	1,127	6,331	2,887
500	2,328	1,787	1,123	6,535	2,896
550	2,300	1,896	1,129	6,850	2,958
600	2,404	2,011	1,159	7,255	3,059
650	2,466	2,097	1,229	7,687	3,201
700	2,623	2,042	1,386	8,173	3,484
750	2,787	1,896	1,507	8,803	3,778
800	3,002	1,840	1,601	9,885	4,131
850	3,117	1,861	1,783	11,198	4,319
900	3,067	1,876	1,962	12,650	4,366

Spring-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	1,089	784	18,228	731	1,144	127,116
75	1,097	867	17,536	737	1,251	126,494
100	1,118	977	17,041	726	1,407	127,924
125	1,135	985	16,923	756	1,655	130,415
150	1,156	934	16,981	749	1,655	129,286
175	1,244	807	17,177	757	1,666	130,070
200	1,346	730	17,823	783	1,686	131,919
225	1,414	691	18,684	747	1,765	133,275
250	1,430	695	19,441	751	1,883	134,972
275	1,571	731	20,605	907	1,930	141,192
300	1,716	761	21,914	844	2,019	143,221
350	1,742	795	23,529	882	2,062	142,856
400	1,825	826	24,899	961	1,935	146,002
450	1,886	830	25,873	1,010	1,836	149,028
500	1,929	804	27,156	1,051	1,830	152,636
550	1,951	754	27,971	1,102	1,798	155,903
600	1,941	720	29,483	1,130	1,821	162,051
650	1,989	700	30,803	1,144	1,837	168,225
700	2,128	717	32,506	1,178	1,827	176,777
750	2,215	765	34,676	1,173	1,816	184,361
800	2,293	833	37,393	1,198	1,822	196,658
850	2,348	939	41,297	1,266	1,762	211,735
900	2,266	1,051	45,562	1,380	1,715	226,197

Fall-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	6,042	7,208	5,511	29,006	10,804
75	6,309	7,113	5,411	27,803	10,875
100	6,291	7,021	5,235	26,400	10,661
125	6,080	6,944	5,127	25,032	10,233
150	5,794	6,939	4,983	23,884	9,771
175	5,576	6,938	4,825	22,875	9,299
200	5,511	6,886	4,705	22,096	8,994
225	5,346	6,790	4,660	21,445	8,782
250	5,257	6,654	4,633	20,965	8,604
275	5,139	6,535	4,641	20,552	8,497
300	5,024	6,493	4,659	20,179	8,401
350	4,908	6,318	4,647	19,398	8,274
400	4,710	6,262	4,649	18,738	8,316
450	4,476	6,259	4,681	18,089	8,120
500	4,458	6,243	4,671	17,129	7,805
550	4,472	6,153	4,614	16,351	7,482
600	4,476	5,925	4,674	15,708	6,926
650	4,537	5,843	4,661	15,248	6,934
700	4,548	5,748	4,622	14,831	6,676
750	4,575	5,645	4,579	14,398	6,423
800	4,461	5,539	4,414	13,814	6,169
850	4,305	5,492	4,353	13,294	6,021
900	4,259	5,452	4,349	12,997	5,863

Fall-run Chinook salmon fry rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	5,592	2,188	50,950	6,800	8,857	536,166
75	5,863	2,138	49,438	6,702	8,756	528,779
100	5,934	2,025	48,539	6,504	8,526	515,513
125	5,965	1,877	48,095	6,312	8,232	501,845
150	5,930	1,750	47,989	6,163	7,941	490,718
175	5,779	1,670	48,020	5,951	7,619	478,203
200	5,685	1,631	48,679	5,838	7,401	470,453
225	5,688	1,585	49,495	5,740	7,218	463,637
250	5,618	1,591	50,233	5,644	7,166	458,051
275	5,561	1,597	51,454	5,563	7,137	454,405
300	5,471	1,557	52,547	5,491	7,157	450,992
350	5,296	1,466	54,026	5,361	7,171	444,511
400	5,113	1,370	55,187	5,295	7,127	440,975
450	4,819	1,302	55,181	5,690	7,062	438,123
500	4,509	1,230	56,956	5,188	7,005	425,804
550	4,385	1,198	57,376	5,158	6,900	418,842
600	4,303	1,218	57,925	5,611	6,774	417,735
650	4,162	1,258	59,303	5,218	6,633	410,118
700	4,080	1,331	61,244	4,941	6,449	404,258
750	3,955	1,362	63,424	4,773	6,450	400,288
800	3,886	1,367	65,884	4,572	5,962	393,976
850	3,778	1,308	69,603	4,424	5,687	390,482
900	3,669	1,230	73,549	4,333	5,465	389,928

