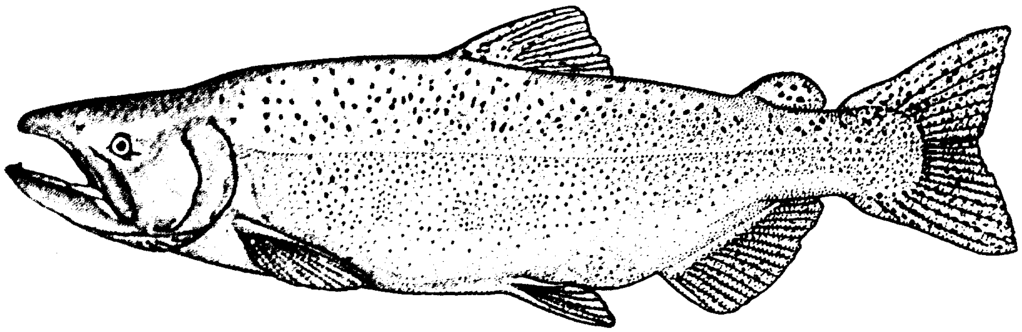
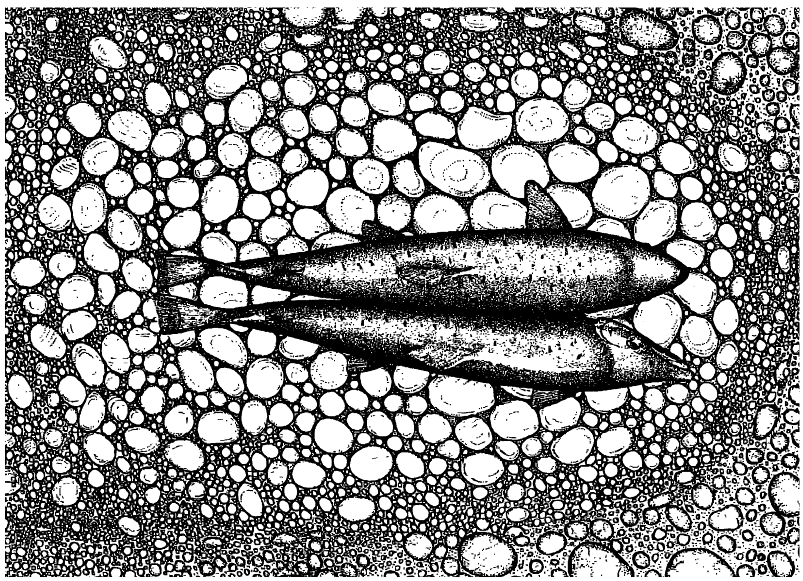
FLOW-HABITAT RELATIONSHIPS FOR FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING IN CLEAR CREEK BETWEEN CLEAR CREEK ROAD AND THE SACRAMENTO RIVER





U. S. Fish and Wildlife Service
Sacramento 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 FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING

PREFACE

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

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

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

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

ACKNOWLEDGMENTS

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ABSTRACT

Flow-habitat relationships were derived for fall-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Clear Creek Road Bridge and the Sacramento River. A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this study to model available habitat. Habitat was modeled for five sites in the Lower Alluvial segment, which were among those which received the heaviest use by spawning fall-run Chinook salmon. Bed topography was collected for these sites using a total station. Additional data were collected to develop stage-discharge relationships at the upstream and downstream end of the sites as an input to RIVER2D. Velocities measured in the site were used to validate the velocity predictions of RIVER2D. The raw topography data were refined by defining breaklines going up the channel along features such as thalwegs, tops of bars and bottoms of banks. A finite element computational mesh was then developed to be used by RIVER2D for hydraulic calculations. RIVER2D hydraulic data were calibrated by adjusting bed roughnesses until simulated water surface elevations matched measured water surface elevations. The calibrated files for each site were used in RIVER2D to simulate hydraulic characteristics for 23 simulation flows. Fall-run Chinook salmon habitat suitability criteria (HSC) were developed from depth, velocity and substrate measurements collected on 442 fall-run Chinook salmon redds. The horizontal location of a subset of the fall-run Chinook salmon redds, located in the five study sites, was measured with a total station to use in biological validation of the habitat models. Logistic regression, along with a technique to adjust spawning depth habitat utilization curves to account for low availability of deep waters with suitable velocities and substrates (Gard 1998), was used to develop the depth HSC, while the velocity HSC were developed solely from the habitat use data. Substrate HSC were developed based on the relative frequency of redds with different substrate codes. Biological validation was accomplished by testing, with a Mann-Whitney U test, whether the combined suitability predicted by RIVER2D was higher at redd locations versus at locations where redds were absent. The steelhead/rainbow trout HSC used in this study were those developed in a previous study of the Upper Alluvial and Canyon segments (U.S. Fish and Wildlife Service 2007). No biological validation was performed for the steelhead/rainbow trout in the Lower Alluvial segment. The optimum depth for fall-run Chinook salmon was 1.10 feet (0.34 m), while optimum velocities were 1.83 to 1.97 ft/s (0.56 to 0.60 m/s) and optimum substrate was 1 to 3 inches (2.5 to 7.5 cm). The flow with the maximum habitat was 300 cfs for both fall-run Chinook salmon and steelhead/rainbow trout.

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act provided for enactment of all reasonable efforts to double sustainable natural production of anadromous fish stocks including the four races of Chinook salmon (fall, late-fall, winter, and spring runs), steelhead, white and green sturgeon, American shad and striped bass. Clear Creek is a tributary of the Sacramento River, located in the Sacramento River basin portion of the Central Valley of California. For Clear Creek, the Central Valley Project Improvement Act Anadromous Restoration Plan calls for a release from Whiskeytown Dam of 200 cfs from October through June and a release of 150 cfs or less from July through September (U. S. Fish and Wildlife Service 2001) as a high priority action to restore anadromous fish populations in Clear Creek.

The Clear Creek study is a 7-year effort, the goals of which are to determine the relationship between stream flow and physical habitat availability for all life stages of Chinook salmon (fall- and spring-run) and steelhead/rainbow trout. Clear Creek was selected for study because of a number of factors, including the presence of listed threatened or endangered species, the number of target species or races, and whether current instream flows were inadequate. There are four phases to this study based on the life stages to be studied and the number of segments delineated for Clear Creek from downstream of Whiskeytown Reservoir to the confluence with the Sacramento River[2]. Spawning habitat study sites for the third phase of the study were selected that encompassed the Lower Alluvial segment of the creek, excluding a 2-mile restoration reach (U.S. Fish and Wildlife Service 2005). The goal of this study was to produce models predicting the availability of physical habitat in Clear Creek between Clear Creek Road and the Sacramento River, excluding the 2-mile restoration reach, for fall-run Chinook salmon and steelhead/rainbow trout spawning over a range of stream flows that meet, to the extent feasible, the levels of accuracy specified in the methods section. The tasks and their associated objectives are given in Table 1.

To develop a flow regime which will accommodate the habitat needs of anadromous species inhabiting streams it is necessary to determine the relationship between streamflow and habitat availability for each life stage of those species. We are using the models and techniques contained within the Instream Flow Incremental Methodology (IFIM) to establish these relationships. The IFIM is a habitat-based tool developed by the U.S. Fish and Wildlife Service

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

Table 1. Study tasks and associated objectives.

Task	Objective
study segment selection	determine the number and aerial extent of study segments
field reconnaissance and study site selection	select study sites which receive heavy spawning use by spring and fall-run Chinook salmon and steelhead/rainbow trout
transect placement (study site setup)	delineate the upstream and downstream boundaries of the study sites, coinciding with the boundaries of the heavy spawning use areas
hydraulic and structural data collection	collect the data necessary to: 1) develop stage-discharge relationships at the upstream and downstream boundaries of the site; 2) develop the site topography and substrate distribution; and 3) validate the velocity predictions of the hydraulic model of the study sites
hydraulic model construction and calibration	predict depths and velocities throughout the study sites at a range of simulation flows
habitat suitability criteria data collection	collect depth, velocity and substrate data for spring and fall-run Chinook salmon and steelhead/rainbow trout redds to be used in developing habitat suitability criteria (HSC)
biological verification data collection	record the horizontal location of redds within the study sites to use in the biological verification of the habitat models of the study sites
habitat suitability criteria development	develop indices to translate the output of the hydraulic models into habitat quality
biological verification	determine if the combined suitability of locations with redds had higher suitability that those of unoccupied locations
habitat simulation	compute weighted useable area for each study site over a range of simulation flows using the habitat suitability criteria and the output of the hydraulic model

(Service) to assess instream flow problems (Bovee 1996). The decision variable generated by the IFIM is total habitat for each life stage (fry, juvenile and spawning) of each evaluation species (or race as applied to Chinook salmon). Habitat incorporates both macro- and microhabitat features. Macrohabitat features, with a spatial scale of 10 to 100 km, include longitudinal changes in channel characteristics, base flow, water quality, and water temperature. Microhabitat features, with a spatial scale of 1 to 5 m, include the hydraulic and structural conditions (depth, velocity, substrate or cover) which define the actual living space of the organisms. The total habitat available to a species/life stage at any streamflow is the area of overlap between available microhabitat and suitable macrohabitat conditions.

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

There are a variety of techniques available to quantify the functional relationship between flow and spawning habitat availability, but they can be broken down into three general categories: 1) habitat modeling; 2) biological response correlations; and 3) demonstration flow assessment (Annear et al. 2002). Biological response correlations can be used to evaluate spawning habitat by examining the degree of redd superposition at different flows (Snider et al. 1996). Disadvantages of this approach are: 1) difficulty in separating out effects of flows from year to year variation in escapement and other factors; 2) the need for many years of data; 3) the need for intermediate levels of spawning – at low spawning levels, there will not be any redd superposition even at low habitat levels, while at high spawning levels, the amount of superposition cannot be determined because individual redds can no longer be identified; 4) the need to assume a linear relationship between superposition and flow between each observed flow; and 5) the inability to extrapolate beyond the observed range of flows. Demonstration flow assessments (CIFGS 2003) use direct observation of river habitat conditions at several flows; at each flow, polygons of habitat are delineated in the field. Disadvantages of this approach are: 1) the need to have binary habitat suitability criteria; 2) limitations in the accuracy of delineation of the polygons; 3) the need to assume a linear relationship between habitat and flow between each observed flow; and 4) the inability to extrapolate beyond the observed range of flows (Gard 2009a). Based on the above discussion, we concluded that habitat modeling was the best technique for evaluating anadromous salmonid spawning habitat in Clear Creek. Modeling approaches are widely used to assess the effects of instream flows on fish habitat availability despite potential assumption, sampling, and measurement errors that, as in the other methods described above, can contribute to the uncertainty of results.

The results of this study are intended to support or revise the flow recommendations above. The range of Clear Creek flows to be evaluated for management generally falls within the range of 50 cfs (the minimum required release from Whiskeytown Dam) to 900 cfs (75% of the outlet capacity of the controlled flow release from Whiskeytown Dam). Accordingly, the range of study flows encompasses the range of flows to be evaluated for management. The assumptions of this study are: 1) that physical habitat is the limiting

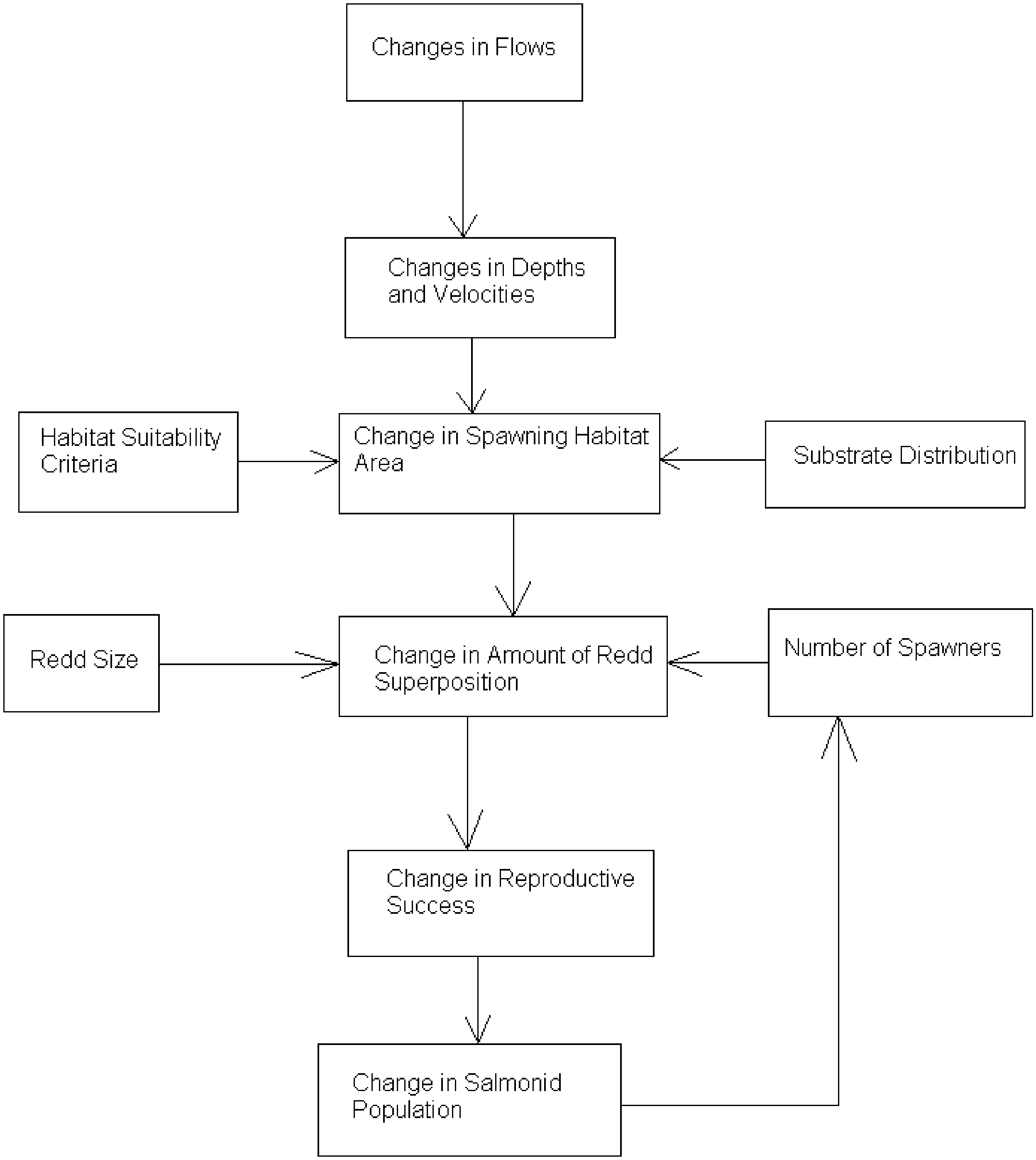

Figure 1. Conceptual model of the linkage between flow and salmonid populations.

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

METHODS

Approach

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

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

modeling can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate. Bed topography and substrate mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the up- and downstream ends of the site and flow, and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

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

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

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

Study Segment Delineation

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

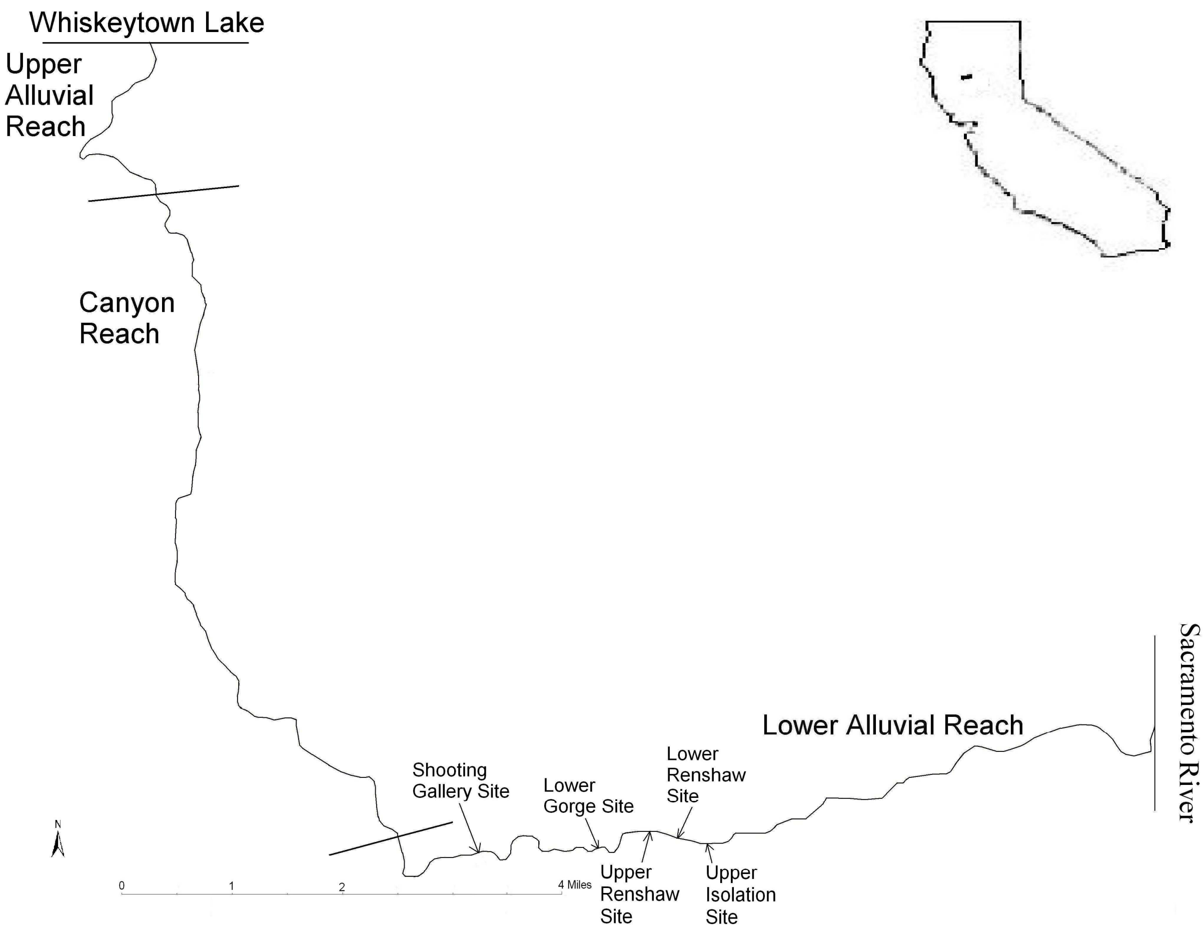

Figure 2. Clear Creek stream segments and spawning study sites.

Field Reconnaissance and Study Site Selection

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

Transect Placement (study site setup)

The study sites were established in July and August 2006. The study site boundaries (upstream and downstream) were generally selected to coincide with the upstream and downstream ends of the heavy spawning use areas. A PHABSIM transect was placed at the upstream and downstream end of each study site. The downstream transect was modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. The upstream transect was used in calibrating the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. Transect pins (headpins and tailpins) were marked on each river bank above the 900 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Data Collection

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

Hydraulic and structural data collection began in August 2006 and was completed in December 2007. The data collected on the upstream and downstream transect included: 1) water surface elevations (WSELs), measured to the nearest 0.01 foot (0.003 m) at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bank-full discharge surveyed to the nearest 0.1 foot (0.031 m); 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover classification (Tables 2 and 3) at these same locations and also where dry ground elevations were surveyed. In between these transects, the following data were collected: 1) bed elevation;

Table 2. Substrate codes, descriptors and particle sizes.

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

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

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

Table 3. Cover coding system.

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

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

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

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

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

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

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

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

The upstream and downstream transects were modeled with the PHABSIM component of IFIM to provide water surface elevations as an input to the 2-D hydraulic and habitat model (River2D, Steffler and Blackburn 2002) used in this study. By calibrating the upstream and downstream transects with PHABSIM using the collected calibration water surface elevations (WSELs), we were able to predict the WSELs for these transects for the various simulation flows that were to be modeled using River2D. We calibrated the River2D models using the highest simulation flow. The highest simulation WSELs predicted by PHABSIM for the upstream and downstream transects were used for the upstream boundary condition (in addition to flow) and the downstream boundary condition. The PHABSIM-predicted WSEL for the upstream transect at the highest simulation flow was used to ascertain calibration of the River2D model at the highest simulation flow. After the River2D model was calibrated at the highest simulation flow, the

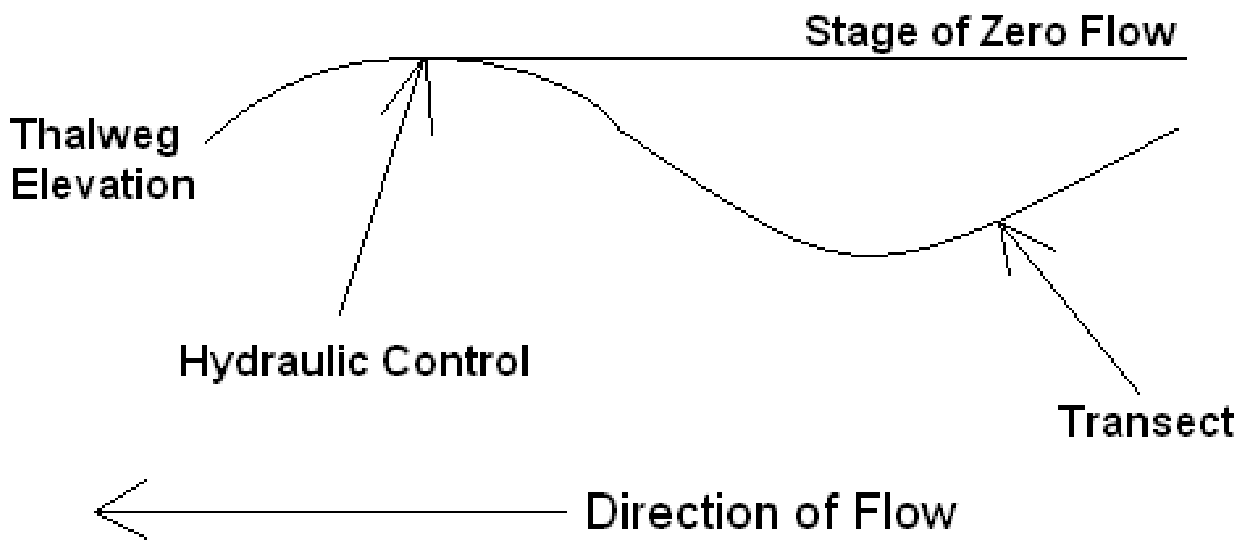

Figure 3. Stage of zero flow diagram.

WSELs predicted by PHABSIM for the downstream transect for each simulation flow were used as an input for the downstream boundary condition for River2D model production files for the simulation flows. The following describes the PHABSIM WSEL calibration process for the upstream and downstream transects.

All data were compiled and checked before entry into PHABSIM data files. A table of substrate ranges/values was created to determine the substrate for each vertical/cell (e.g, if the substrate size class was 2-4 inches (5 to 10 cm) on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the WSEL of the highest flow to be modeled. An ASCII file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton, U.S. Fish and Wildlife Service, 1998) to get the PHABSIM input file and then translated into RHABSIM[5] files. A separate PHABSIM file was constructed for each study site. All of the measured WSELs were checked to make sure that water was not flowing uphill. The slope for each transect was computed at each measured flow as the difference in WSELs between the two transects divided by the distance between the two. The slope used for each transect was calculated by averaging the slopes computed for each flow. A total of four or five WSEL sets at low, medium, and high flows were used. If WSELs were available for several closely spaced flows, the WSEL that

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

corresponded with the velocity set or the WSEL collected at the lowest flow was used in the PHABSIM data files. Calibration flows in the data files were the flows calculated from gage readings. The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. In habitat types without backwater effects (e.g., riffles and runs), this value generally represents the lowest point in the streambed across a transect. However, if a transect directly upstream contains a lower bed elevation than the adjacent downstream transect, the SZF for the downstream transect applies to both. In some cases, data collected in between the transects showed a higher thalweg elevation than either transect; in these cases the higher thalweg elevation was used as the SZF for the upstream transect.

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous et al. 1989) was run on each deck to compare predicted and measured WSELs. This model produces a stage-discharge relationship using a log-log linear rating curve calculated from at least three sets of measurements taken at different flows. Besides *IFG4*, two other hydraulic models are available in PHABSIM to predict stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the condition of the channel and the nature of the streambed controls WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects.

IFG4, the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs[6]. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

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

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

RIVER2D Model Construction

After completing the PHABSIM calibration process to arrive at the simulation WSELs that will be used as inputs to the RIVER2D model, the next step is to construct the RIVER2D model using the collected bed topography data. The total station data and the PHABSIM transect data were combined in a spreadsheet to create the input files (bed and substrate) for the 2-D modeling program. An artificial extension one channel-width-long was added upstream of the topography data collected upstream of the study site, to enable the flow to be distributed by the model when it reached the study area, thus minimizing boundary conditions influencing the flow distribution at the upsteam transect and within the study site.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point, while the substrate files contain the horizontal location, bed elevation and substrate code for each point. The initial bed roughness value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness values in Table 4, with the bed roughness value for each point computed as the sum of the substrate bed roughness value and the cover bed roughness value for the point. The resulting initial bed roughness value for each point was therefore a combined matrix of the substrate and cover roughness values. The bed roughness values for substrate in Table 4 were computed as five times the average particle size[7]. The bed roughness values for cover in Table 4 were computed as five times the average cover size, where the cover size was measured on the Sacramento River on a representative sample of cover elements of each cover type. The bed and substrate files were exported from the spreadsheet as ASCII files.

A utility program, R2D_BED (Steffler 2002), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines[8] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. The first step in refining the TIN was to conduct a quality assurance/quality control process, consisting of a point-by-point inspection to eliminate quantitatively wrong points, and a qualitative process

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

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

Table 4. Initial bed roughness values.

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05, 0.71, 1.95[9]	9	0.29
10	1.4	9.7	0.57
		10	3.05

where we checked the features constructed in the TIN against aerial photographs to make sure we had represented landforms correctly. Breaklines were also added along lines of constant elevation.

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

[9] For substrate code 9, we used bed roughnesses of 0.71 and 1.95, respectively, for cover codes 1 and 2, and a bed roughness of 0.05 for all other cover codes. Bed roughnesses of zero were used for cover codes 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

computational mesh was to define mesh breaklines[10] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and then additional nodes were added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Waddle and Steffler 2002). The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. The final step with the R2D_MESH software was to generate the computational (cdg) file.

RIVER2D Model Calibration

Once a RIVER2D model has been constructed, calibration is then required to determine that the model is reliably simulating the flow-WSEL relationship that was determined through the PHABSIM calibration process using the measured WSELs. The cdg files were opened in the RIVER2D software, where the computational bed topography mesh was used together with the WSEL at the bottom of the site, the flow entering the site, and the bed roughnesses of the computational mesh elements to compute the depths, velocities and WSELs throughout the site. The basis for the current form of RIVER2D is given in Ghanem et al (1995). The computational mesh was run to steady state at the highest flow to be simulated, and the WSELs predicted by RIVER2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the upstream transect. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the upstream transect. The minimum groundwater depth was adjusted to a value of 0.05 m to increase the stability of the model. The values of all other River2D hydraulic parameters were left at their default values (upwinding coefficient = 0.5, groundwater transmissivity = 0.1, groundwater storativity = 1, and eddy viscosity parameters $\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.5$ and $\varepsilon_3 = 0.1$). A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than 1% (Steffler and Blackburn 2002). In addition,

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

solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than 1[11]. Finally, the WSEL predicted by the 2-D model should be within 0.1 foot (0.031 m) of the WSEL measured at the upstream transect[12].

RIVER2D Model Velocity Validation

Velocity validation is the final step in the preparation of the hydraulic models for use in habitat simulation. Velocities predicted by RIVER2D were compared with measured velocities to determine the accuracy of the model's predictions of mean water column velocities. The measured velocities used were the velocities measured on the upstream and downstream transects, and the 50 velocities per site measured in between the upstream and downstream transects. The criterion used to determine whether the model was validated was whether the correlation coefficient (R) between measured and simulated velocities was greater than 0.6. A correlation of 0.5 to 1.0 is considered to have a large effect (Cohen 1992). The model would be in question if the simulated velocities deviated from the measured velocities to the extent that the correlation between measured and simulated velocities fell below 0.6.

RIVER2D Model Simulation Flow Runs

After the River2D model was calibrated, the flow and downstream WSEL in the calibrated cdg file were changed to provide initial boundary conditions for simulating hydrodynamics of the sites at the simulation flows. The cdg file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each discharge was run in RIVER2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions will usually have a Max F of less than 1.

Habitat Suitability Criteria (HSC) Data Collection

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

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

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

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

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

Biological Verification Data Collection

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

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

Habitat Suitability Criteria (HSC) Development

The collected redd depth and velocity data must be processed through a series of steps to arrive at the HSC that will be used in the RIVER2D model to predict habitat suitability. Using the fall-run Chinook salmon HSC data that were collected in 2004-2006, we applied a method presented in Guay et al. (2000) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability). Criteria are developed by using a logistic regression procedure, with presence or absence of redds as the dependent variable and depth and velocity as the independent variables, with all of the data (in both occupied and unoccupied locations) used in the regression.

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

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

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

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

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

In cases where the results of the logistic regression were biologically unrealistic, we developed the criteria by calculating frequency distributions from the use data and input into the PHABSIM suitability index curve development program (CURVE). The HSI curves were then developed using exponential smoothing. The curves generated were exported into a spreadsheet and modified by truncating at slowest/shallowest and deepest/fastest ends, so that the next shallower depth or slower velocity value below the shallowest observed depth or the slowest observed velocity had a SI value of zero; and eliminating points above the optimal suitability to account for the effects of availability on habitat use.

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

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

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

Biological Verification

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

Habitat Simulation

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

RESULTS

Study Segment Delineation

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

Field Reconnaissance and Study Site Selection

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

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

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

Hydraulic and Structural Data Collection

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

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

Table 6. Level loop error results.

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

Table 7. Horizontal benchmark error results.

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

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

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

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

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

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

RIVER2D Model Construction

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

RIVER2D Model Calibration

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

RIVER2D Model Velocity Validation

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

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

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

RIVER2D Model Simulation Flow Runs

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

Habitat Suitability Criteria (HSC) Data Collection

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

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

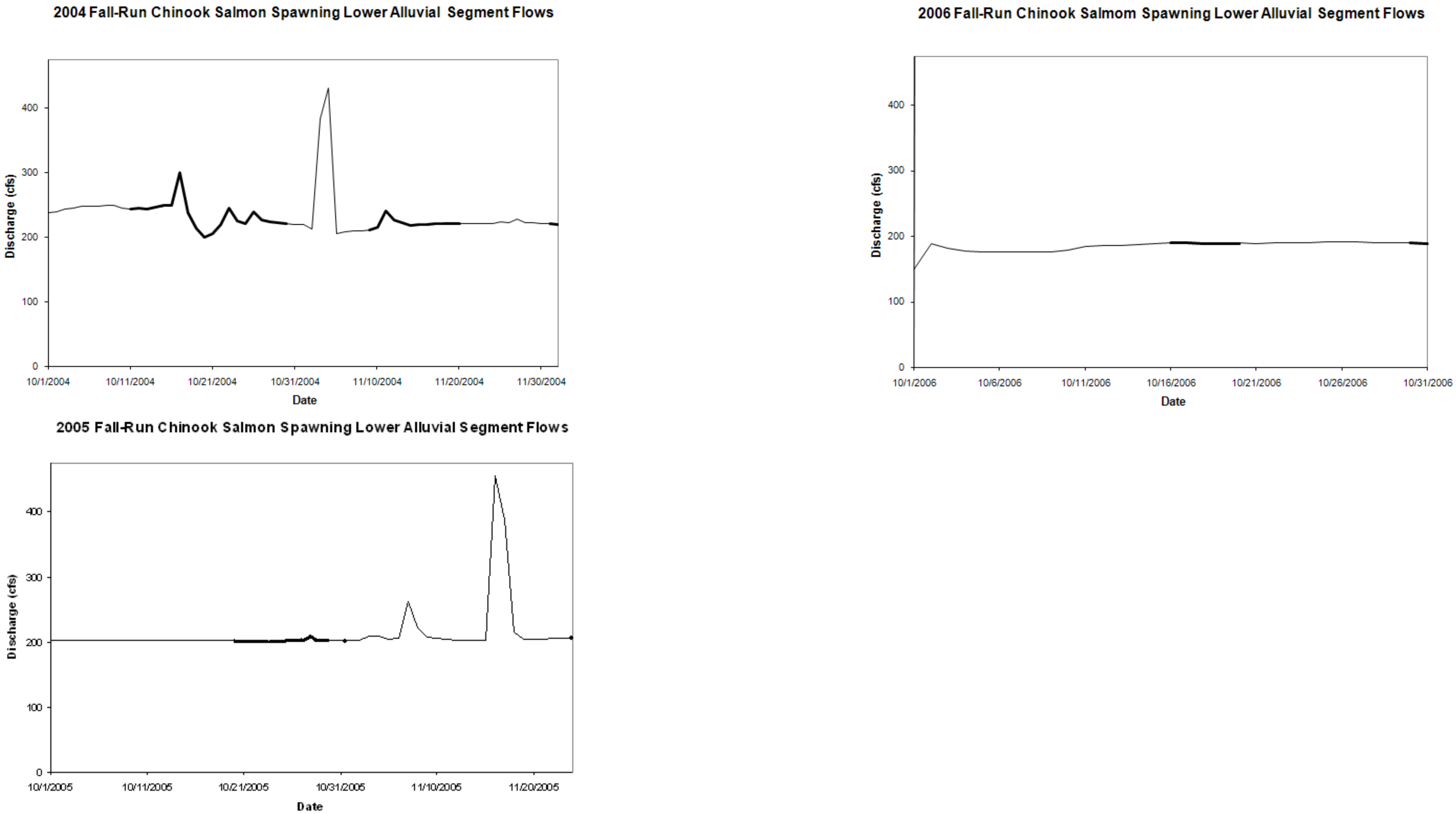

Figure 4. 2004-2006 flows in the Lower Alluvial Segment during the fall-run Chinook salmon spawning data collection. The thicker lines show the sampling periods.

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

Biological Verification Data Collection

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

Habitat Suitability Criteria (HSC) Development

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

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

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

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

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

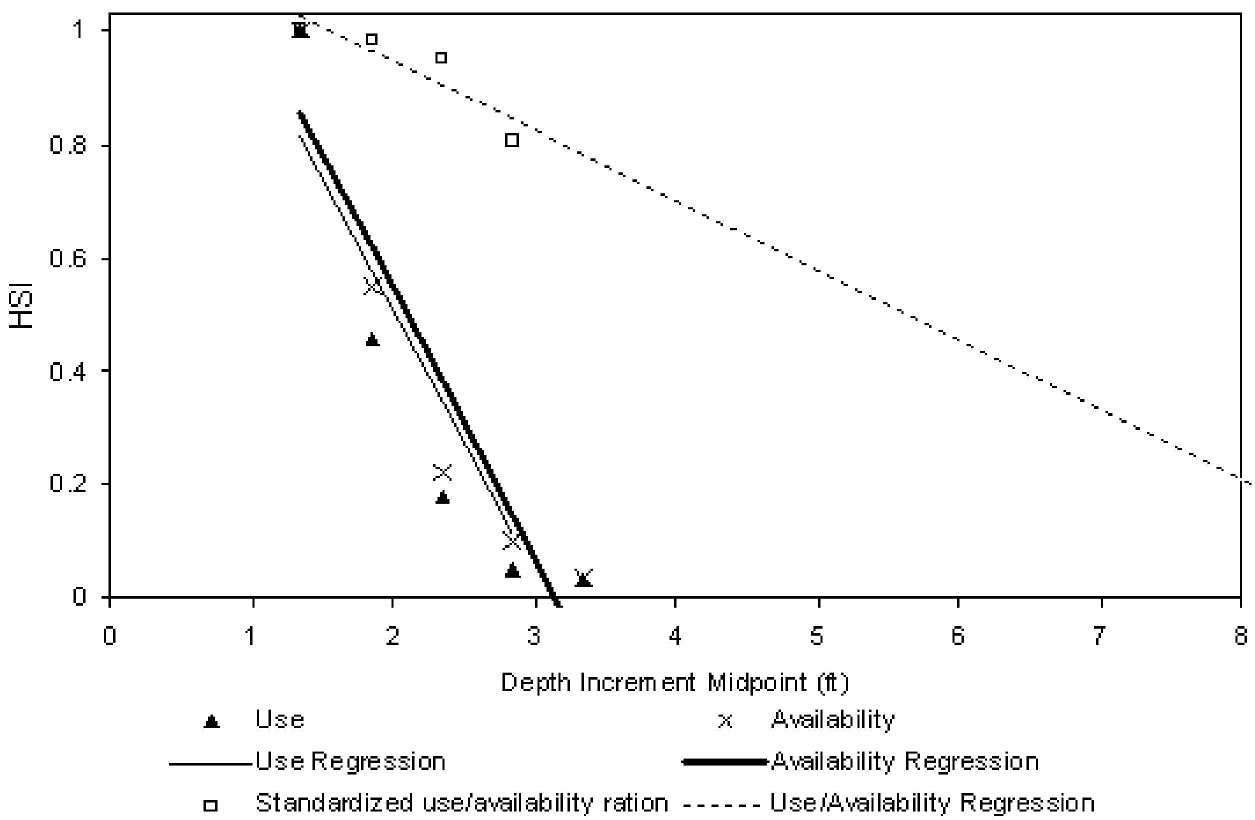

Figure 5. Relations between availability and use and depth for fall-run Chinook salmon. Points are relative use, relative availability, or the standardized ratio of linearized use to linearized availability. Lines are the results of the linear regressions of the depth increment midpoint versus relative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

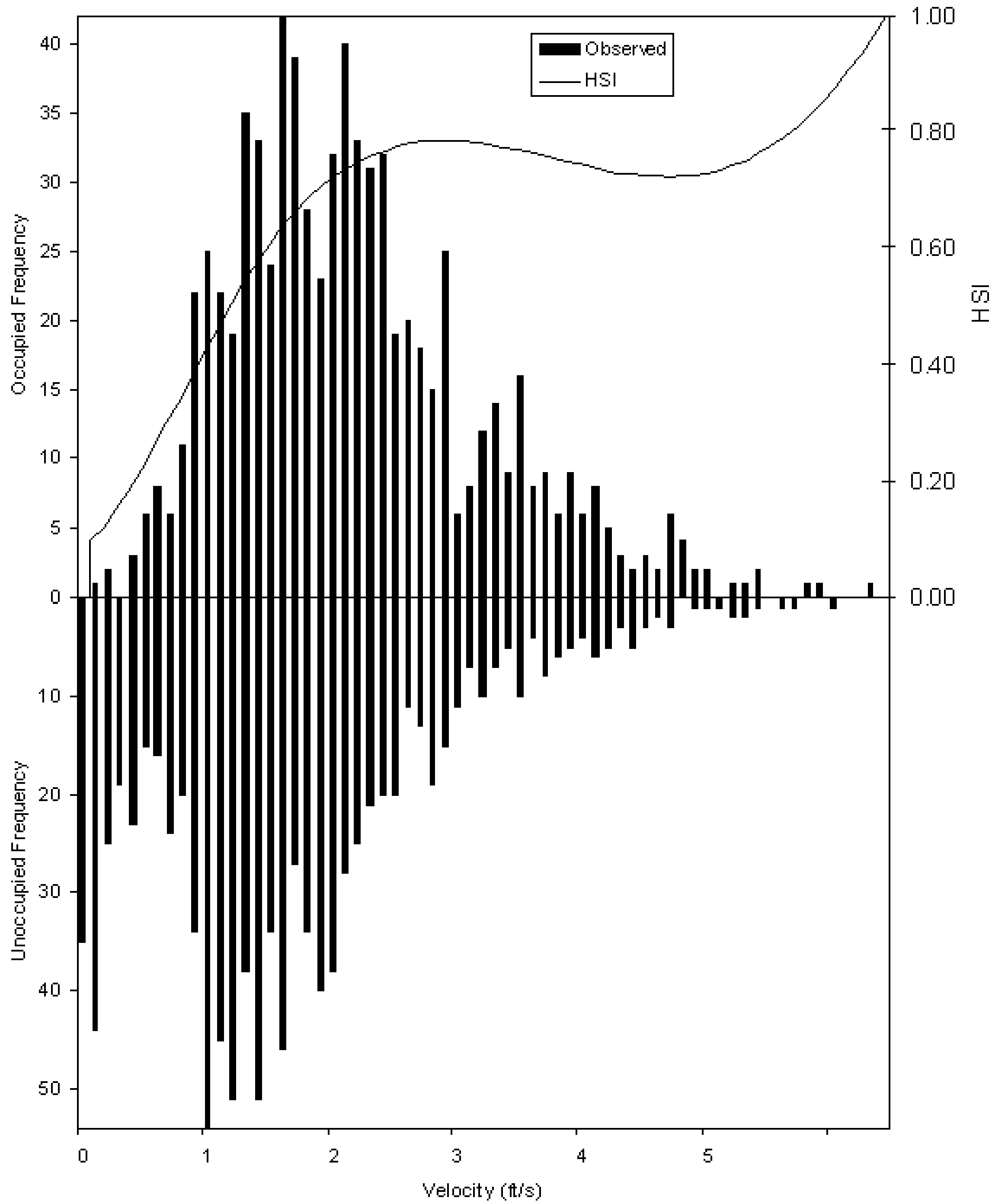

Figure 6. Fall-run Chinook salmon spawning velocity HSC using occupied and unoccupied data. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for velocities of 0.10 to 6.30 ft/sec (0.03 and 1.92 m/sec) and an optimum suitability at velocity of 6.30 ft/sec (1.90 m/sec).

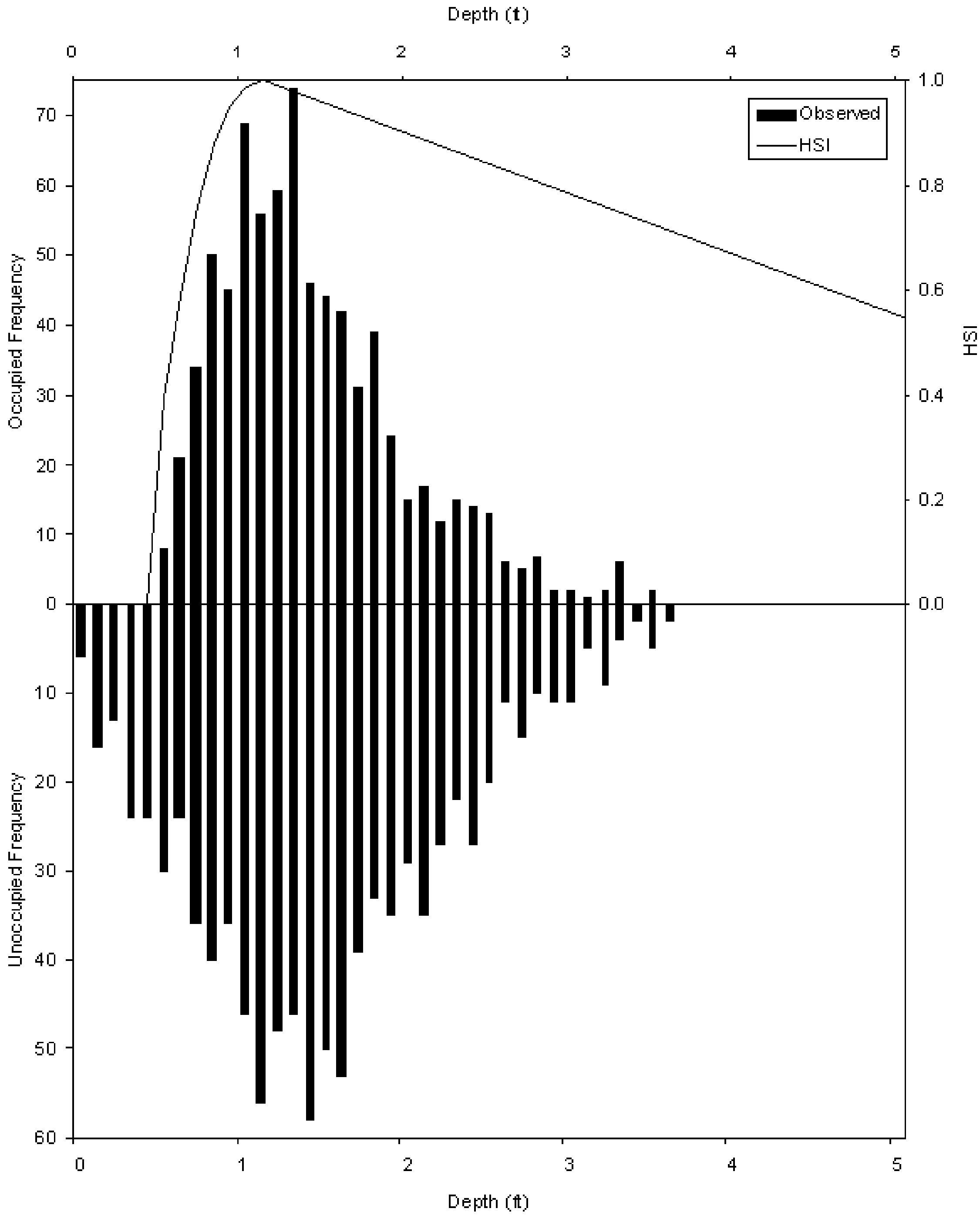

Figure 7. Fall-run Chinook salmon spawning depth HSC. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for depths of 0.5 to 6.7 feet (0.15 to 2.04 m) and an optimum suitability at a depth of 1.1 feet (0.34 m).