Steelhead/rainbow trout fry rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	1,452	939	1,071	7,741	2,273
75	1,542	921	1,012	7,127	2,247
100	1,532	920	923	6,514	2,187
125	1,471	891	870	5,831	2,045
150	1,417	918	810	5,456	1,900
175	1,399	981	725	5,093	1,766
200	1,357	963	669	4,875	1,672
225	1,341	944	649	4,697	1,597
250	1,332	896	640	4,479	1,562
275	1,357	877	643	4,322	1,551
300	1,375	849	640	4,232	1,554
350	1,434	851	612	4,044	1,530
400	1,516	874	571	3,840	1,602
450	1,516	947	571	3,783	1,734
500	1,541	1,013	554	3,857	1,625
550	1,676	1,092	554	3,755	1,482
600	1,749	1,064	585	3,658	1,460
650	1,794	1,051	661	3,696	1,422
700	1,834	1,073	720	3,894	1,415
750	1,943	1,063	796	3,959	1,445
800	1,949	1,076	887	4,019	1,465
850	1,875	1,042	925	4,020	1,482
900	1,851	1,018	1,022	4,017	1,476

Steelhead/rainbow trout fry rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	1,105	526	10,284	1,268	1,782	110,573
75	1,203	483	9,921	1,134	1,716	107,877
100	1,219	451	9,825	1,017	1,667	102,746
125	1,182	415	9,728	938	1,630	96,754
150	1,122	398	9,795	890	1,590	93,114
175	1,075	385	9,940	837	1,539	89,942
200	1,036	379	10,230	787	1,493	87,201
225	1,022	387	10,677	770	1,455	85,807
250	1,022	418	10,998	736	1,416	84,039
275	1,008	432	11,308	699	1,351	83,164
300	978	439	12,001	663	1,306	83,079
350	911	432	13,110	599	1,296	82,580
400	879	416	13,702	558	1,270	82,669
450	850	415	14,371	639	1,220	85,798
500	798	429	15,205	506	1,190	85,039
550	774	414	15,576	477	1,140	84,361
600	790	393	16,191	536	1,066	86,183
650	757	424	16,928	510	1,041	87,029
700	706	461	17,706	493	1,068	88,024
750	693	512	18,545	496	1,068	90,407
800	695	533	19,862	489	1,003	93,064
850	674	523	21,600	477	908	94,319
900	674	483	24,020	484	823	97,105

Spring-run Chinook salmon and Steelhead/rainbow trout juvenile rearing
WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	2,325	1,456	903	4,476	1,487
75	3,085	1,893	1,171	5,863	1,930
100	3,757	2,262	1,407	7,041	2,309
125	4,340	2,590	1,616	8,134	2,675
150	4,867	2,874	1,822	9,125	3,006
175	5,326	3,163	2,039	10,174	3,355
200	5,694	3,391	2,217	11,022	3,638
225	6,028	3,590	2,380	11,826	3,903
250	6,285	3,776	2,535	12,579	4,149
275	6,500	3,930	2,680	13,282	4,378
300	6,671	4,070	2,814	13,943	4,601
350	6,891	4,306	3,062	15,154	5,000
400	7,008	4,484	3,272	16,240	5,364
450	7,023	4,616	3,448	17,170	5,687
500	7,059	4,731	3,612	18,023	5,995
550	6,990	4,817	3,741	18,723	6,245
600	6,939	4,897	3,832	19,308	6,448
650	6,897	4,931	3,909	19,790	6,618
700	6,734	4,938	3,965	20,180	6,759
750	6,632	4,930	4,002	20,489	6,870
800	6,432	4,896	4,024	20,747	6,945
850	6,252	4,888	4,026	20,900	7,009
900	6,064	4,891	4,011	21,006	7,028