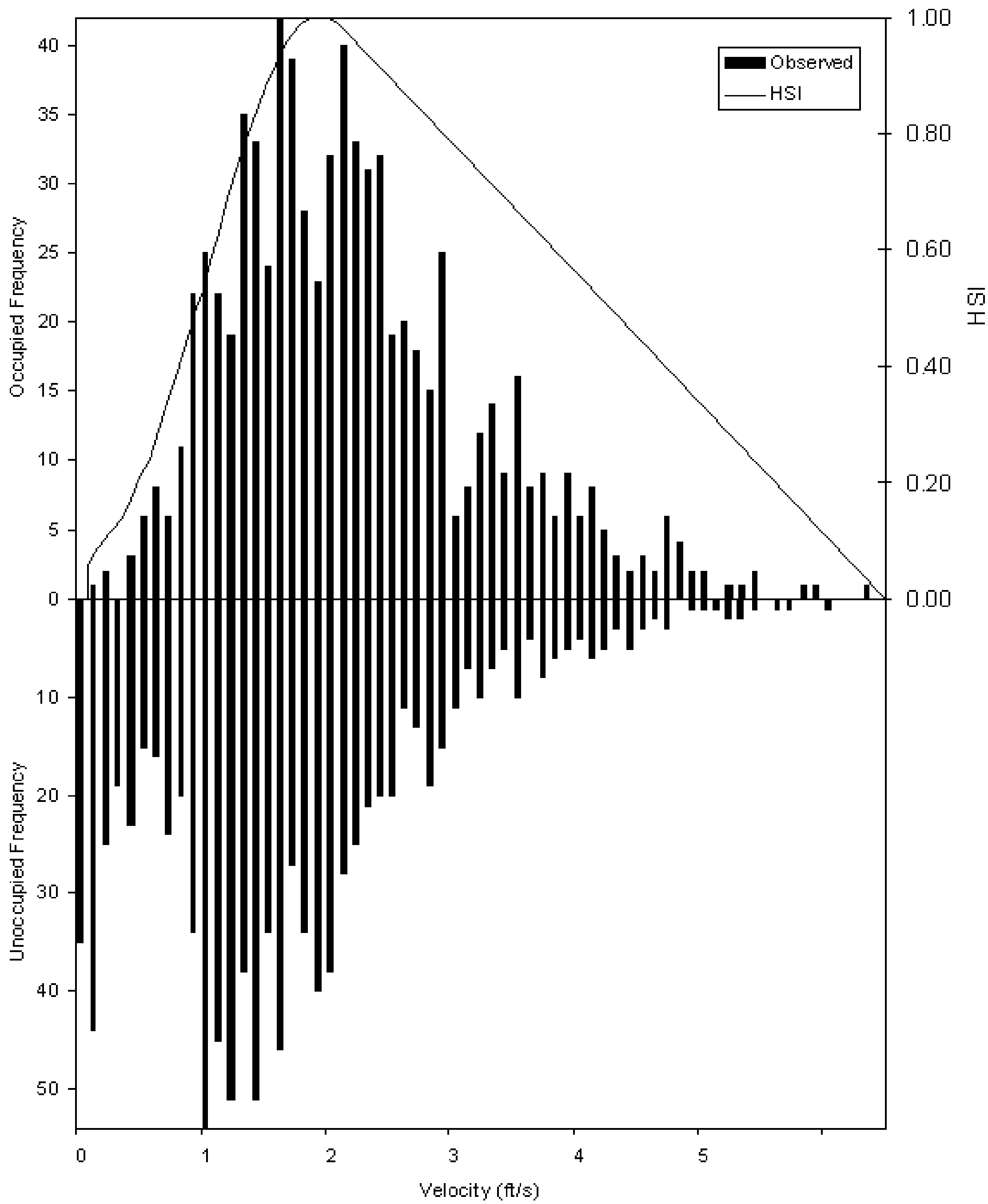

Figure 8. Fall-run Chinook salmon spawning velocity HSC using only occupied data. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for velocities of 0.10 to 6.30 ft/sec (0.03 and 1.92 m/sec) and an optimum suitability at velocity of 1.83 to 1.97 ft/sec (0.56 to 0.60 m/sec).

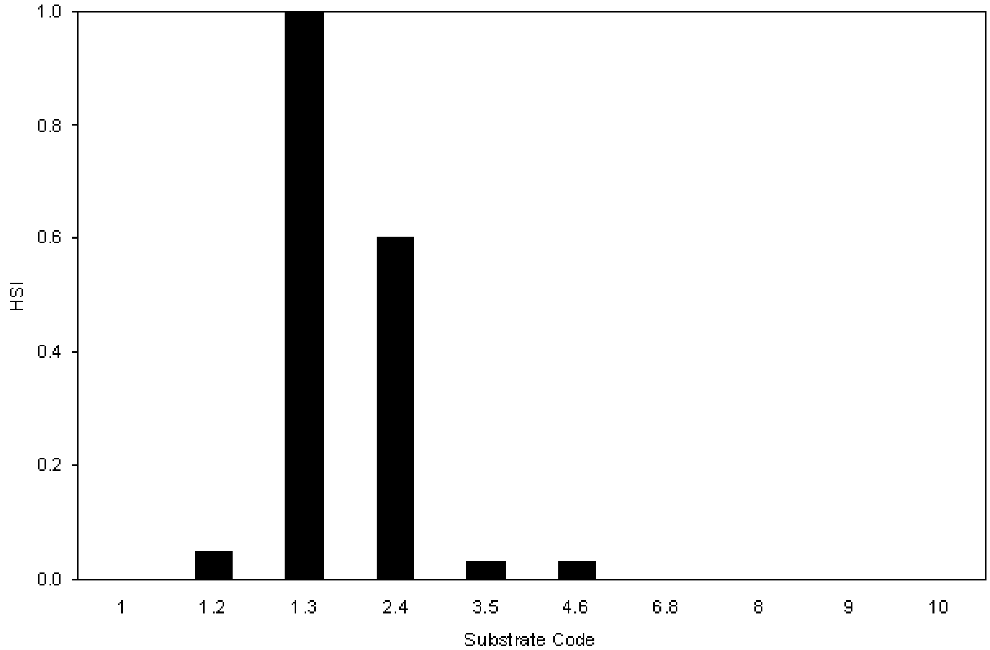

Figure 9. Fall-run Chinook salmon HSC for substrate. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for substrate codes 1.2 to 4.6 and an optimum suitability for substrate code 1.3.

Biological Verification

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

Habitat Simulation

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

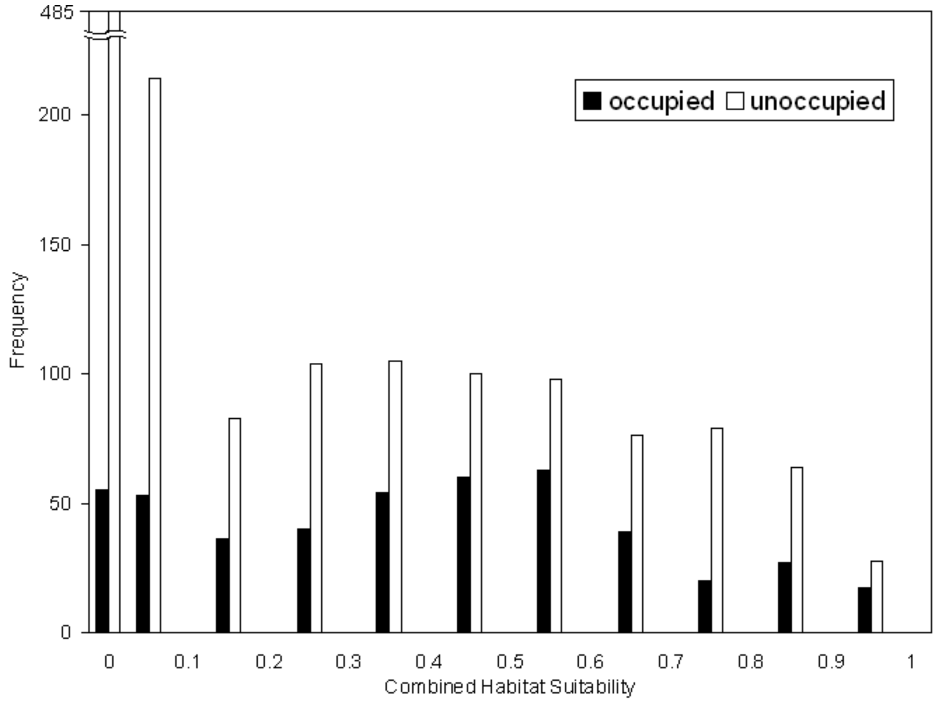

Figure 10. Combined suitability for 2-D model locations with (occupied) and without (unoccupied) fall-run Chinook salmon redds. The median combined suitability for occupied and unoccupied locations was, respectively, 0.41 and 0.03.

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

DISCUSSION

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

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

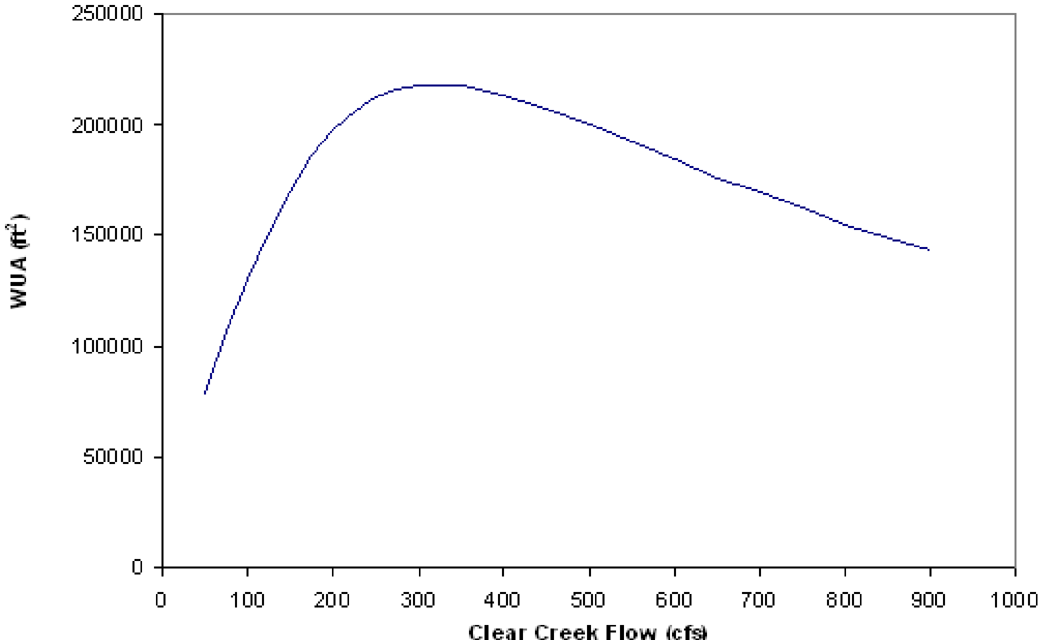

Figure 11. Fall-run Chinook salmon spawning flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum fall-run Chinook salmon spawning habitat was 300 cfs.

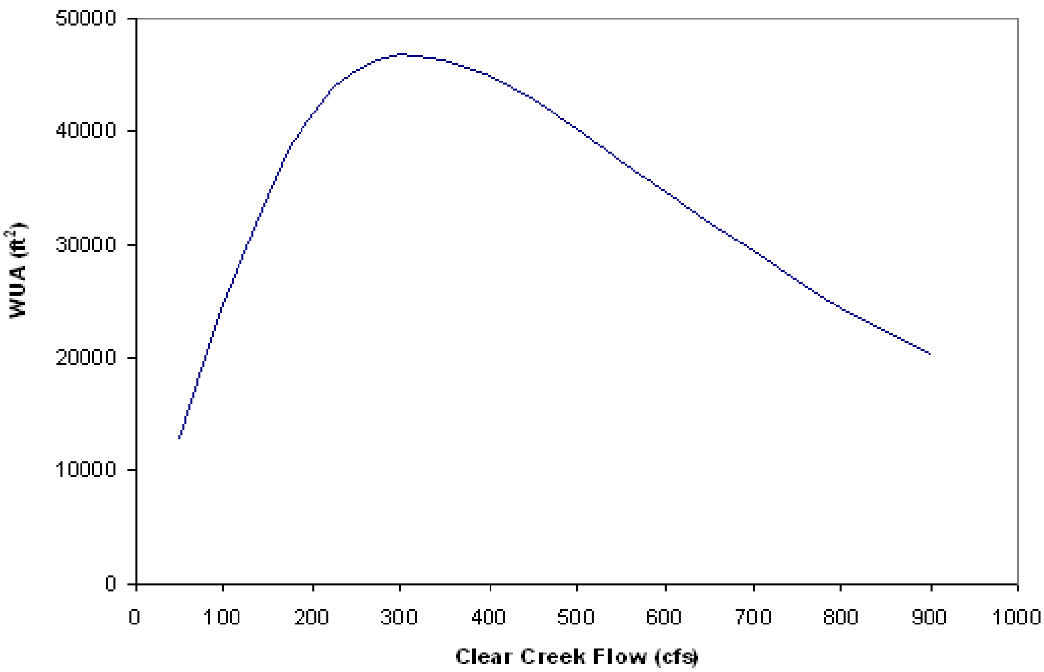

Figure 12. Steelhead/rainbow trout spawning flow-habitat relationship for the Lower Alluvial segment. The flow with the maximum steelhead/rainbow trout spawning habitat was 300 cfs.

RIVER2D Model Construction

In most cases, the portions of the mesh where there was greater than a 0.1 foot (0.031 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.031 m) vertically of the bed file within 1.0 foot (0.30 m) horizontally of the bed file location. Given that we had a 1-foot (0.30 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file.

RIVER2D Model Calibration

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

We considered the solution to be acceptable for the study site cdg files which had a maximum Froude Number greater than 1, since the Froude Number only exceeded one at a few nodes, with the vast majority of the site having Froude Numbers less than one. Furthermore, these nodes were located either at the water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results. The average and maximum difference between measured and simulated WSELs for Lower Gorge exceeded the 0.1 foot (0.031 m) criterion. However, at the 705 cfs flow at which the WSELs were measured, we were only able to take a measurement next to the right bank due to safety concerns. The WSELs simulated in this portion of the upstream transect were within 0.02 foot (0.01 m) of the measured value. Because of this result and since the simulated left bank WSELs only a short distance (approximately 4 feet (1.22 m)) downstream of the upstream transect were also found to be within 0.1 foot (0.031 m) of the measured, the calibration was considered acceptable.

RIVER2D Model Velocity Validation

Differences in magnitude in most cases are likely due to (1) aspects of the bed topography of the site that were not captured in our data collection; (2) operator error during data collection, i.e., the probe was not facing precisely into the direction of current; (3) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations; and (4) the measured velocities on the transects being the component of the velocity in the downstream direction, while the velocities predicted by the 2-D model were the absolute magnitude of velocity[16]. As shown in the figures in Appendix G, we attribute most of the differences between measured and predicted velocities to noise in the measured velocity measurements; specifically, for the transects, the simulated velocities typically fell within the range of the measured. The 2-D model integrates effects from the surrounding elements at each point. Thus, point measurements of velocity can differ from simulated values simply due to the local area integration that takes place. As a result, the area integration effect noted above will produce somewhat smoother lateral velocity profiles than the observations. For the Lower Gorge downstream transect where RIVER2D over or under-predicted the velocities on both sides of the channel, we attribute this to errors in the bed topography that did not properly characterize features that resulted in faster/slower velocities. There was a long, deep pool and a vertical rock wall on one side of the channel just upstream of the downstream transect. These features may have hindered the collection of the density of points necessary to properly characterize the bed in that area. Further supporting this assessment, the measured discharge at the Lower Gorge downstream transect using the above validation velocities only differed from the actual discharge, based on gage readings, by 0.1 %.

RIVER2D Model Simulation Flow Runs

Two of the three lowest simulation flow run cdg files for Lower Renshaw, where the net Q was greater than 1%, were still considered to have a stable solution since the net Q was not changing and the net Q in all cases was less than 5%. In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is within the same range as the accuracy for USGS gages, and is considered acceptable. In the case of the Lower Renshaw lowest flow production cdg file, where the net Q significantly exceeded the 5% level, we consider that a level of uncertainty applies to results for that production file. We attribute the high net Q in this case to an eddy that the model generated at the downstream boundary (Figure 13). It is likely that we could have reduced the net Q for this file by adding a downstream extension onto the hydraulic model.

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

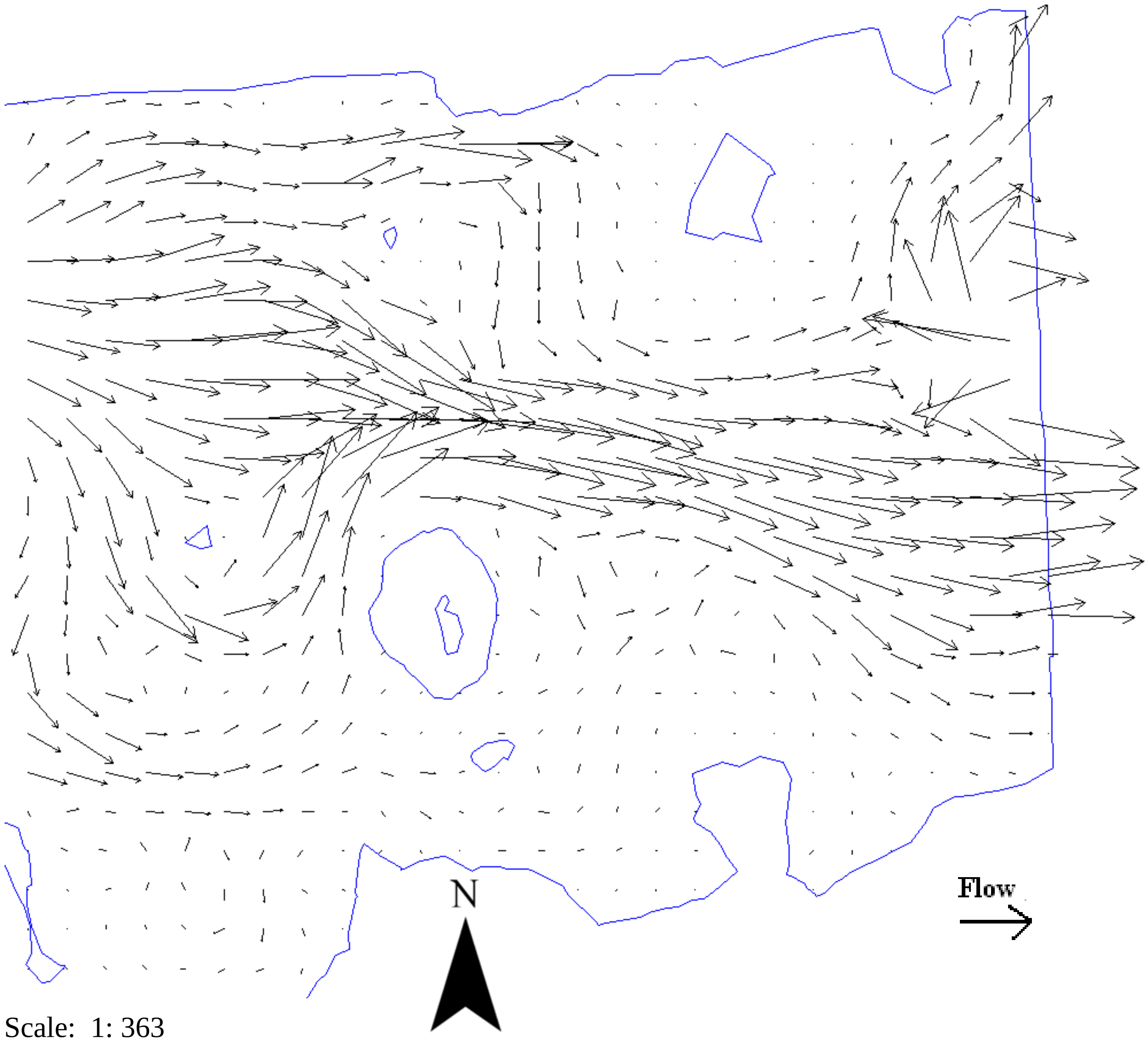

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Figure 13. Velocity vectors (black arrows) near the downstream boundary (right side of figure) of Lower Renshaw site at 50 cfs. An eddy (velocity vectors going upstream) is shown in the middle of the boundary. Blue lines denote water's edge – at this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

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

Habitat Suitability Criteria (HSC) Data Collection

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

Habitat Suitability Criteria (HSC) Development

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

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

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

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

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

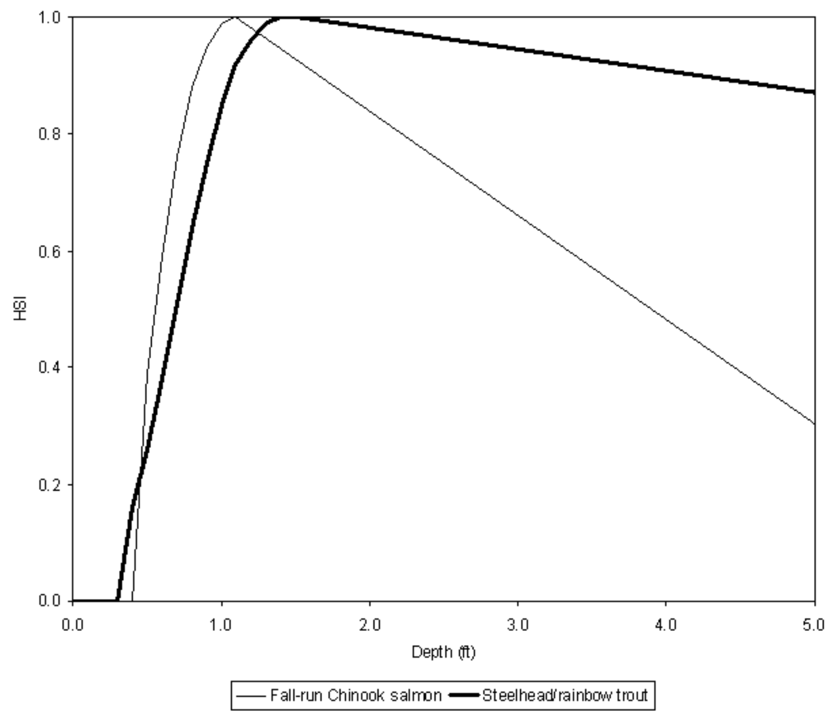

Figure 14. Comparison of depth HSC from this study. These criteria indicate that steelhead/rainbow trout selected deeper conditions than fall-run Chinook salmon.

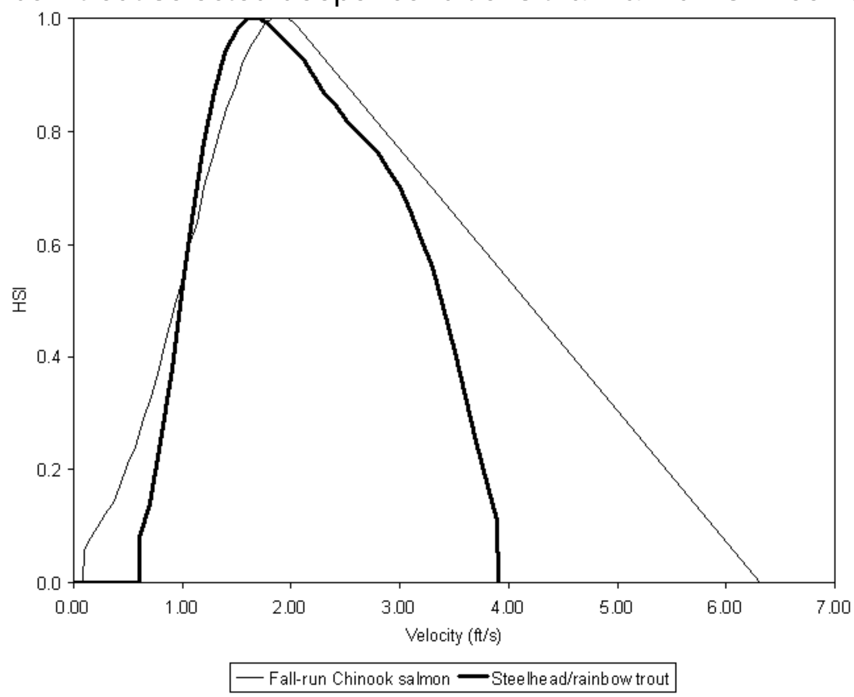

Figure 15. Comparison of velocity HSC from this study. These criteria indicate that fall-run Chinook salmon selected a wider range of velocities than steelhead/rainbow trout.

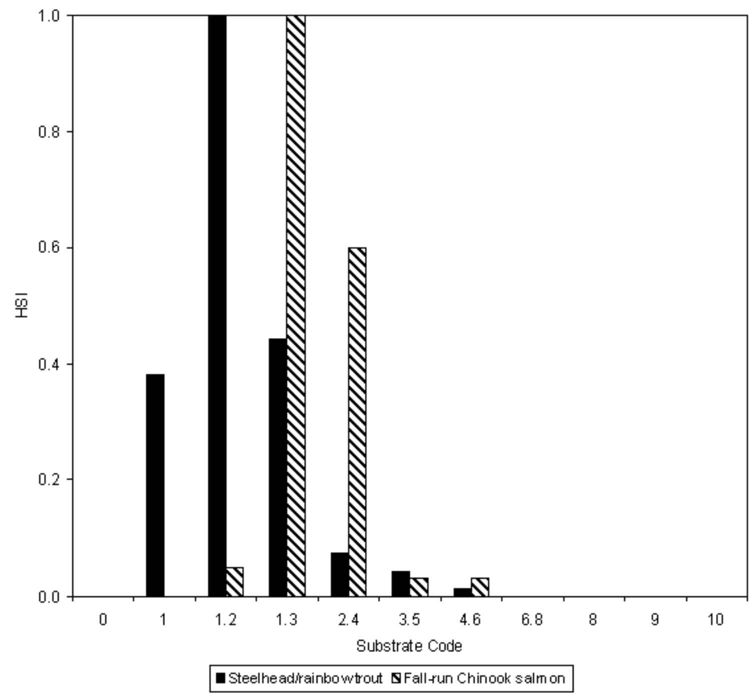

Figure 16. Comparison of substrate HSC from this study. These criteria indicate that steelhead/rainbow trout selected smaller substrates than fall-run Chinook salmon.

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

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

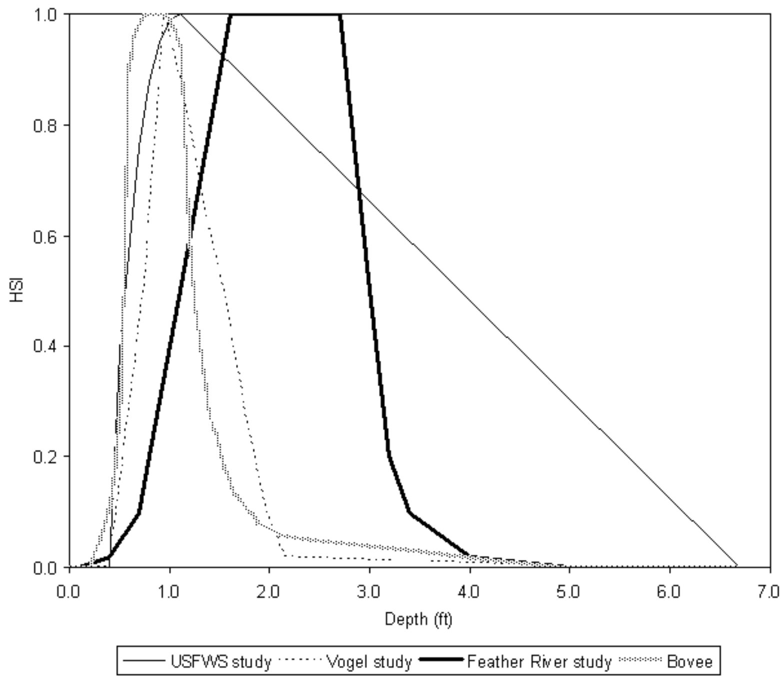

Figure 17. Comparison of fall-run Chinook salmon depth HSC from this study with other fall-run Chinook salmon spawning depth HSC. The criteria from this study show a slower decline in suitability with increasing depth than those from other studies.

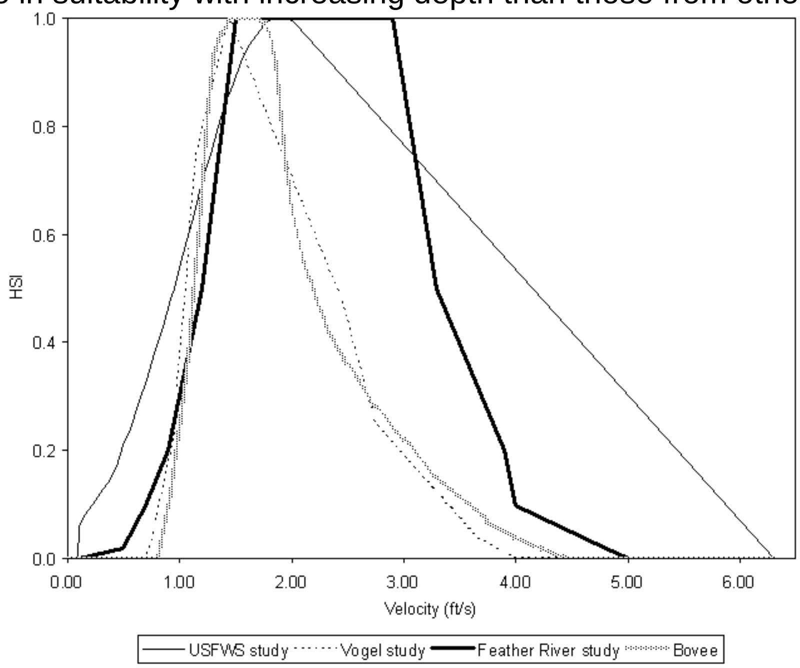

Figure 18. Comparison of fall-run Chinook salmon velocity HSC from this study with other fall-run Chinook salmon spawning velocity HSC. The criteria from this study show non-zero suitability extending to higher velocities than the criteria from other studies.

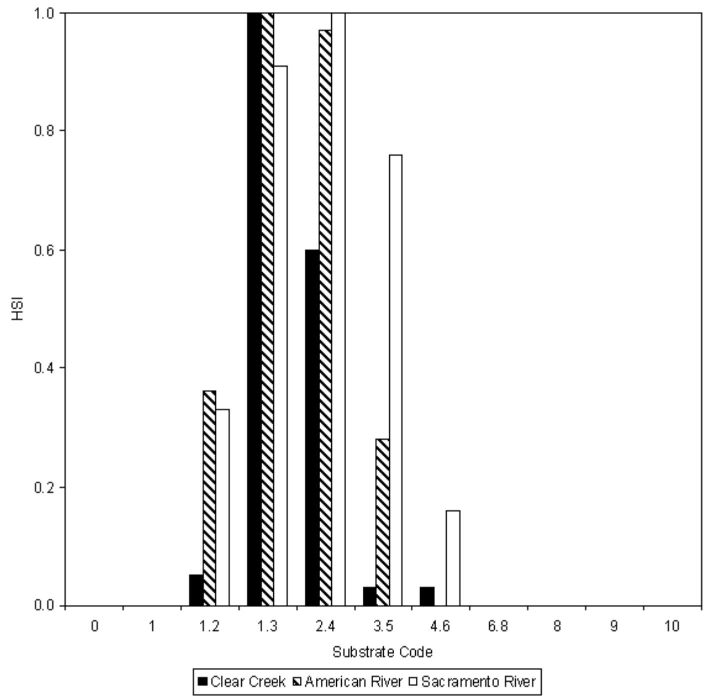

Figure 19. Comparison of fall-run Chinook salmon substrate HSC from this study with other fall-run Chinook salmon spawning substrate HSC.

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

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

Biological Verification

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

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

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

Habitat Simulation

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

An earlier study (California Department of Water Resources 1985) also modeled fall-run Chinook salmon and steelhead spawning habitat in Clear Creek between Whiskeytown Dam and the confluence with the Sacramento River for flows of 40 to 500 cfs. A representative reach approach was used to place transects, instead of only placing sites for spawning in heavy spawning-use areas. PHABSIM was used to model habitat, instead of two-dimensional models. As shown in Figures 20 and 21, the results from this study predict smaller amounts of habitat at all flows and a peak amount of habitat at the same or slightly higher flows than the California Department of Water Resources (1985) study. The difference between studies in the flow with the peak amount of habitat varied by species. The differences between the results of the two studies can primarily be attributed to the following: 1) the California Department of Water Resources (1985) study used HSC generated only from use data, as opposed to the criteria generated with logistic regression in this study; 2) the California Department of Water Resources (1985) study did not apply the method used in this report for correcting depth HSC for availability; 3) sites for the California Department of Water Resources (1985) study were placed using a representative reach approach, as opposed to only placing sites in high-spawning-use areas, as was employed in this study; and 4) the use of PHABSIM in the California Department of Water Resources (1985) study, versus 2-D modeling in this study. We conclude that the flow-habitat results in the California Department of Water Resources (1985) study were slightly biased towards lower flows, since the HSC, generated only from use data and without correcting depth HSC for availability, were biased towards slower and shallower conditions. We conclude that the difference in criteria are responsible for most of the differences between the two studies. We attribute the remainder of the difference between the two studies to a combination of using 2-D versus PHABSIM and modeling only high-use spawning areas. Using a representative reach-based approach for modeling spawning habitat fails to take into account salmonids' preference for spawning in areas with high gravel permeability (Vyverberg et al 1996), while having sites only in high-use spawning areas indirectly takes into account preference for high gravel permeability (Gallagher and Gard 1999). The assumption is that high-use spawning areas have high gravel permeability since salmonids are selecting these areas for spawning. We attribute the difference in magnitude of the results from this study versus California Department of Water

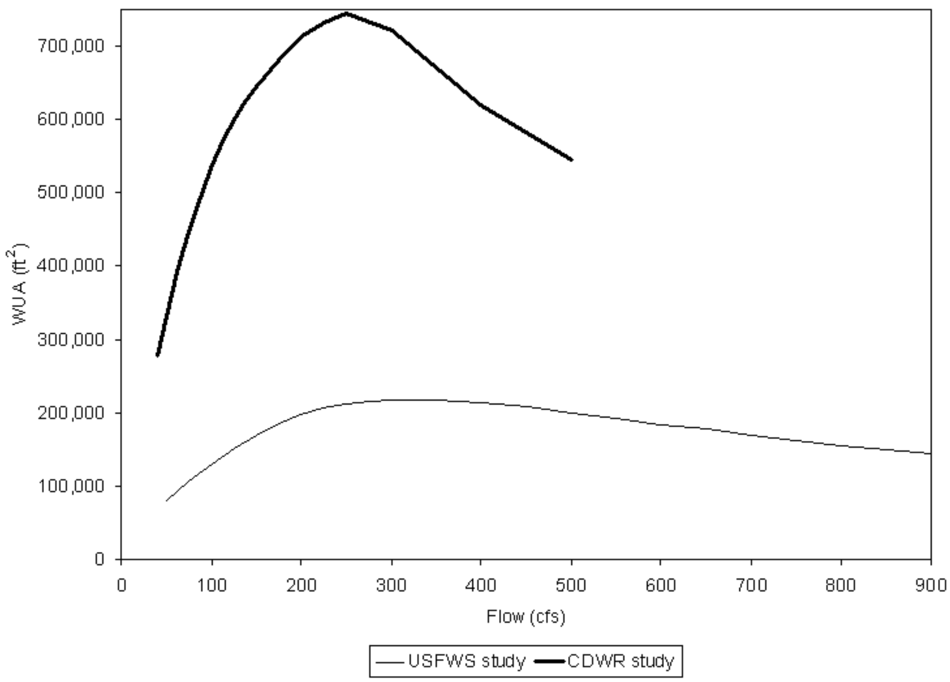

Figure 20. Comparison of fall-run Chinook salmon flow-habitat relationship from this study and the CDWR (1985) study. This study predicted less habitat at all flows and the peak habitat at a slightly higher flow than the CDWR (1985) study.

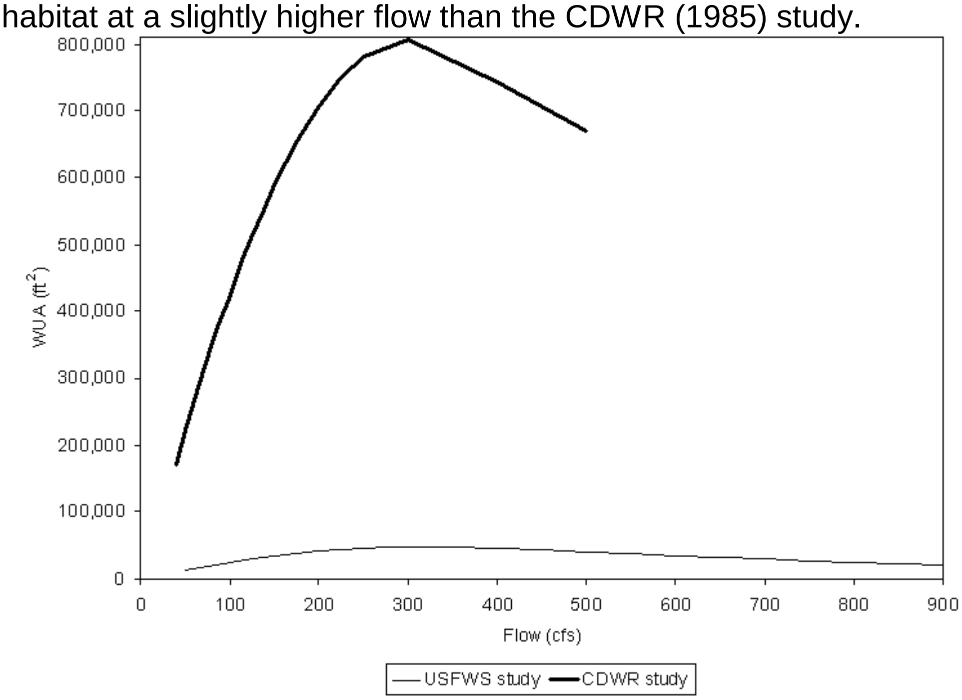

Figure 21. Comparison of steelhead/rainbow trout flow-habitat relationship from this study and the CDWR (1985) study. This study predicted less habitat at all flows and the peak habitat at the same flow as the CDWR (1985) study.

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

CONCLUSION

The model developed in this study is predictive for flows ranging from 50 to 900 cfs. The results of this study can be used to evaluate 161 different hydrograph management scenarios (each of the 23 simulation flows in each of the 7 spawning months –October to December for fall-run, and January to April for steelhead/rainbow trout). For example, increasing flows from 200 cfs to 300 cfs in October would result in an increase of 10.2% of habitat during this month for fall-run Chinook salmon spawning in the Lower Alluvial segment. Based on the conceptual model presented in the introduction, this increase in spawning habitat could decrease redd superimposition, increasing reproductive success which could result in an increase in fall-run Chinook salmon populations. Evaluation of alternative hydrograph management scenarios will also require the consideration of flow-habitat relationships for Chinook salmon and steelhead/rainbow trout fry and juvenile rearing, which will be addressed in future reports. We do not feel that there are any significant limitations of the model. This study supported and achieved the objective of producing models predicting the availability of physical habitat in the Lower Alluvial segment of Clear Creek for fall-run Chinook salmon and steelhead/rainbow trout spawning over a range of stream flows. The results of this study are intended to support or revise the flow recommendations in the introduction (i.e., a release from Whiskeytown Dam of 200 cfs from October through June and a release of 150 cfs or less from July through October). The results of this study suggest that the flow recommendations in the introduction during the fall-run Chinook salmon and steelhead/rainbow trout spawning and incubation period of October-June (200 cfs) may be close to achieving maximum habitat availability and productivity for spawning fall-run Chinook salmon and steelhead/rainbow trout in Clear Creek (greater than 89 % of maximum WUA).

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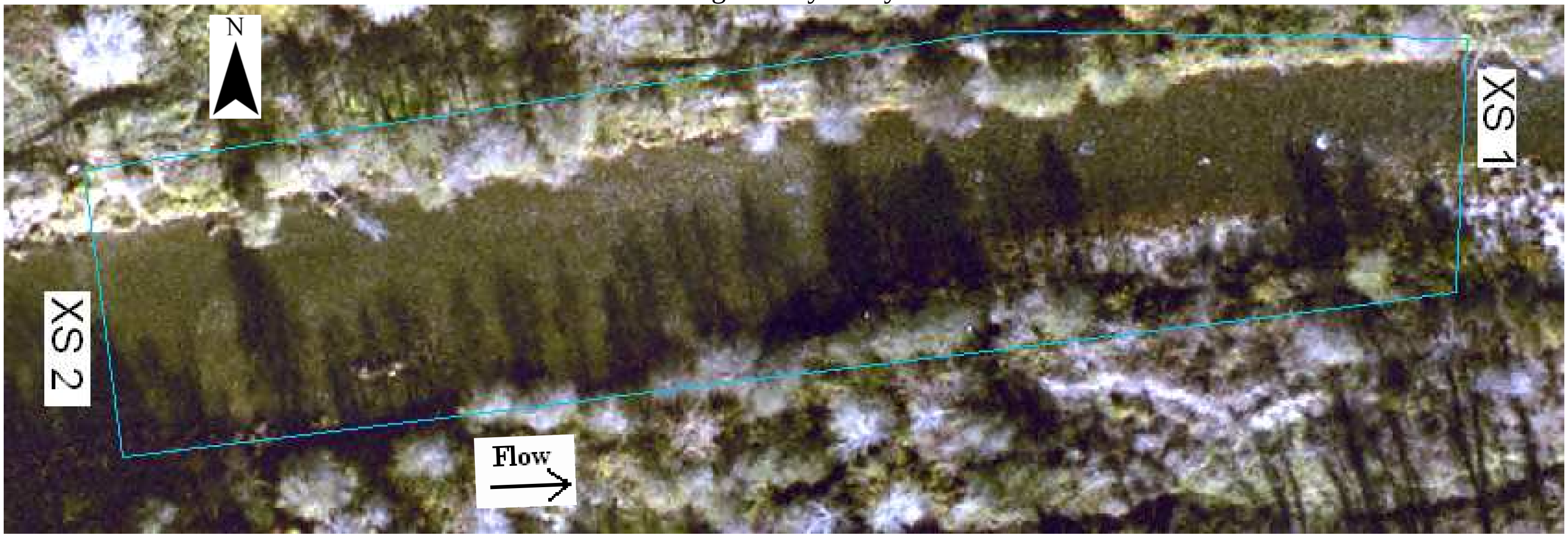
APPENDIX A
STUDY SITE AND TRANSECT LOCATIONS

Shooting Gallery Study Site



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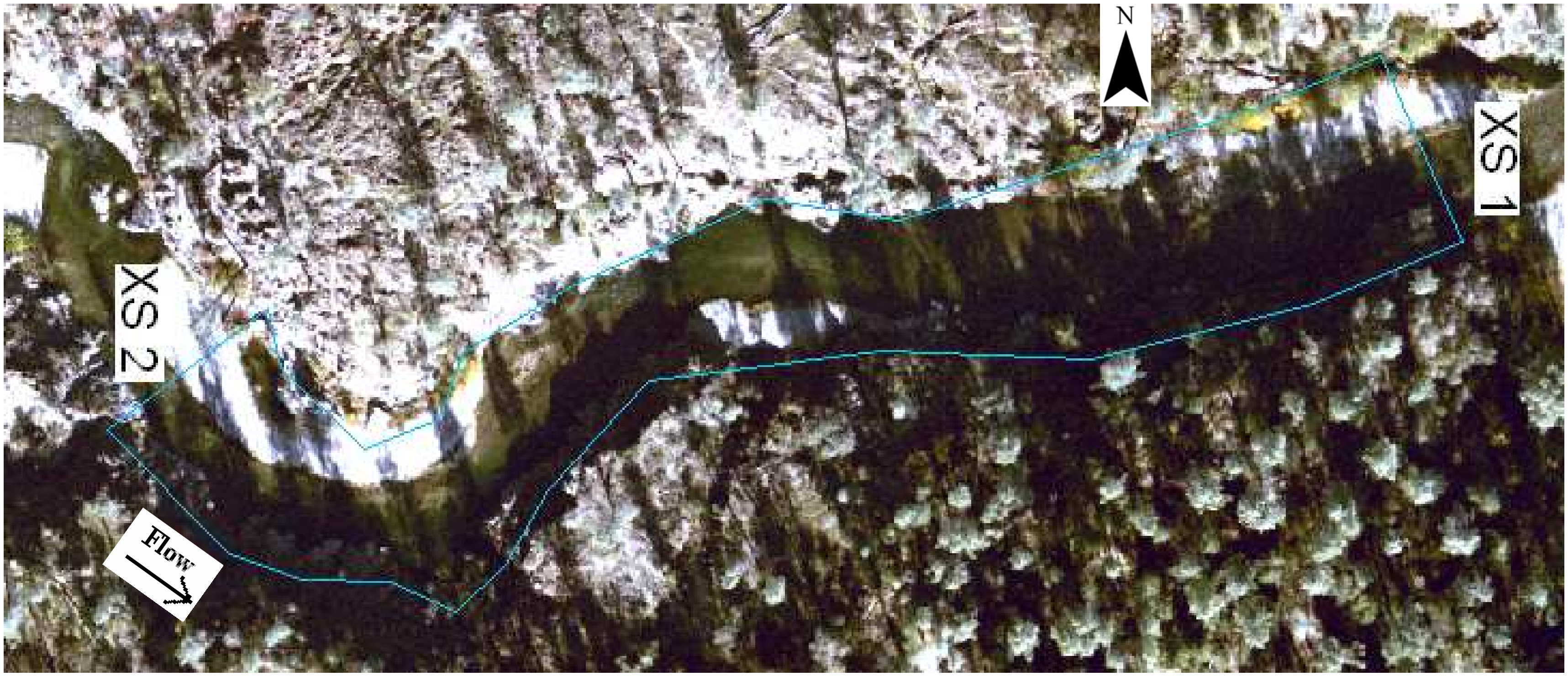
Lower Gorge Study Site