Spring-run Chinook salmon and Steelhead/rainbow trout juvenile rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	900	418	7,639	735	751	84,765
75	1,183	555	9,735	948	956	109,949
100	1,439	678	11,587	1,138	1,149	131,778
125	1,686	782	13,185	1,306	1,327	151,521
150	1,929	860	14,585	1,460	1,496	169,463
175	2,185	931	16,111	1,622	1,687	188,198
200	2,394	996	17,281	1,748	1,844	203,305
225	2,587	1,066	18,372	1,861	1,991	217,275
250	2,769	1,119	19,440	1,965	2,115	230,218
275	2,943	1,171	20,418	2,057	2,225	241,875
300	3,106	1,221	21,243	2,141	2,329	252,459
350	3,399	1,308	22,708	2,281	2,515	270,939
400	3,656	1,389	23,979	2,387	2,674	286,641
450	3,876	1,461	24,877	2,041	2,812	294,252
500	4,071	1,519	25,767	2,528	2,935	310,507
550	4,234	1,564	26,247	2,553	3,029	318,737
600	4,383	1,600	26,416	2,048	3,109	319,283
650	4,504	1,631	26,654	2,147	3,168	325,605
700	4,621	1,657	26,807	2,241	3,212	330,086
750	4,690	1,678	26,857	2,298	3,212	333,135
800	4,756	1,692	26,758	2,327	3,251	334,596
850	4,791	1,702	26,586	2,323	3,256	334,724
900	4,794	1,691	26,393	2,212	3,243	332,802

Fall-run Chinook salmon juvenile rearing WUA (ft^2) in Lower Alluvial Segment

Flow (cfs)	Shooting Gallery	Lower Gorge	Upper Renshaw	Lower Renshaw	Upper Isolation
50	3,172	4,231	2,075	9,724	3,512
75	3,809	4,529	2,470	11,038	3,938
100	4,182	4,791	2,781	12,188	4,230
125	4,309	4,963	3,088	13,184	4,488
150	4,444	5,074	3,330	14,050	4,709
175	4,535	5,143	3,598	14,892	4,934
200	4,656	5,165	3,799	15,530	5,122
225	4,657	5,150	4,006	16,069	5,297
250	4,514	5,116	4,177	16,510	5,448
275	4,346	5,091	4,337	16,801	5,569
300	4,105	5,084	4,482	16,989	5,671
350	3,660	4,964	4,699	16,957	5,788
400	3,328	4,789	4,846	16,481	5,831
450	3,011	4,599	4,912	15,675	5,794
500	2,821	4,396	4,832	14,536	5,644
550	2,773	4,197	4,630	13,501	5,439
600	2,667	4,048	4,423	12,522	5,388
650	2,524	3,932	4,089	11,580	4,837
700	2,369	3,875	3,720	10,646	4,443
750	2,241	3,736	3,353	9,758	4,066
800	2,120	3,665	2,985	8,891	3,733
850	2,096	3,609	2,707	8,155	3,477
900	2,045	3,579	2,494	7,603	3,234

Fall-run Chinook salmon juvenile rearing WUA (ft^2) in Lower Alluvial Segment (continued)

Flow (cfs)	Side Channel Run Pool	North State Riffle	Restoration Site 3B	Tarzan Pool	ACID Glide	Total
50	2,410	433	19,585	2,910	4,554	224,915
75	2,700	524	21,195	3,295	4,558	248,454
100	2,906	568	22,735	3,613	4,637	267,634
125	3,075	579	24,021	3,884	4,735	283,272
150	3,214	581	25,125	4,114	4,844	296,863
175	3,333	582	26,045	4,321	4,970	308,968
200	3,412	570	26,704	4,496	5,087	318,200
225	3,489	541	27,187	4,649	5,206	325,414
250	3,514	464	27,456	4,780	5,367	330,224
275	3,574	516	27,698	4,890	5,533	334,768
300	3,595	499	27,933	4,985	5,684	337,862
350	3,553	457	27,962	5,121	5,952	338,627
400	3,426	433	27,899	5,197	6,156	334,869
450	3,244	423	26,985	4,327	6,292	315,866
500	3,105	400	27,342	5,157	6,335	315,769
550	3,065	392	26,752	5,035	6,269	304,825
600	3,088	390	25,790	4,015	6,114	284,289
650	3,053	390	25,664	3,910	5,916	273,178
700	3,052	378	25,720	3,825	5,681	263,294
750	2,960	356	25,880	3,740	5,681	253,609
800	2,898	333	26,064	3,613	5,183	242,998
850	2,793	306	26,375	3,435	4,948	234,032
900	2,658	287	26,669	3,269	4,745	226,215