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Upper Renshaw

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Lower Renshaw

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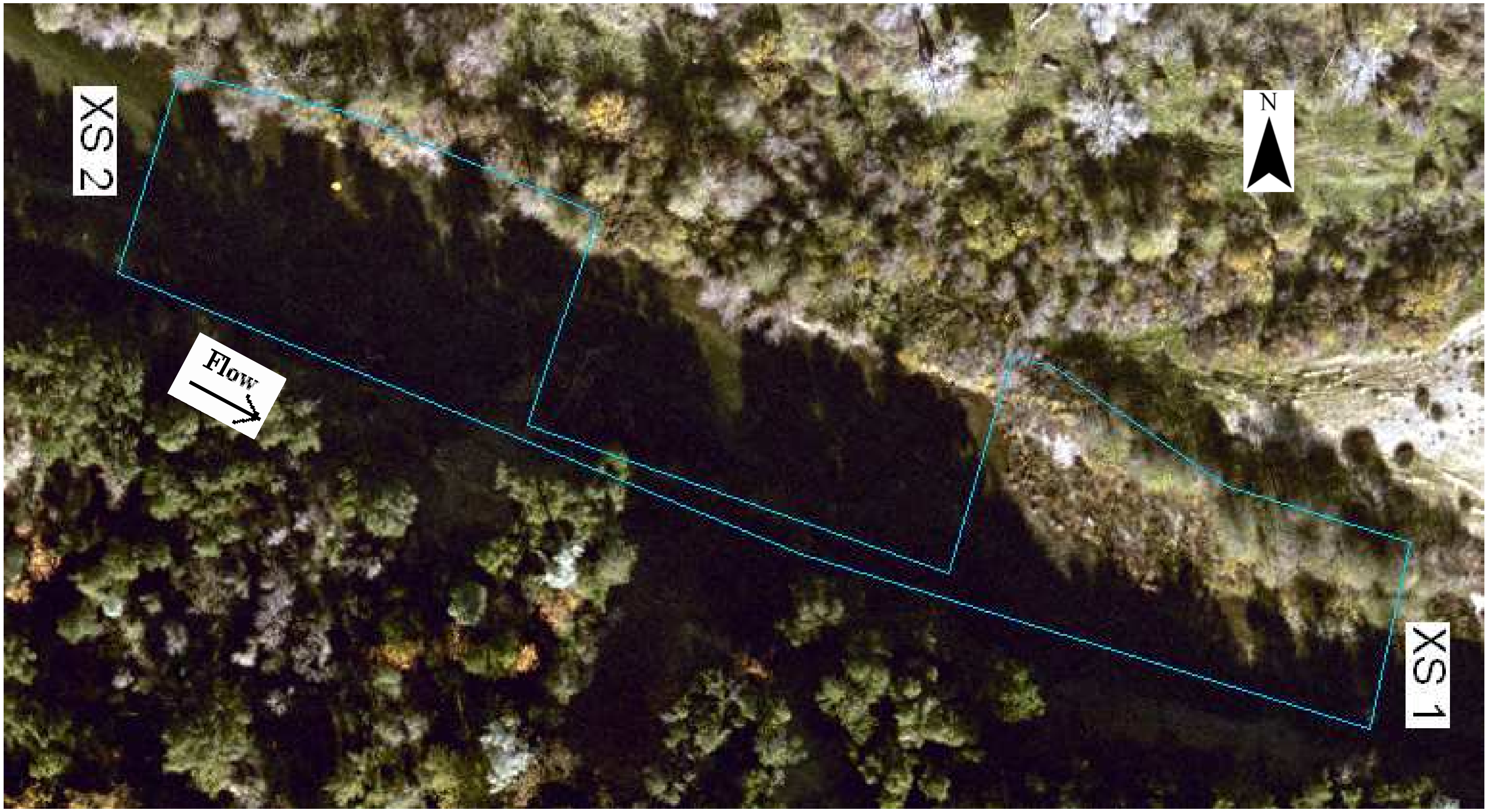
Upper Isolation



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APPENDIX B
RHABSIM WSEL CALBRATION

Stage of Zero Flow Values

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

Calibration Methods and Parameters Used

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

Shooting Gallery Study Site

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

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

Lower Gorge Study Site

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

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

Upper Renshaw Study Site

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

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

Lower Renshaw Study Site

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

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

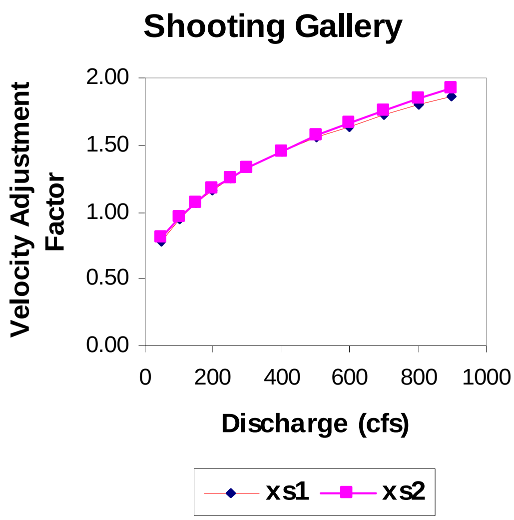
Upper Isolation Study Site

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

APPENDIX C
VELOCITY ADJUSTMENT FACTORS

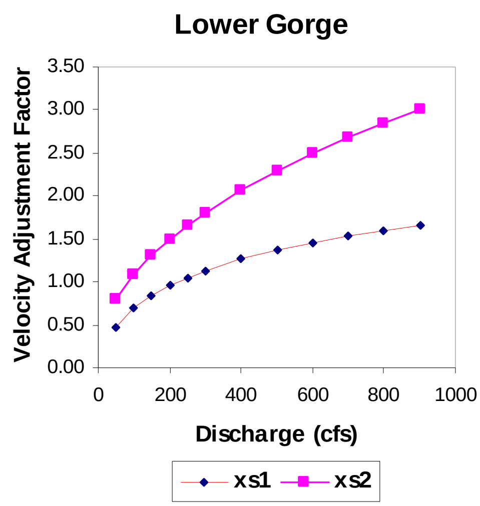
Shooting Gallery Study Site

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



Lower Gorge Study Site

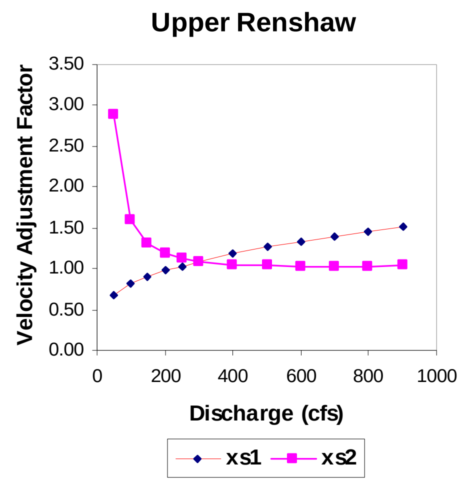
	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
50	0.48	0.79
100	0.69	1.09
150	0.84	1.31
200	0.95	1.49
250	1.05	1.66
300	1.13	1.80
400	1.26	2.06
500	1.37	2.29
600	1.46	2.49
700	1.53	2.68
800	1.60	2.85
900	1.66	3.01



Upper Renshaw Study Site

Velocity Adjustment Factors

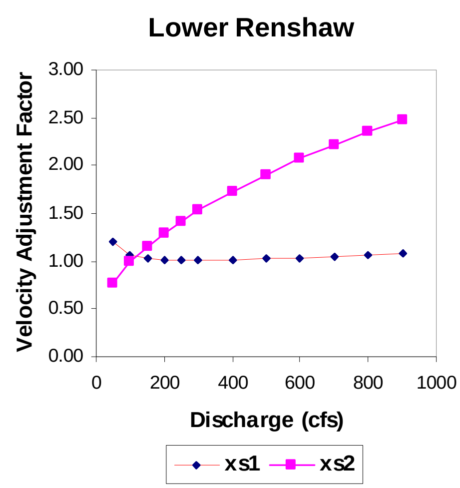
Discharge	Xsec 1	Xsec 2
50	0.68	2.88
100	0.82	1.60
150	0.91	1.31
200	0.97	1.19
250	1.03	1.13
300	1.09	1.09
400	1.18	1.05
500	1.26	1.04
600	1.33	1.03
700	1.40	1.03
800	1.46	1.03
900	1.51	1.03



Lower Renshaw Study Site

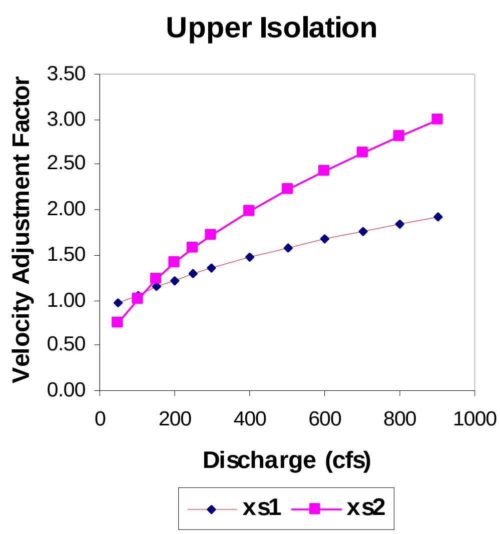
Velocity Adjustment Factors

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



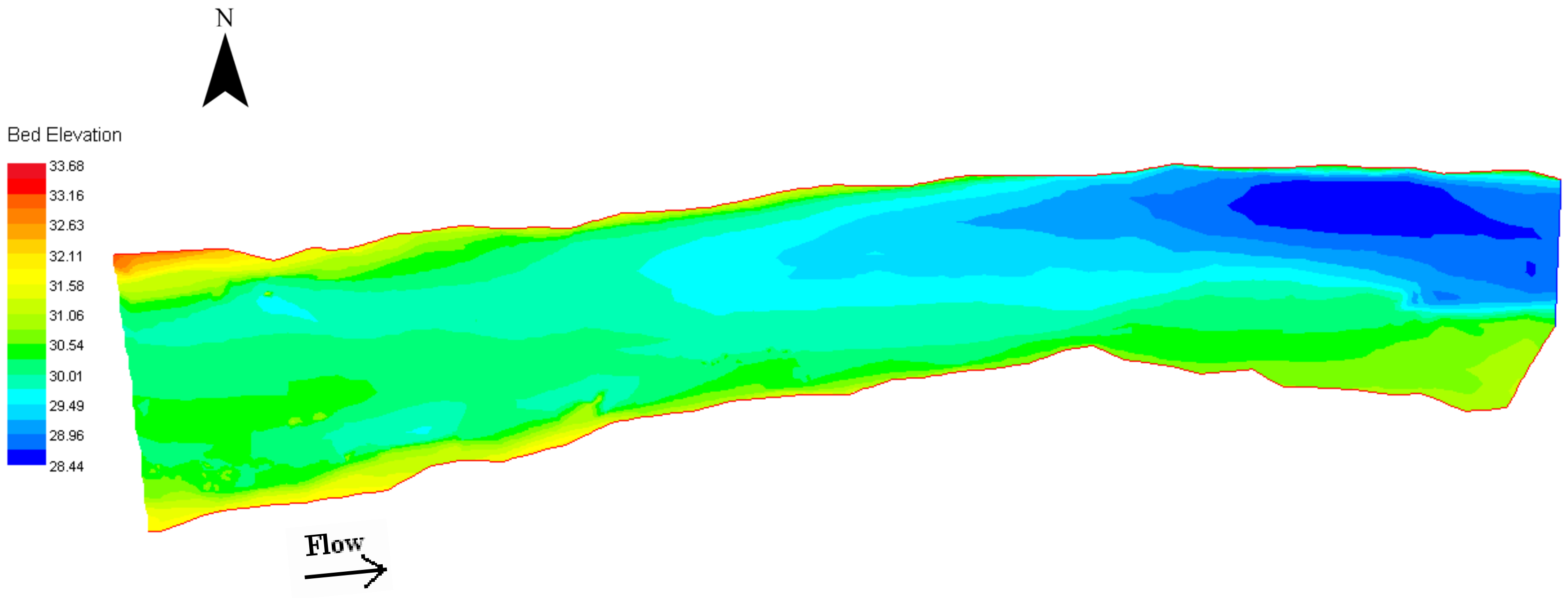
Upper Isolation Study Site

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



APPENDIX D
BED TOPOGRAPHY OF STUDY SITES

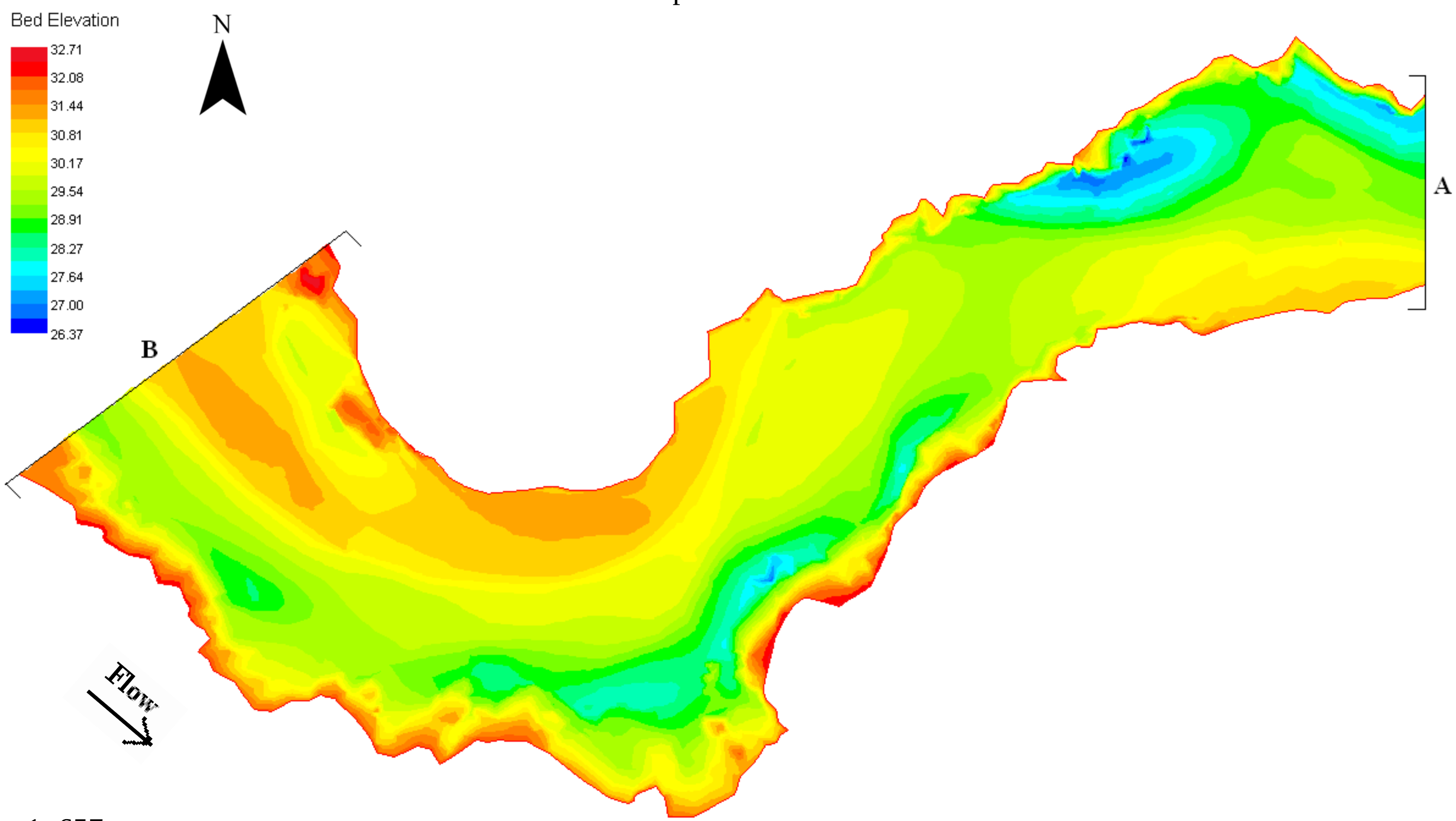
Shooting Gallery Study Site



Scale: 1: 1078

Units of bed elevation are meters

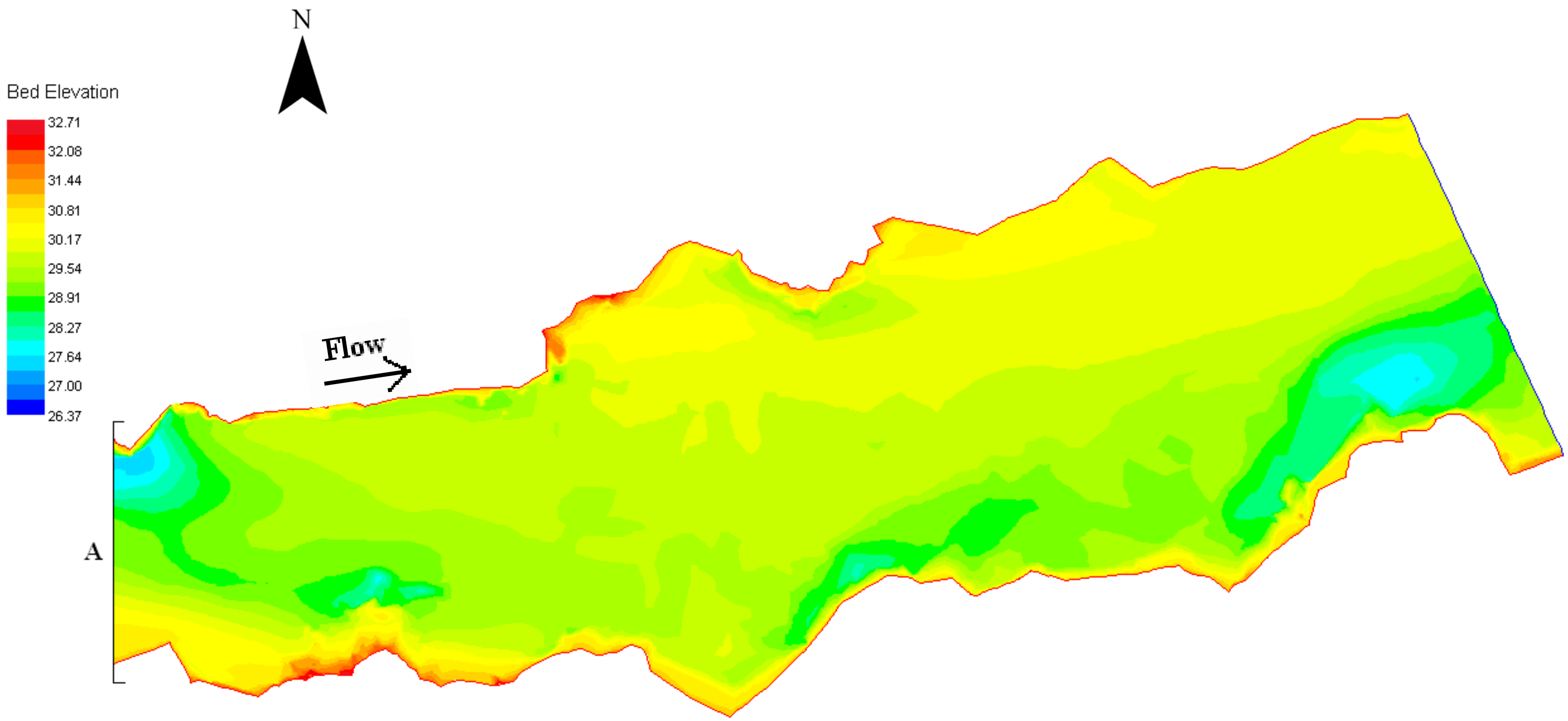
Lower Gorge Study Site
Upstream Section



Scale: 1: 657

Units of bed elevation are meters.

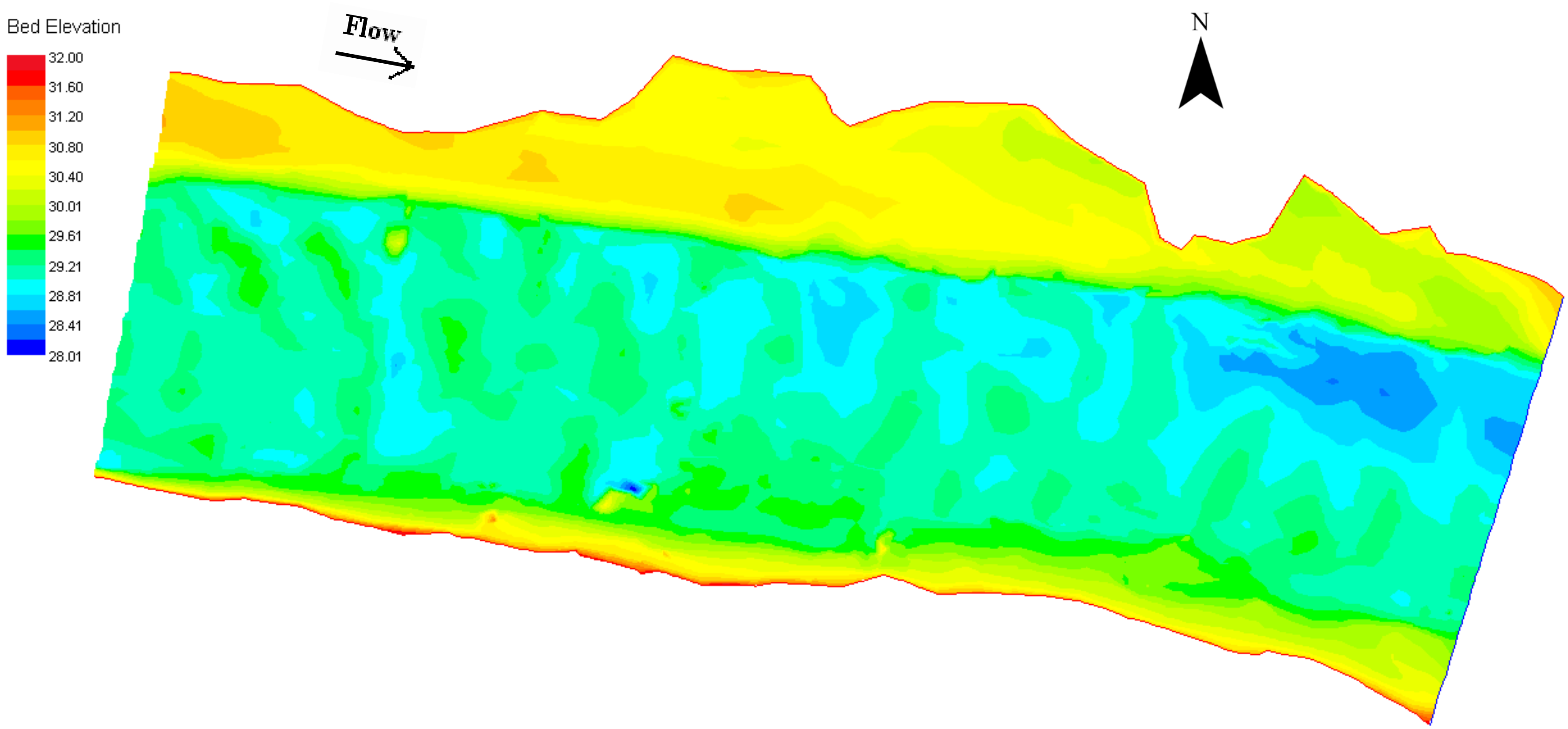
Lower Gorge Study Site
Downstream Section



Scale: 1: 910

Units of bed elevation are meters.

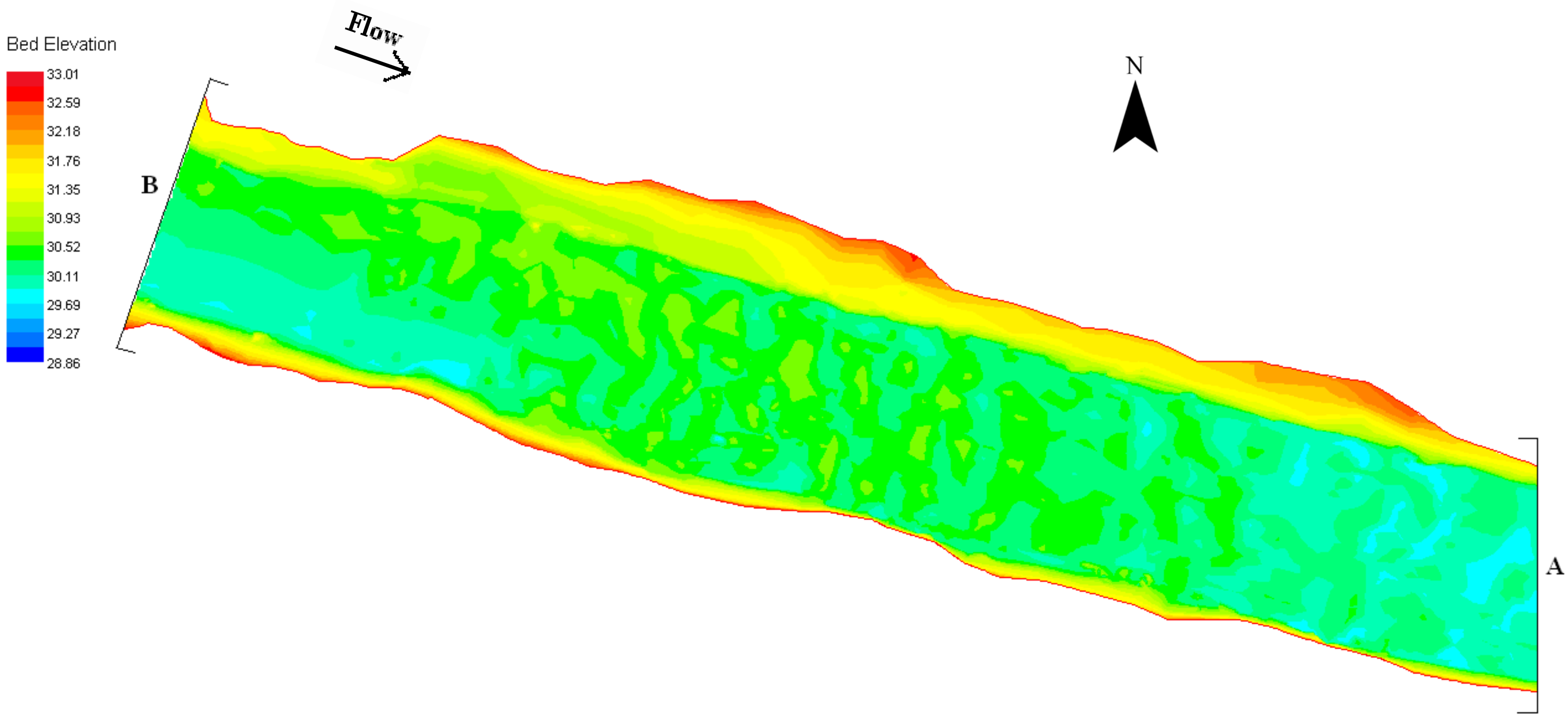
Upper Renshaw



Scale: 1: 590

Units of bed elevation are meters.

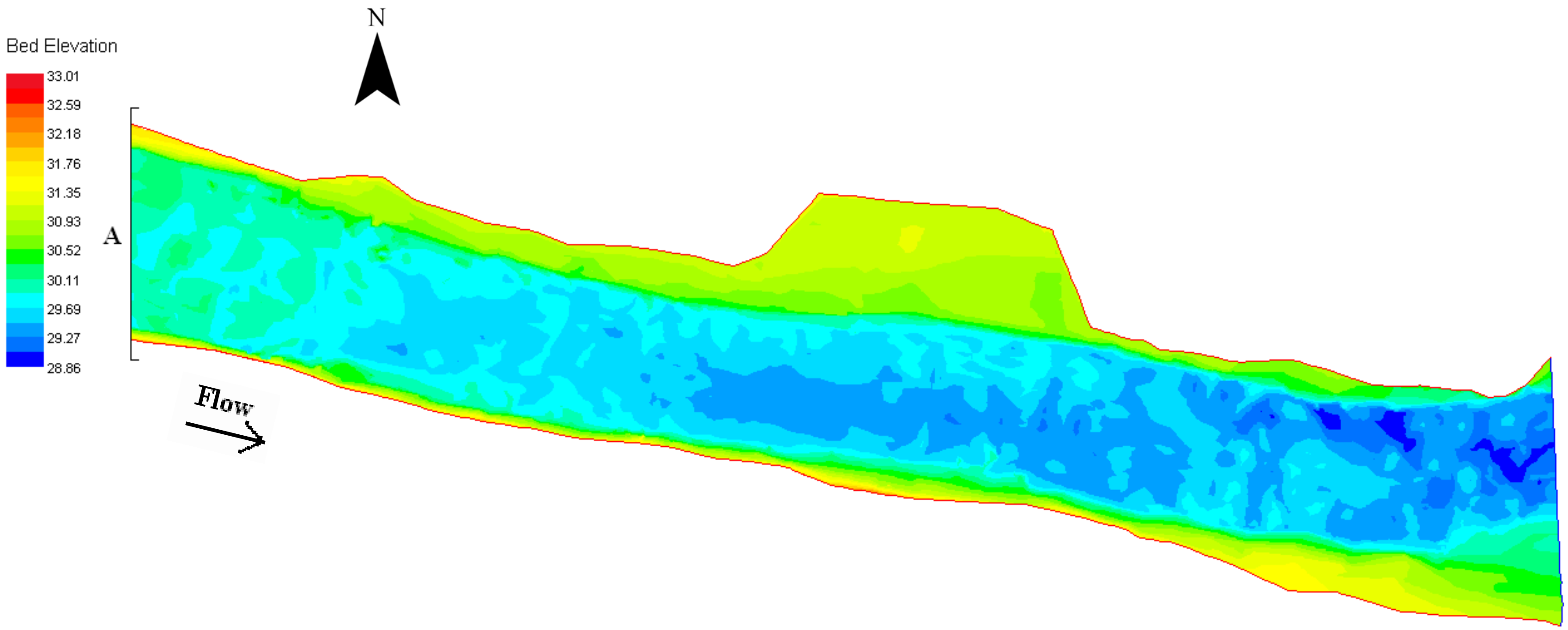
Lower Renshaw
Upstream Section



Scale: 1: 902

Units of bed elevation are meters.

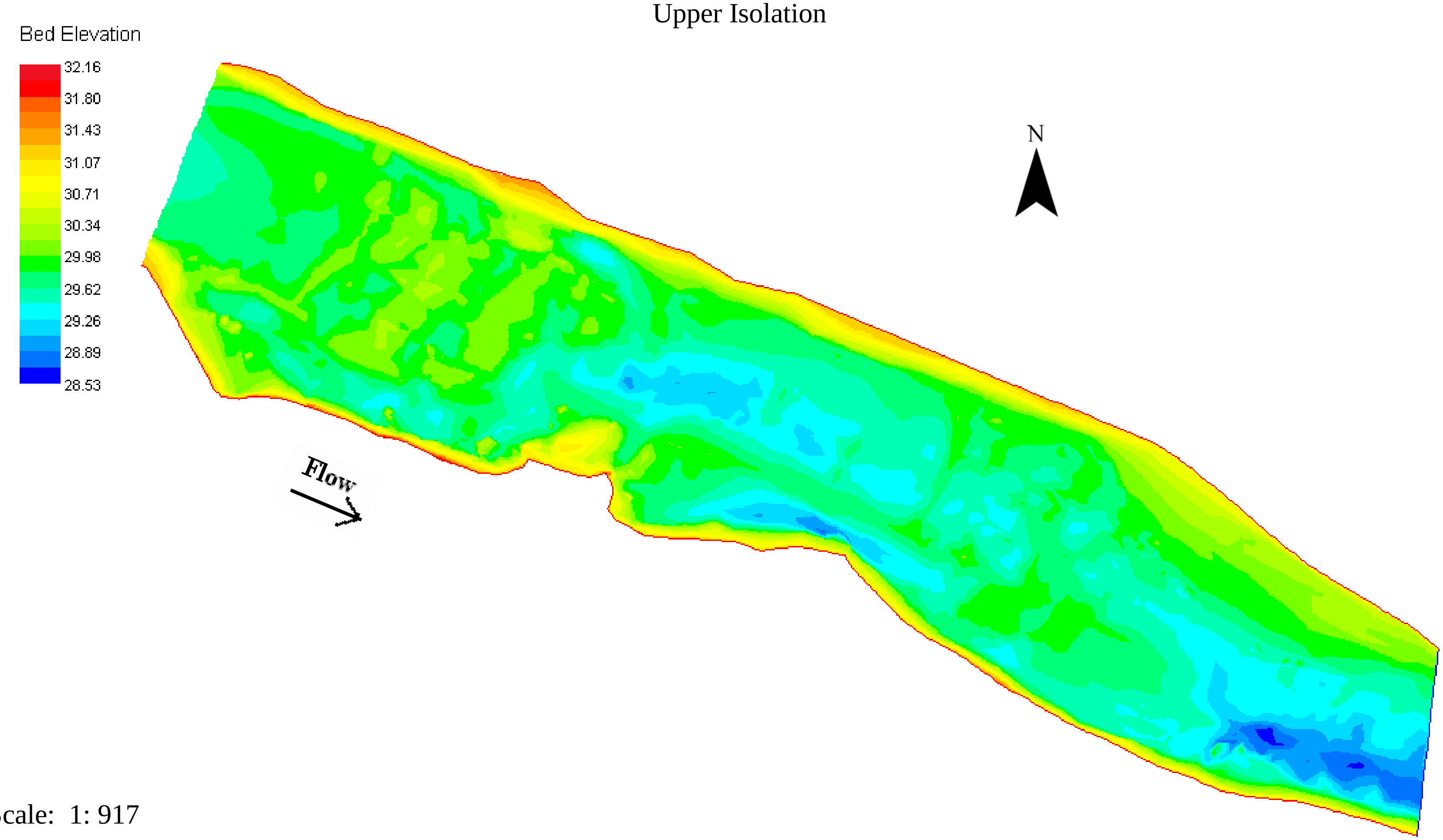
Lower Renshaw
Downstream Section



Scale: 1: 968

Units of bed elevation are meters.

Upper Isolation

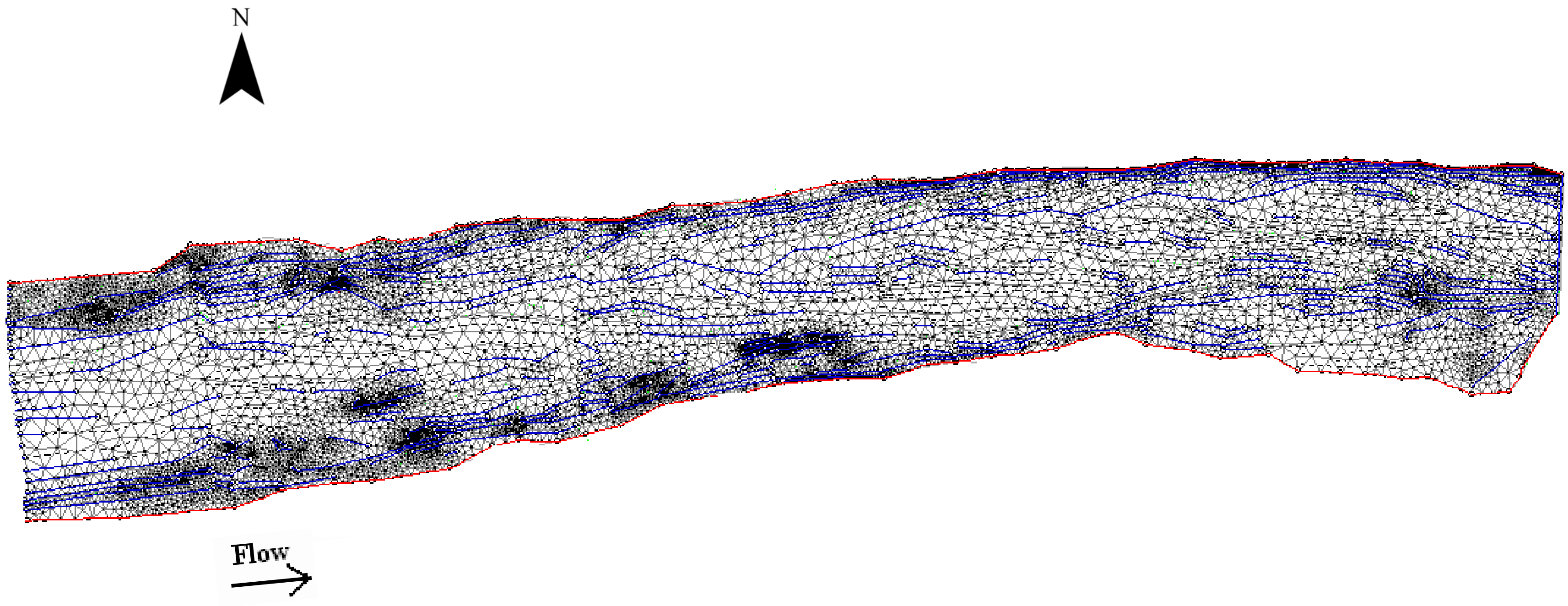


Scale: 1: 917

Units of bed elevation are meters.

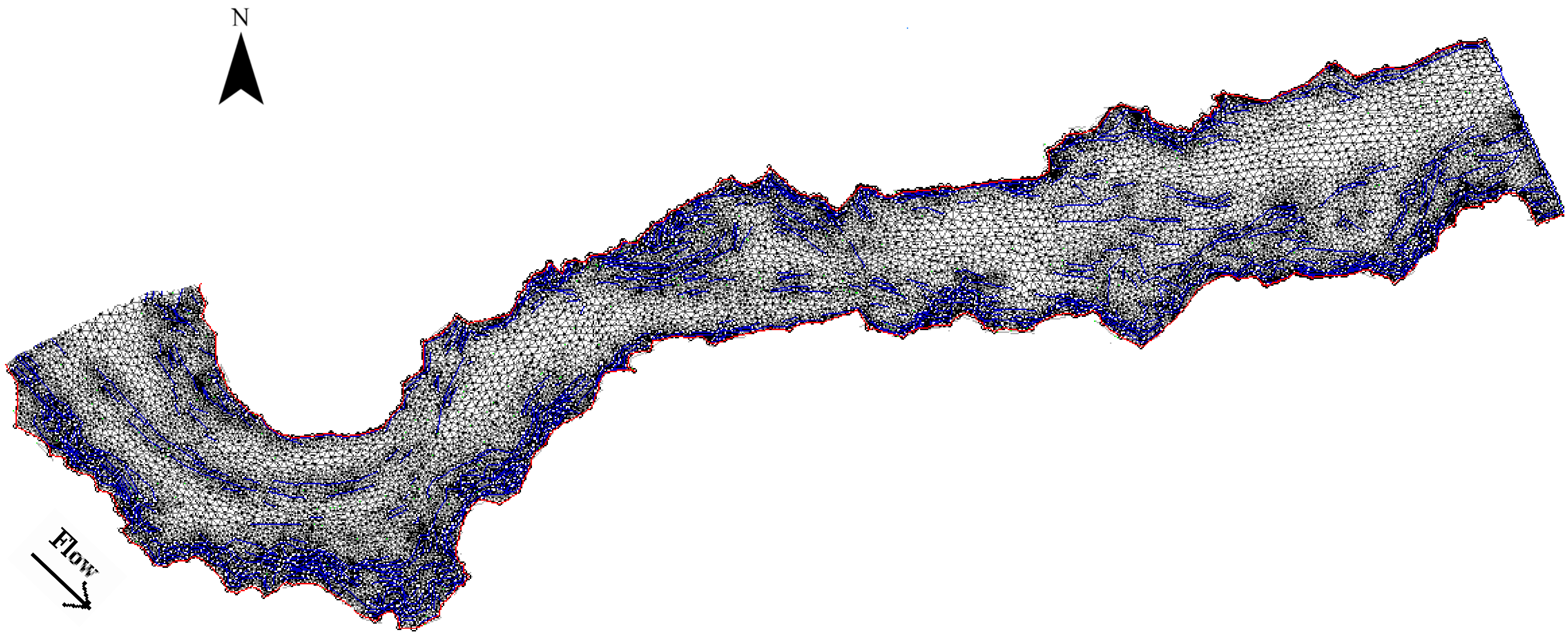
APPENDIX E
COMPUTATIONAL MESHES OF STUDY SITES

Shooting Gallery Study Site



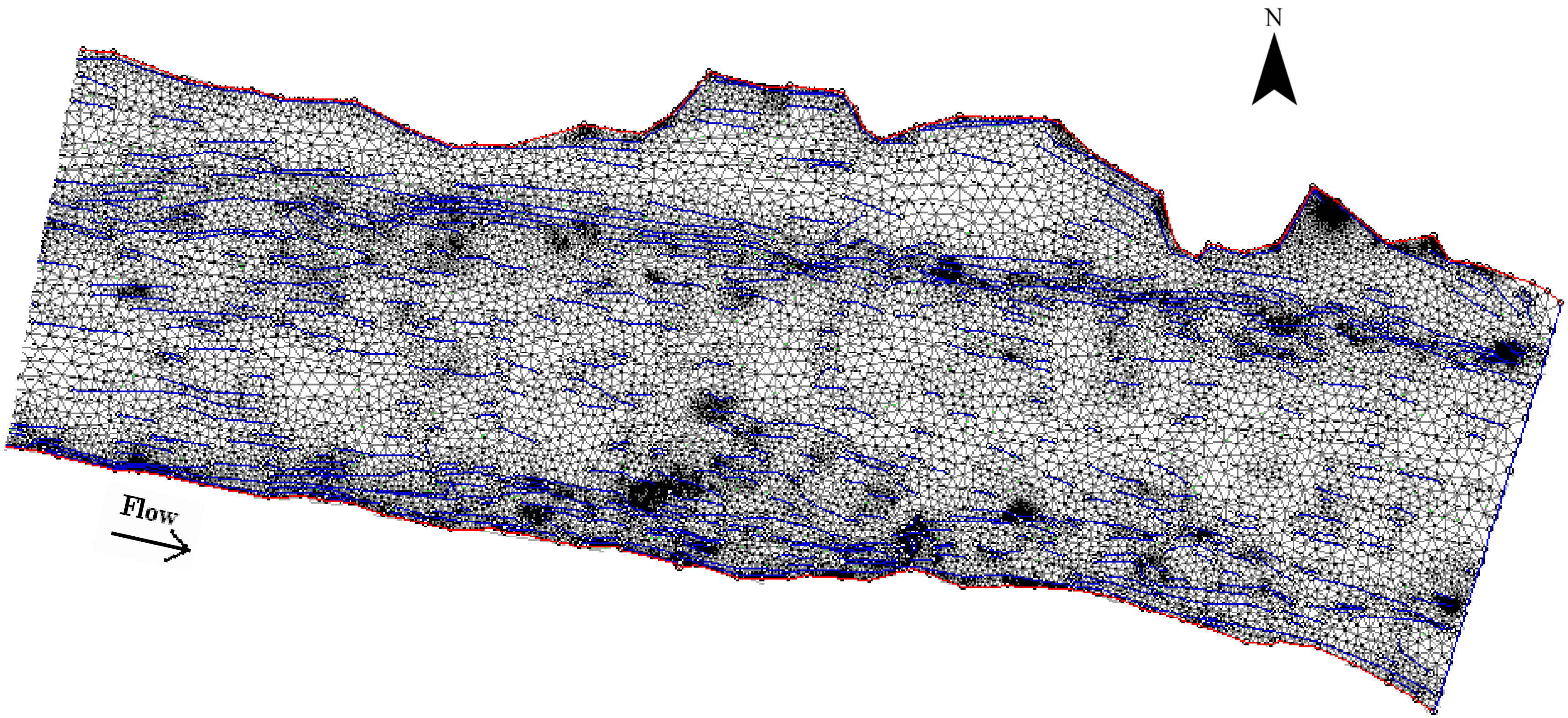
Scale: 1: 1078

Lower Gorge Study Site



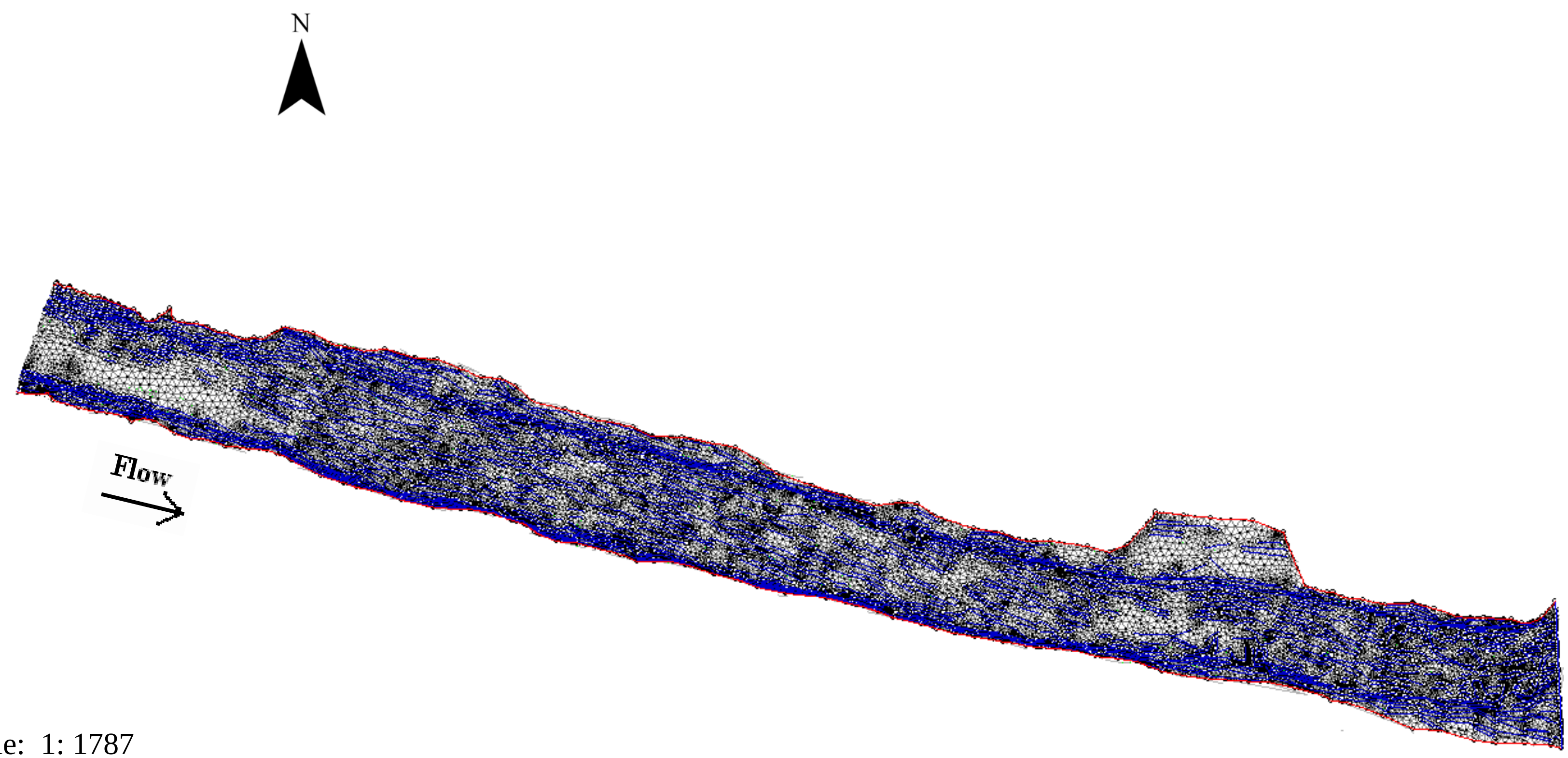
Scale: 1: 1568

Upper Renshaw Study Site



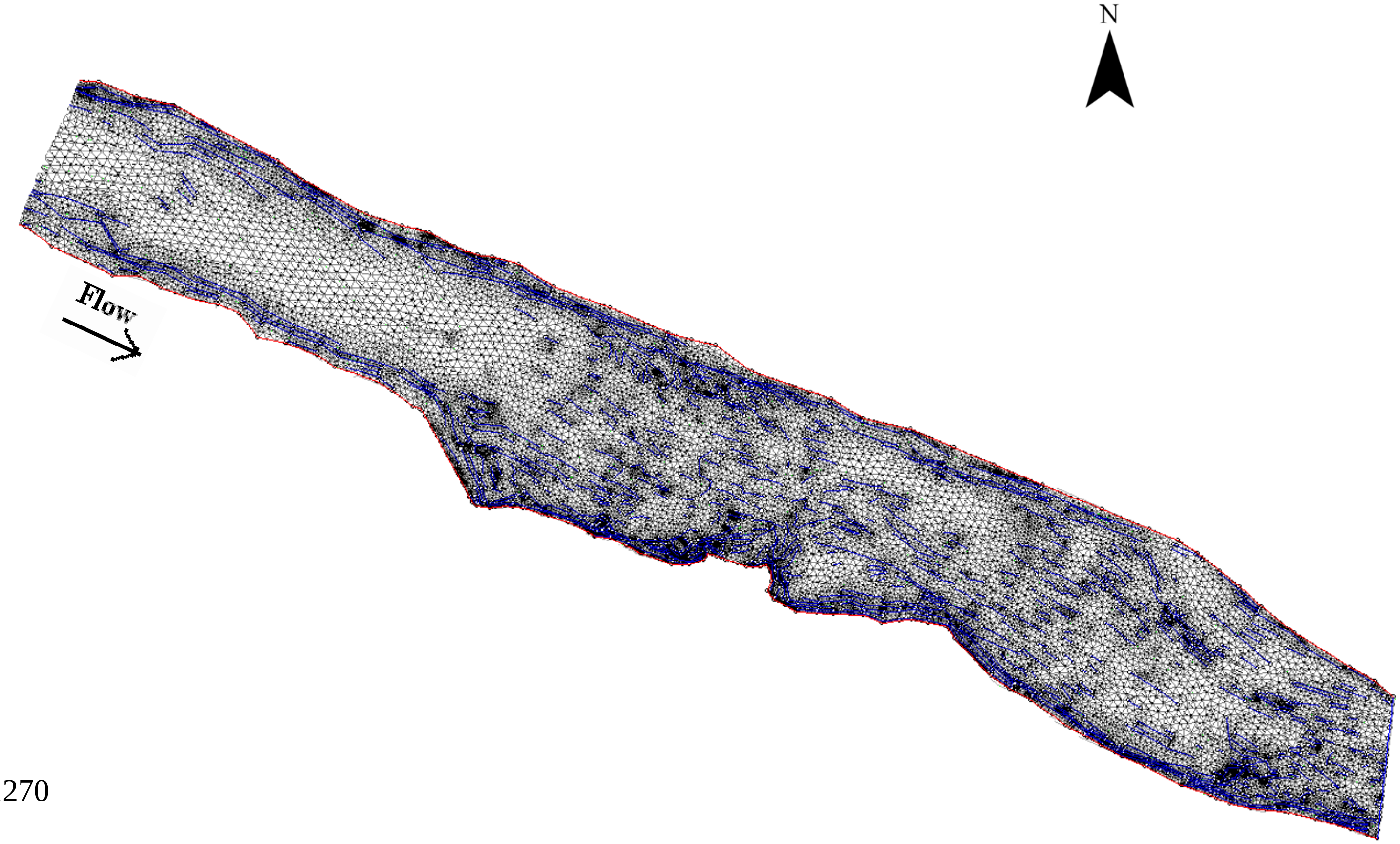
Scale: 1: 620

Lower Renshaw



Scale: 1: 1787

Upper Isolation



Scale: 1: 1270

APPENDIX F
2-D WSEL CALIBRATION

Calibration Statistics

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

Shooting Gallery

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

Lower Gorge

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

Upper Renshaw

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

Lower Renshaw

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

Upper Isolation

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

APPENDIX G
VELOCITY VALIDATION STATISTICS

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

Measured Velocities less than 3 ft/s

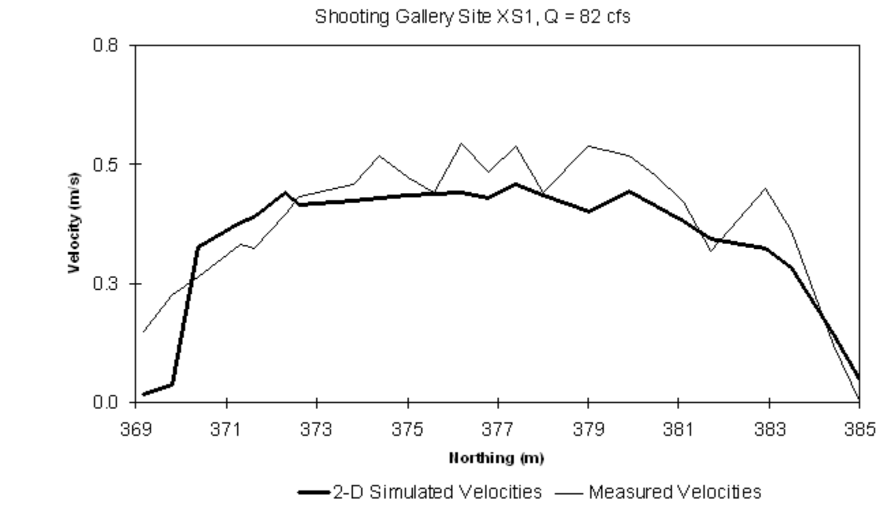
Difference (measured vs. pred. velocities, ft/s)

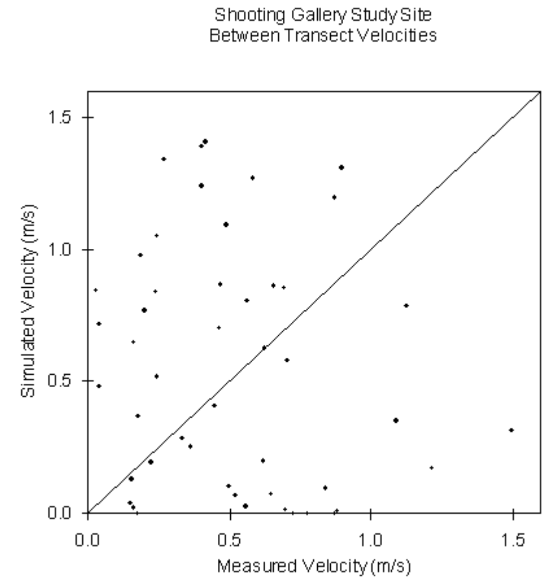
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Shooting Gallery	92	0.56	0.52	2.43
Lower Gorge	85	0.34	0.25	1.15
Upper Renshaw	94	0.38	0.33	1.50
Lower Renshaw	92	0.59	0.63	2.47
Upper Isolation	78	0.2	0.32	1.37

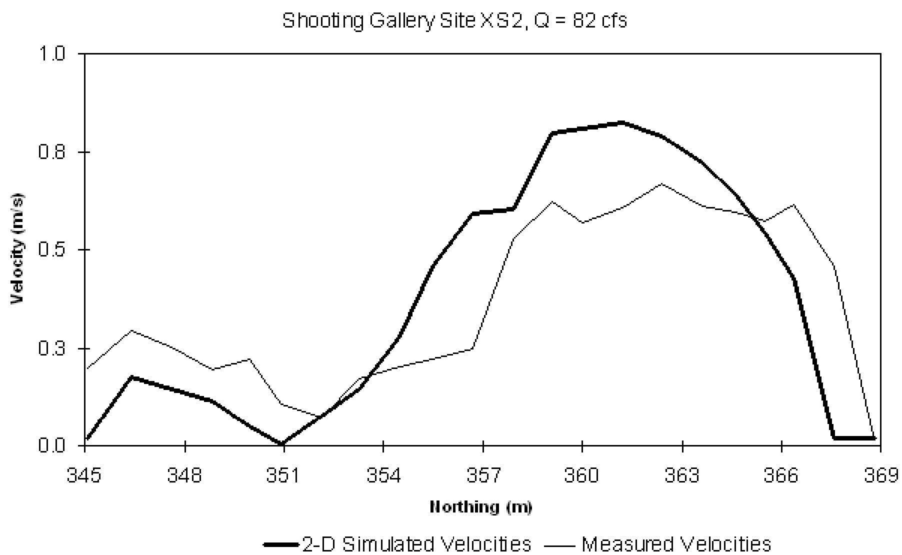
Measured Velocities greater than 3 ft/s

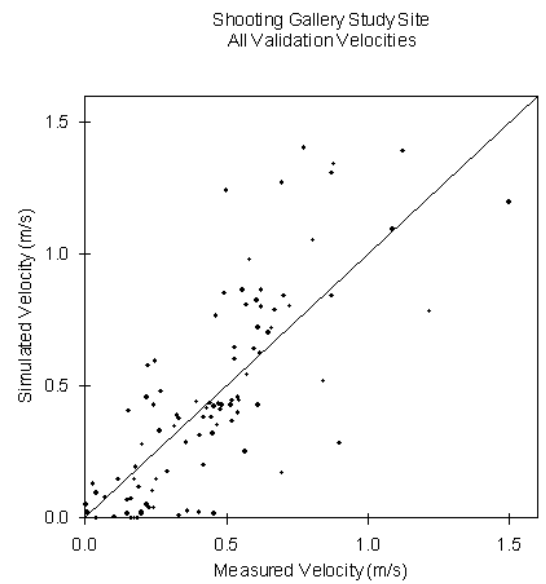
Percent difference (measured vs. pred. velocities)

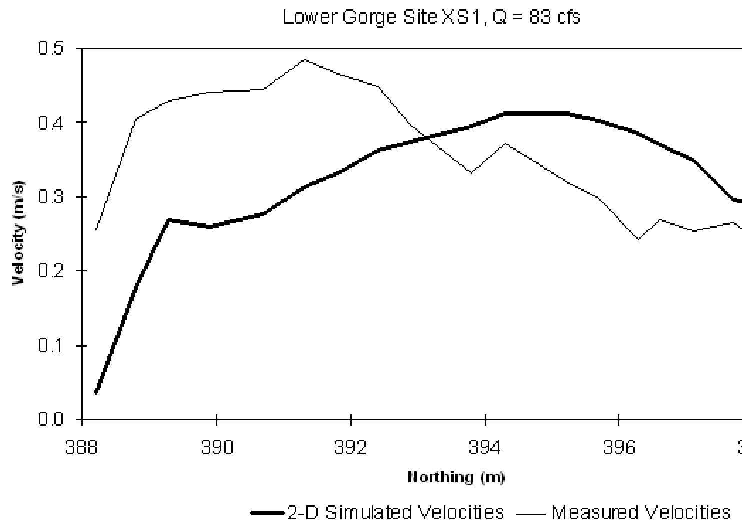
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Shooting Gallery	4	20%	14%	35%
Lower Gorge	7	24%	15%	51%
Upper Renshaw	--	--	--	--
Lower Renshaw	10	10%	7%	21%
Upper Isolation	12	16%	8%	26%


Shooting Gallery Site XS1, Q = 82 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities

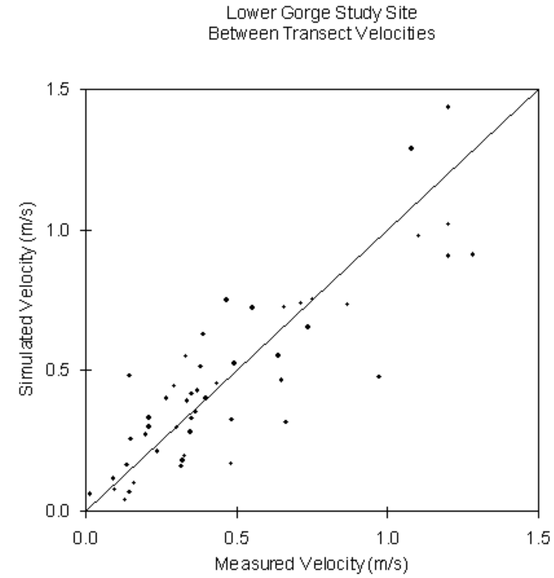

Shooting Gallery Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)


Shooting Gallery Site XS2, Q = 82 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities

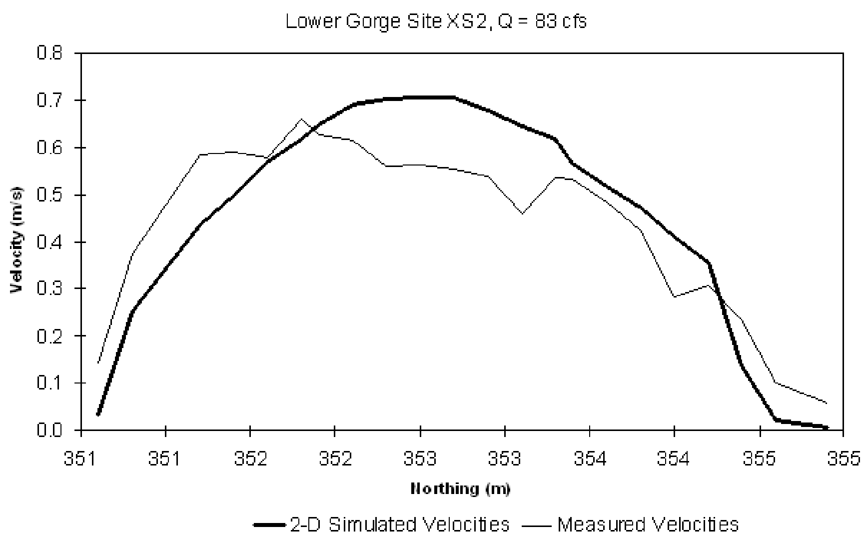

Shooting Gallery Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)



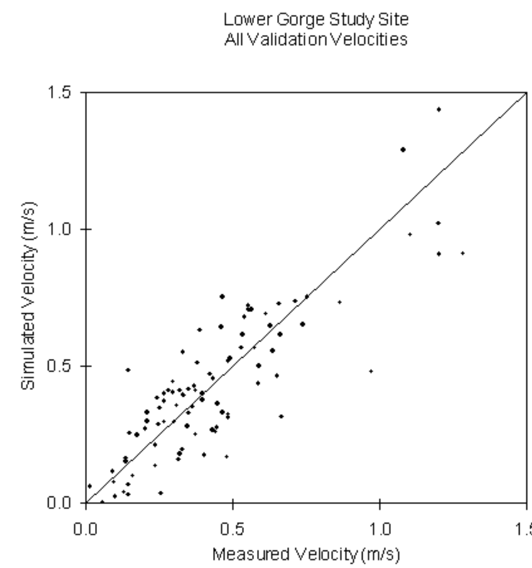
Lower Gorge Site XS1, Q = 83 cfs
Velocity (m/s)
0.0
0.1
0.2
0.3
0.4
0.5
388
390
392
394
396
398
Northing (m)
2-D Simulated Velocities
Measured Velocities



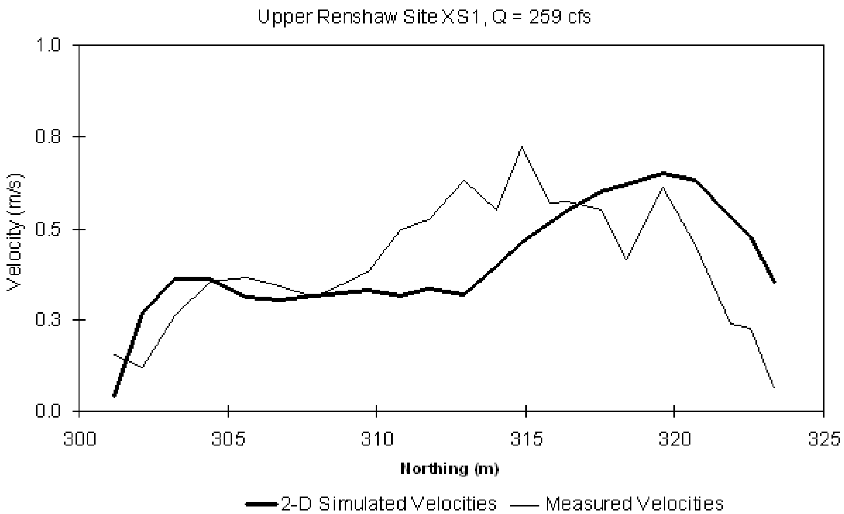
Lower Gorge Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5

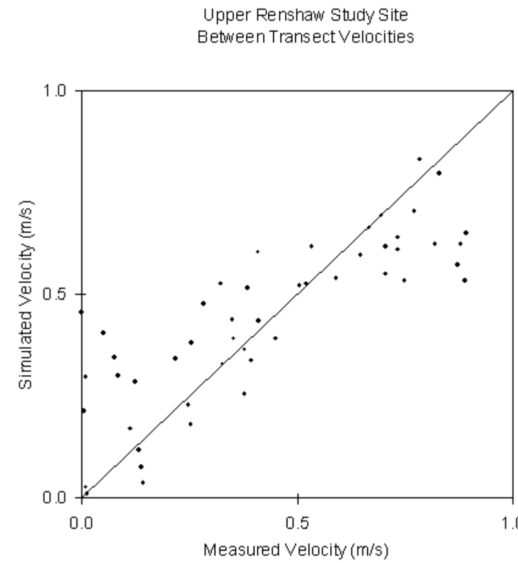


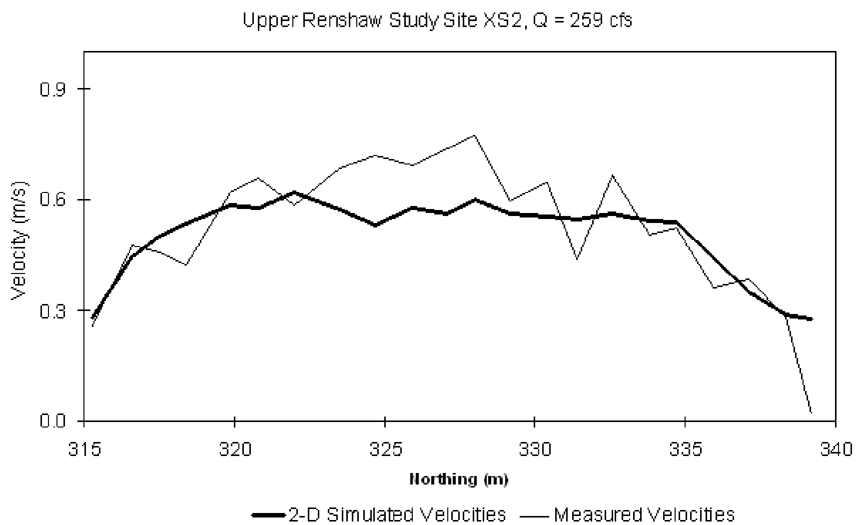
Lower Gorge Site XS2, Q = 83 cfs
Velocity (m/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
351
351
352
352
353
353
354
354
355
355
Northing (m)
2-D Simulated Velocities
Measured Velocities

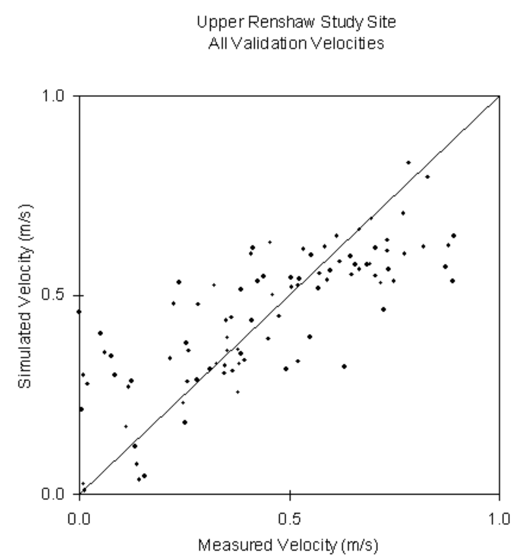


Lower Gorge Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.5
1.0
1.5

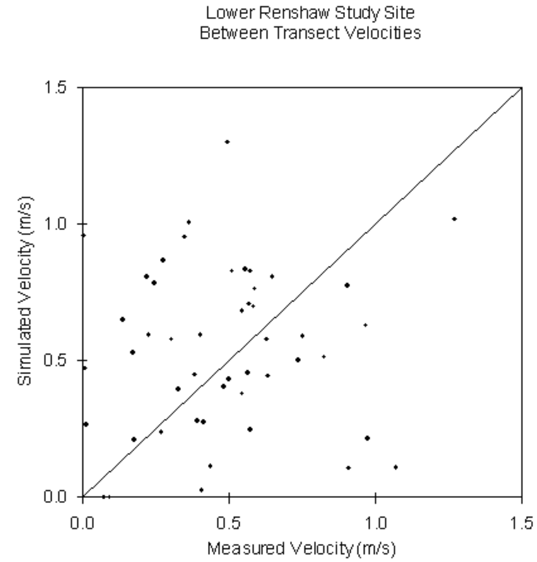

Upper Renshaw Site XS1, Q = 259 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities

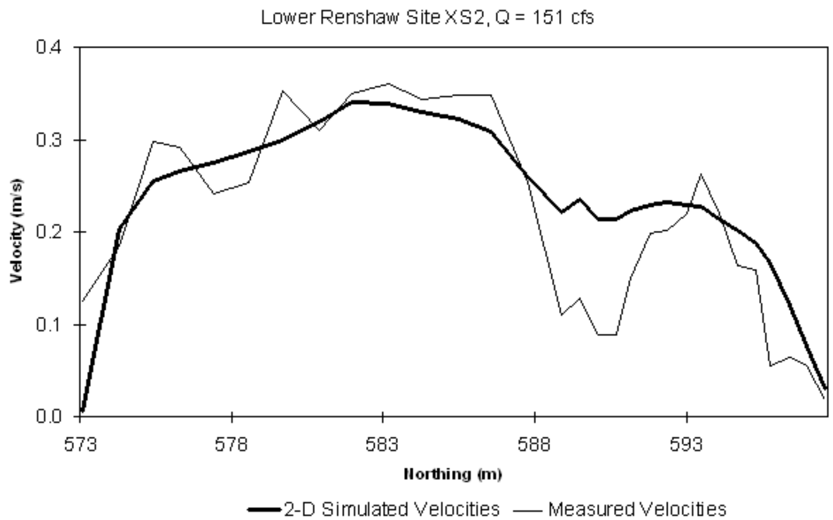

Upper Renshaw Study Site
Between Transect Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

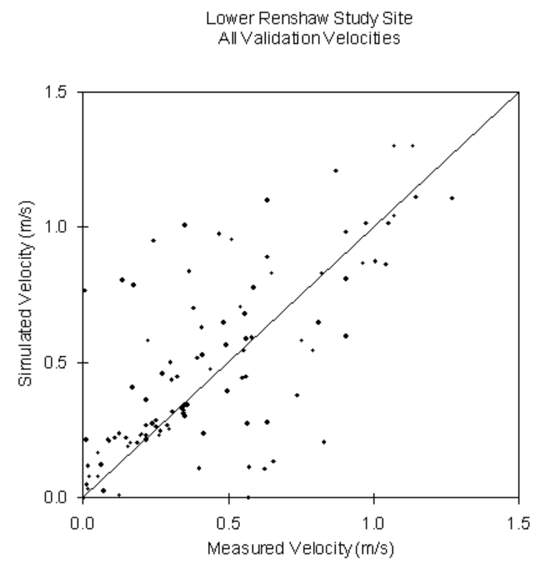

Upper Renshaw Study Site XS2, Q = 259 cfs
Velocity (m/s)
Northing (m)
2-D Simulated Velocities
Measured Velocities

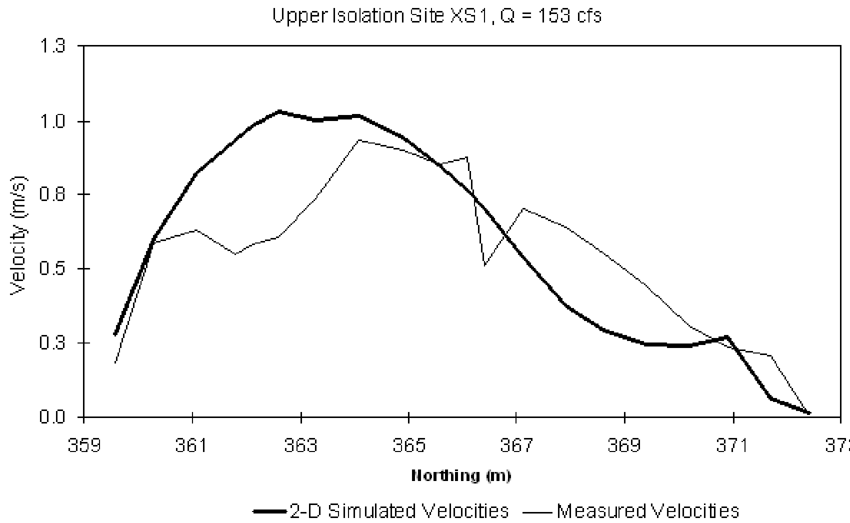

Upper Renshaw Study Site
All Validation Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)

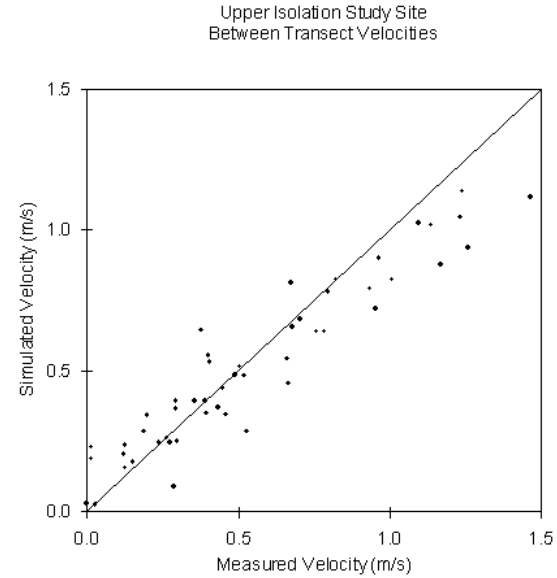

Lower Renshaw Site XS1, Q = 151 cfs
Velocity (m/s)
1.3
1.0
0.8
0.5
0.3
0.0
481
486
491
496
Northing (m)
2-D Simulated Velocities
Measured Velocities

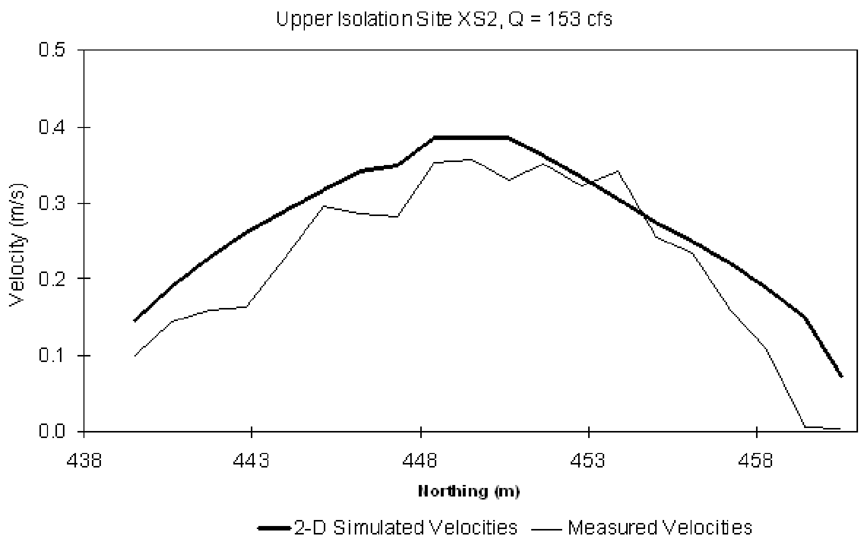

Lower Renshaw Study Site
Between Transect Velocities
Simulated Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Measured Velocity (m/s)

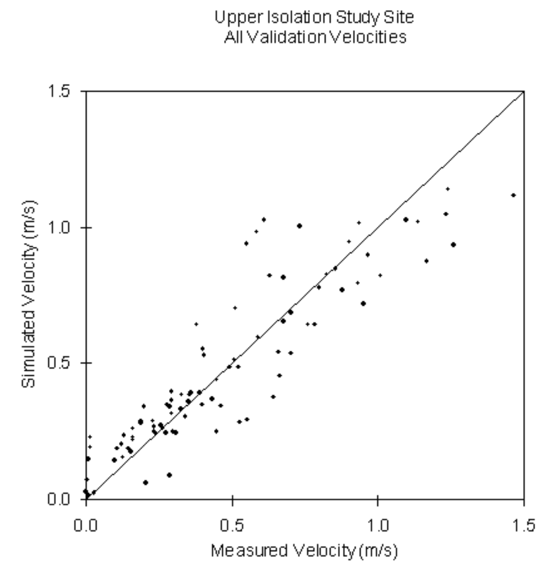

Lower Renshaw Site XS2, Q = 151 cfs
Velocity (m/s)
0.4
0.3
0.2
0.1
0.0
573
578
583
588
593
Northing (m)
2-D Simulated Velocities
Measured Velocities


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


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


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


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


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

APPENDIX H
SIMULATION STATISTICS

Shooting Gallery

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

Lower Gorge

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

Upper Renshaw

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

Lower Renshaw

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

Upper Isolation

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

APPENDIX I
HABITAT SUITABILITY CRITERIA

Fall-run Chinook Salmon Spawning HSC

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

Steelhead/rainbow Trout Spawning HSC

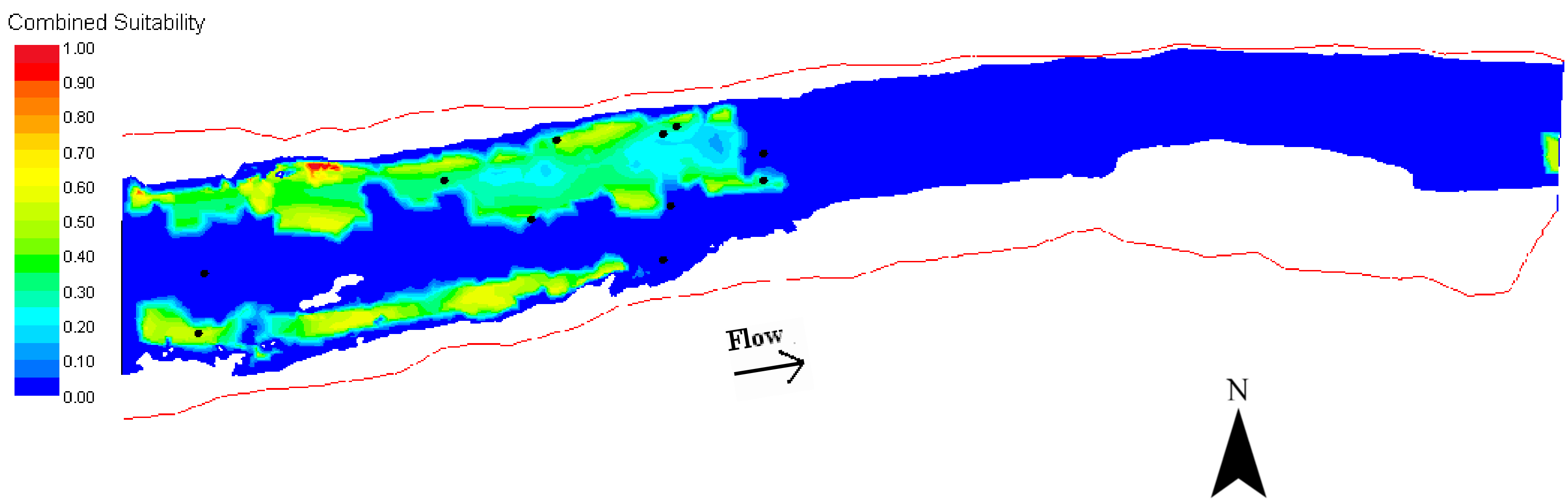
Water Depth (ft)	SI Value
0.00	0
0.3	0
0.4	0.16
0.5	0.26
0.6	0.38
0.7	0.51
0.8	0.64
0.9	0.75
1.0	0.85
1.1	0.92
1.2	0.96
1.3	0.99
1.4	1
1.5	1
28.6	0
100	0

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

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

APPENDIX J
RIVER2D COMBINED SUITABILITY OF REDD LOCATIONS

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

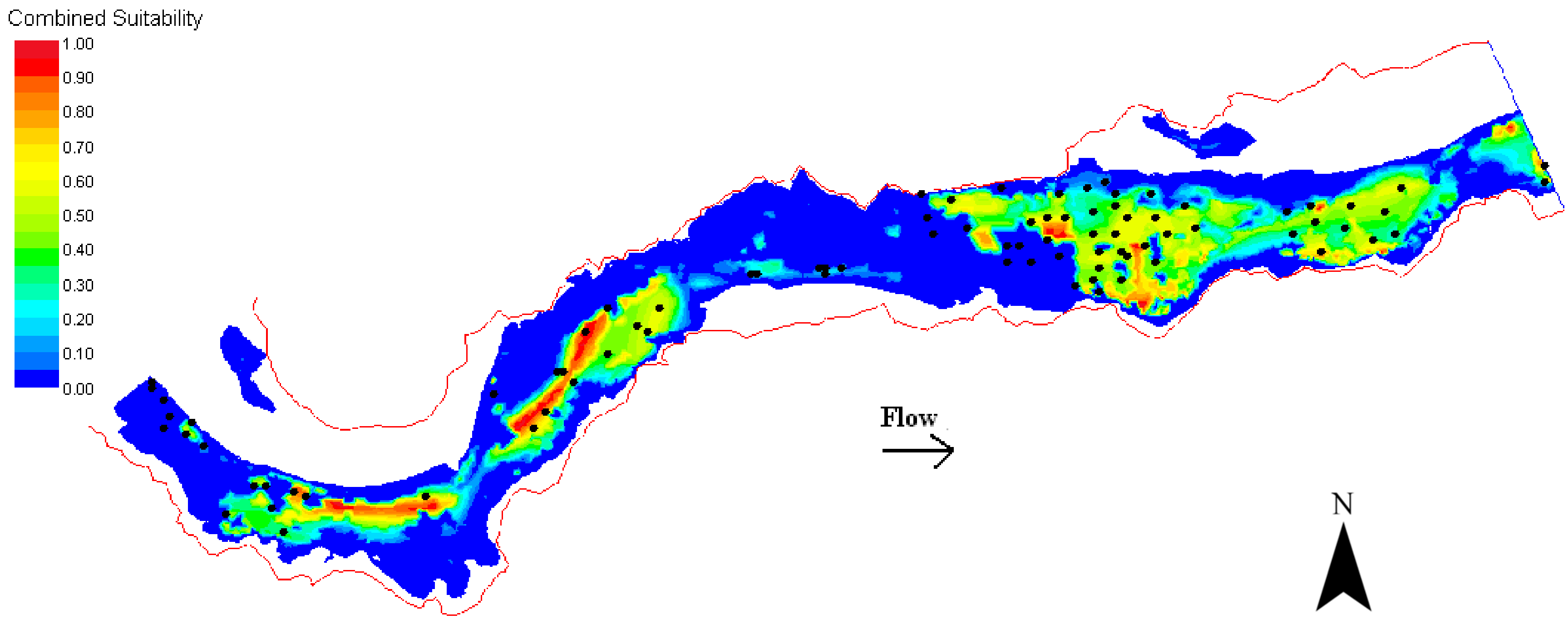


Scale: 1: 1001

Redd locations: ●

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

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

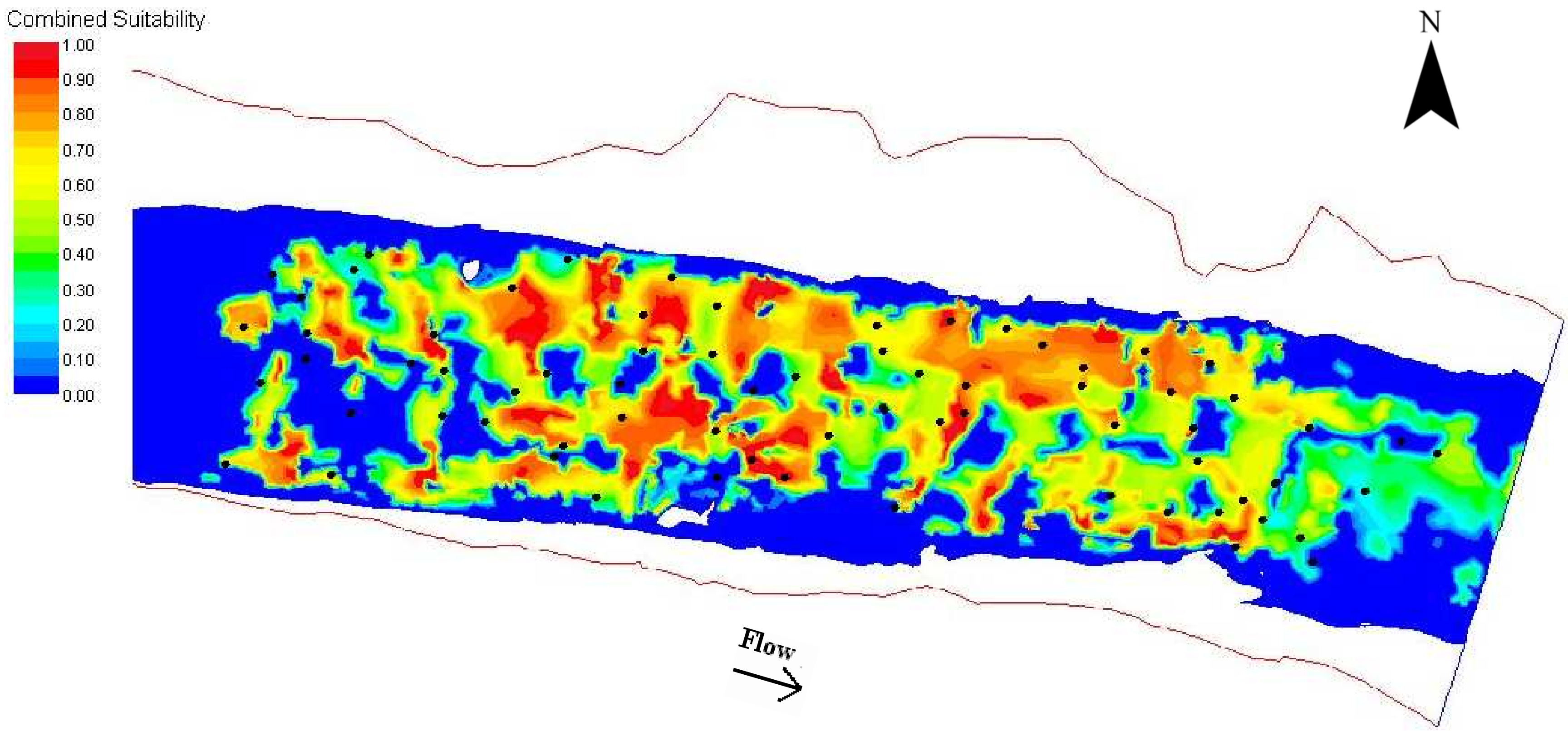


Scale: 1: 1660

Redd locations: ●

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

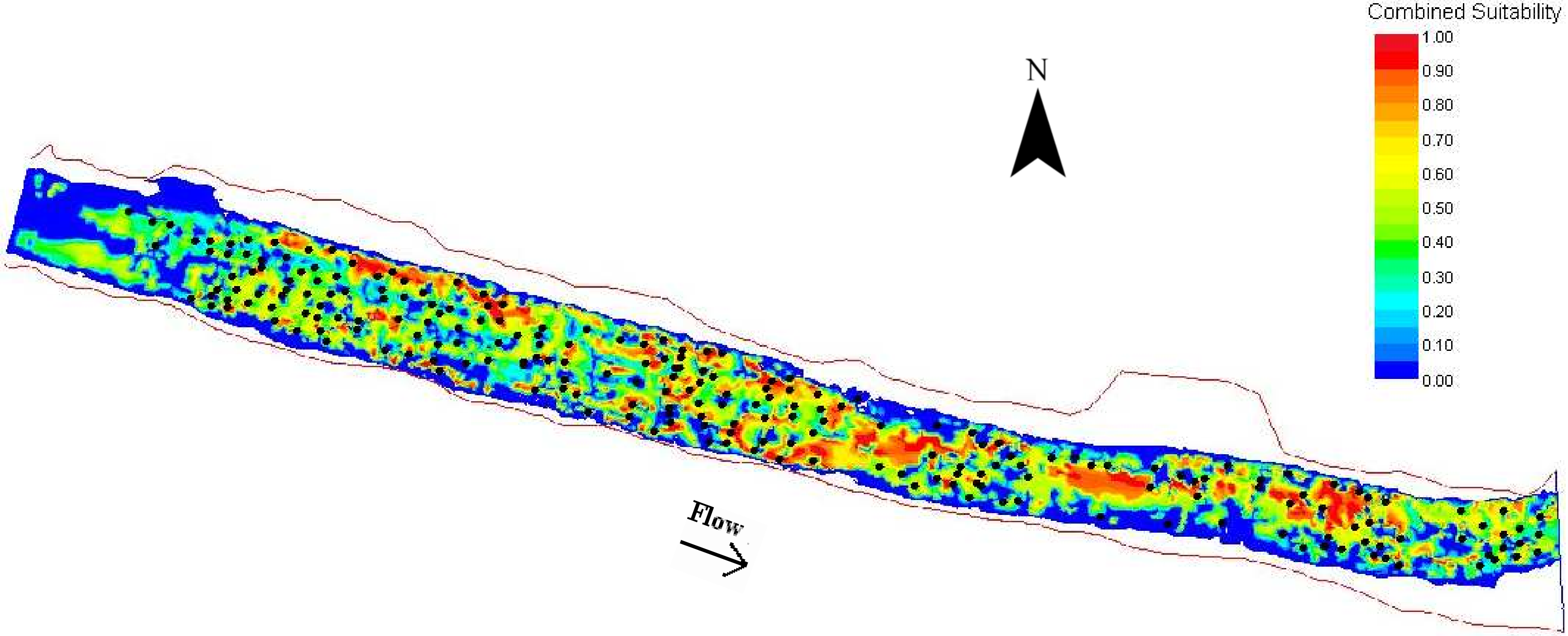
UPPER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 187 CFS



Scale: 1: 515

Redd locations: ●

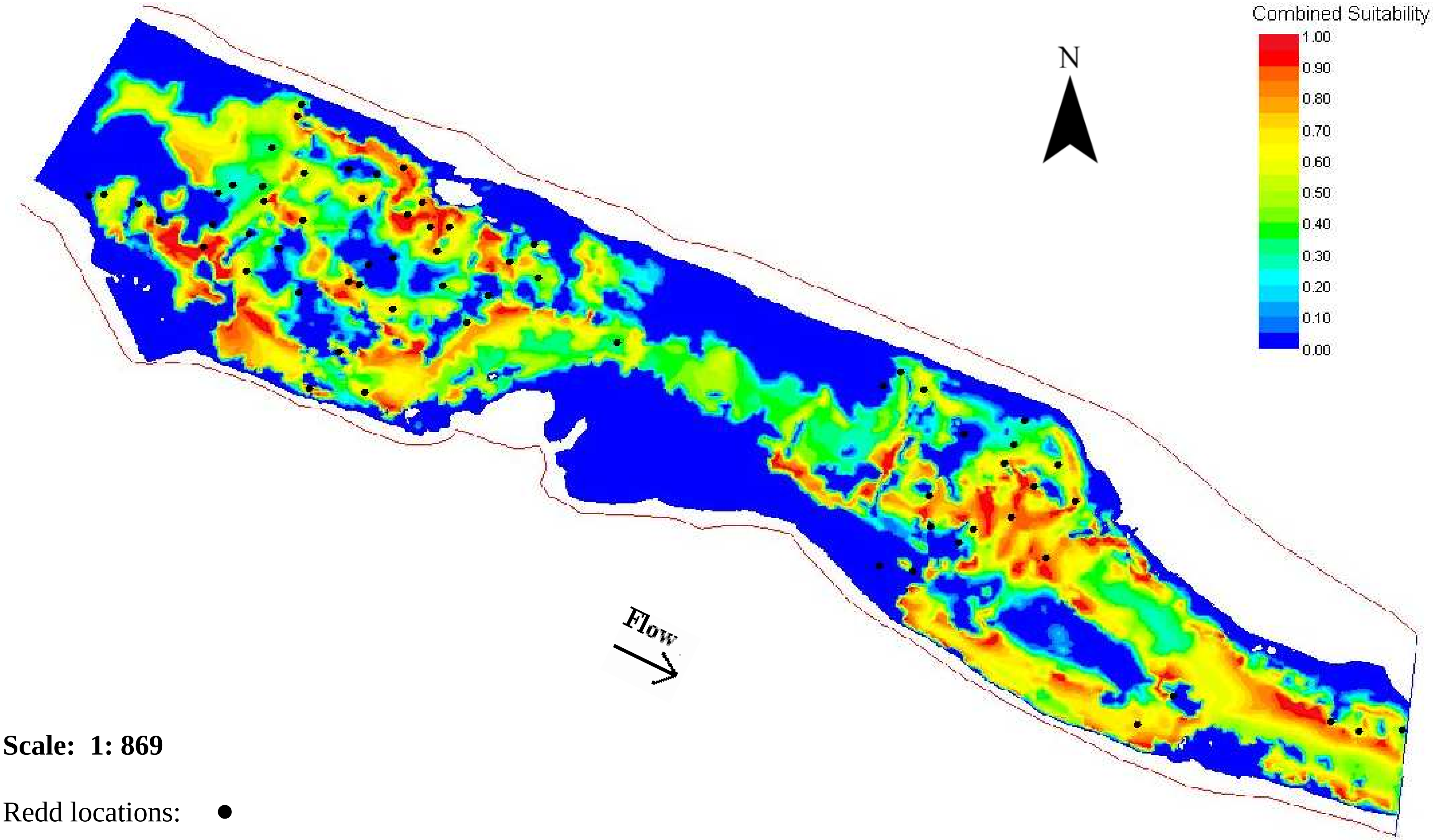
LOWER RENSHAW STUDY SITE
FALL-RUN CHINOOK SALMON SPAWNING, FLOW = 186 CFS



Scale: 1: 1787

Redd locations: ●

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



Scale: 1: 869

Redd locations: ●

USFWS, SFWO, Restoration and Monitoring Program
Lower Clear Creek Spawning Report
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APPENDIX K
HABITAT MODELING RESULTS

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

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

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

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